Office of the Chief Scientist for Human Factors

Human Factors General Aviation

Program Review
FY02

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The Federal Aviation Administration Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100) directs a general aviation research program that focuses on reducing fatalities, accidents, and incidents within the general aviation flight environment. This environment is defined as all flights that are conducted under FAR Part 91 as well as the general aviation maintenance community. The research addresses better methods for the detection, classification, and reporting of human factors accidents; developing certification and flight standards and guidelines based on human factors research, and identifying and implementing intervention strategies to impact general aviation accidents.

The following report summarizes projects between October 1st, 2001 and December 31st, 2002. These projects attempt to address requirements identified by the Federal Aviation Administration Flight Standards and Certification offices. The intent of this report is to allow Federal Aviation Administration sponsors to determine whether their requirements have been satisfactorily addressed, allow investigators to receive feedback from Federal Aviation Administration sponsors and other interested parties, and to provide feedback to the AAR-100 general aviation program manager on the quality of the research program. Basically, this document is a means of holding each group (sponsor, investigator, AAR-100 program manager) accountable to ensure that the program is successful.

In FY02, the general aviation research program distributed $596,300 contract dollars to seven performing organizations. In addition, some of these projects received supplemental support from the Civil Aerospace Medical Institute, Oklahoma City, OK. These projects are described in Appendix I and the requirements that are mapped to these projects are located in Appendix II.

Appendix III lists the FY03 funded projects ($500 contract dollars) and the proposed FY04 (estimated $500 contract dollars) and FY05 projects (estimated $400 contract dollars).

To view projects, pages 5-89

To view requirements, pages 89-127

Address questions or comments to:

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Appendix I

Human Factors General Aviation

FY02 Project Summaries

Primary investigators submitted project summaries via world-wide-web. A newly created interactive web-based system modeled after the Office of Naval Research and the National Science Foundation was developed to standardize the yearly report submitted to the Office of the Chief Scientist for Human Factors. The reporting system can be found at http://www.hf.faa.gov/report

Project Title	Page #
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Project Title: *Causal Factors of Accidents and Incident Attributed to Human Error*

Primary Investigator: Dr. Scott Shappell, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: Scott.Shappell@faa.gov)

Co-Primary Investigator: Dr. Doug Wiegmann, University of Illinois, Savoy, IL (e-mail: dwiegman@uiuc.edu)

FAA Sponsor Organization AFS-800 (POC: Michael Henry); ACE-111 (POC: Frank Bick)

Sponsor's Requirement Statement: to identify potential data sources to identify causes of general aviation human error accidents as well describe potential remedies. The outcome of the research should develop and standardize methodologies for identifying, defining, and monitoring human error based incidents and accidents. **Refer to page 93 for a more detailed description.**

Research Project's Goal The analysis of all General Aviation and Commercial Aviation accidents between 1990 and present will allow the FAA to develop "data-driven" interventions based upon the accident record. To date, this effort has led to changes within the GA safety program (AFS 800) and two Safer Skies efforts (Aeronautical Decision Making JSAT and the General Aviation Data Improvement Team). However, a finer-grained analysis of specific error forms such as skill-based errors, decision errors, perceptual errors, and violations as well as the preconditions for those unsafe acts is required. Future efforts will be directed at a better understanding of the specific types of errors inherent in the accident record.

Ultimately, this effort will provide a method for improving the level of detail and quality of human factors accident investigation. It is well known that while the accident record is rich with data describing "what" occurred (e.g., the pilot failed to lower the landing gear), the identification of "why" the error occurred is inadequate. Using HFACS, or a similar human error system, another aim of this program is to provide the NTSB and FAA field investigator the tools necessary to perform a comprehensive human factors accident investigation. Efforts toward these ends have already begun using HFACS.

Best Accomplishment: The human factors analysis of all fatal and non-fatal general aviation accidents occurring between 1990 and 1999 has been completed. To date, nearly 20,000 GA accidents have been analyzed by five independent raters (all were certified flight instructors and GA pilots) using HFACS. Using these data, a series of studies have been conducted to understand: 1) Differences in the patterns of human error associated with fatal and non-fatal GA accidents; 2) Human causes behind controlled flight into terrain; and 3) Regional differences in the human causal factors associated with GA accidents; 4) Similarities and differences between military, commercial, and GA accidents in the U.S.

Project Summary: Scientists at CAMI and the University of Illinois have continued their investigation of the application of the Human Factors Analysis and Classification System (HFACS) taxonomy with civil aviation accidents. The human factors analysis of all GA accidents occurring between 1990 and 1999 was completed in FY02. To date, over 45,000 human causal factors associated with just over 20,000 GA and commercial accidents have been analyzed by pilot-SMEs using HFACS. In the last FY, the focus has been on general aviation. Our initial analyses determined that roughly 80% of all general aviation accidents are attributed, at least in part, to skill-based errors and that many of those are associated with deficiencies in training and/or other issues of proficiency and currency. In addition, fatal accidents were four times more likely (roughly 40% of all accidents examined) to be associated with violations of the rules, than non-fatal accidents (only 10% of non-fatal accidents examined). An equal percentage of decision errors (roughly 40%) were associated with both fatal and non-fatal accidents examined, while perceptual errors were associated with nearly 10% of the accidents examined. Results from the HFACS analysis have been incorporated into two Safer Skies initiatives (Aeronautical Decision Making JSAT and the General Aviation Data Improvement Team).

In addition to the overall analyses of GA accident data, an investigation of GA controlled flight into terrain accidents was completed. Consistent with the overall data, skill-based errors (76.3%) and decision errors (33.5%) were the most frequently cited form of human errors associated with CFIT accidents. More interesting, however, were those human errors that differentiated CFIT from non-CFIT accidents. For instance, while violations and perceptual errors contributed to only 12.4% and 7.2% of the non-CFIT accidents, respectively, they contributed to 31.6% (violations) and 12.5% (perceptual errors) of CFIT accidents. Likewise, adverse mental states and personal readiness failures were more likely to occur during CFIT than non-CFIT accidents. In fact, CFIT accidents were over four times more likely to involve a personal readiness failure and three times more likely to involve at least one violation of the rules. Findings from this effort support many of the interventions identified by the CFIT Joint Safety Analysis Team (JSAT) and Joint Safety Implementation Team (JSIT), permitting safety professionals to better develop, refine, and track the effectiveness of selected intervention strategies.

Scientific and Technical Objectives: The objectives of the HFACS project at CAMI are to conduct applied human factors analysis of general aviation and commercial accident reports to obtain objective, scientifically derived data that will aid in identifying data-driven intervention and mitigation strategies for reducing the number of accidents and incidents in the aviation community. A secondary objective is to provide a scientifically derived human factors approach for accident investigation in the field to improve both the quality and quantity of human factors data obtained in accident and incident investigations.

Technical Approach: Accident data was obtained from the NTSB and FAA for analysis using HFACS. All fixed-wing and rotary wing aircraft were included in the initial analyses (i.e., homebuilt, balloons, and gliders were not included). Causal factors associated with each accident were then classified into HFACS causal categories independently by five GA pilots. All raters were certified flight instructors (mean flight hours = 3,530). After training on HFACS (training consisted of a Four-hour workshop on HFACS; Practice coding 20 accidents as a group; and practice coding 50 accidents independently, followed by a review/consensus meeting), each pilot was assigned 1/3 of the accidents for a given year. Raters were instructed to independently code only those cause factors that were identified by the NTSB (no new cause factors created). Each pilot was then randomly paired with a second pilot who coded the same set of accidents to compare codes and achieve consensus. Pilots were then assigned another 1/3 of the accidents for a particular year and randomly paired with another pilot. This process continued until all the accidents had been coded.

Results: The results this FY are divided into three separate studies of GA accidents: 1) Human error associated with fatal versus non-fatal GA accidents; 2) Human error associated with CFIT accidents; and 3) Regional differences in the patter of human error associated with GA accidents. Each will be briefly described below.

Human error associated with fatal versus non-fatal GA accidents

We examined over 14,000 (3,073 fatal and 10,991 non-fatal) human error related GA accidents using five independent raters (all were certified flight instructors with over 3,500 flight hours) and the HFACS framework. What we found was quite revealing, as previously unknown error trends among general aviation were identified.

Consider first, the roughly 3,000 fatal GA accidents associated with aircrew error. From the graph in the Figure 1, some important observations can be made. For instance, it may surprise some that skill-based errors, not decision errors, were the number one type of human error associated with fatal GA accidents. In fact, skill-based errors (averaging roughly 80% across the years of the study) more than doubled the percentage of accidents seen with decision errors (32%) and violations of the rules (33%). Even perceptual errors, the focus of a great deal of interest over the years, were associated with less than 15% of all fatal accidents.

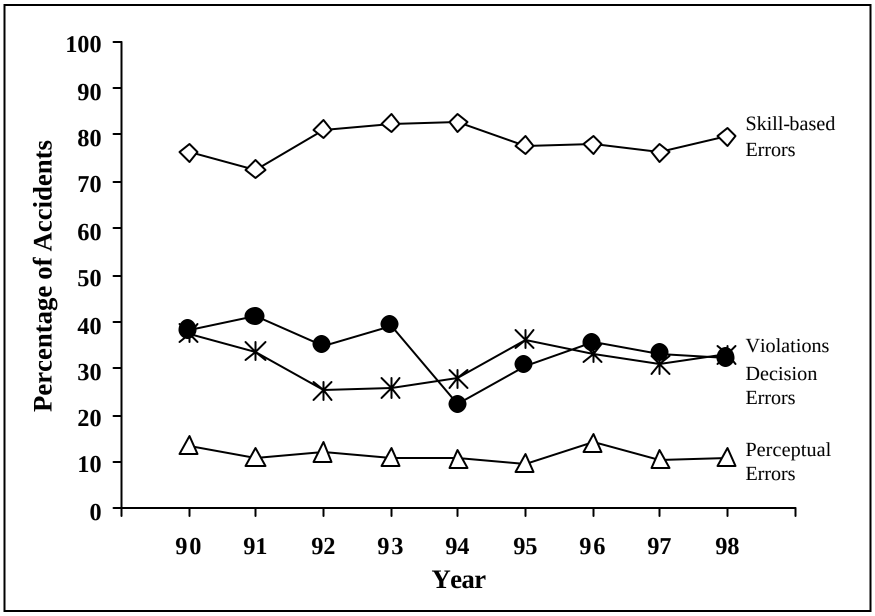

Figure 1. Percentage of fatal GA accidents associated each unsafe act.

Also noteworthy is the observation that the trend lines are essentially flat. This would seem to suggest that safety efforts directed at GA over the last several years have had little impact on any specific type of human error. If anything, there may have been a general, across the board, effect, although this seems unlikely given the safety initiatives employed. The only exceptions seemed to be a small dip in the percentage of decision errors in 1994 and 1995 and a gradual decline in violations observed from 1991-94. In both cases however, the trends quickly re-established themselves at levels consistent with the overall average.

While this is certainly important information, some may wonder how these findings compare with the nearly 11,000 non-fatal accidents. As can be seen in Figure 2, the results were strikingly similar to those associated with fatalities. Again, the trends across the years were relatively flat and as with fatal accidents, skill-based errors were associated with more non-fatal accidents than any other error form followed by decision errors, violations, and perceptual errors.

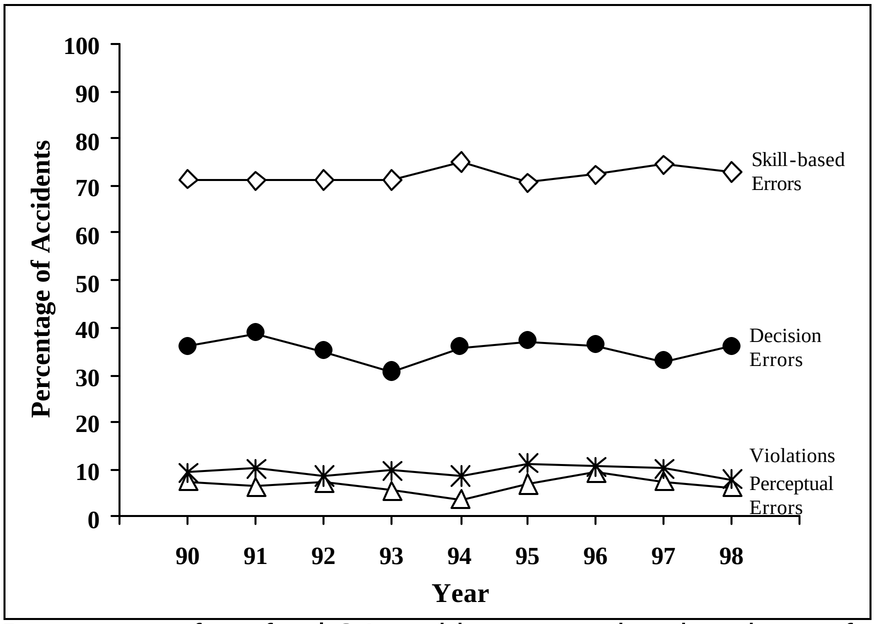

Figure 2. Percentage of nonfatal GA accidents associated each unsafe act.

While the similarities are interesting, it was the differences, or should we say, the difference, that was arguably one of the most important findings. When the error trends are plotted together for fatal and non-fatal GA accidents, as they are in Figure 3, it is readily apparent that the proportion of accidents associated with violations was considerably less for non-fatal than fatal GA accidents. In fact, using a common estimate of risk known as the odds ratio, fatal accidents were more than four times more likely to be associated with violations than non-fatal accidents (odds ratio = 4.588; 95% confidence interval = 4.130 to 5.096, Mantzel-Haenszel test for homogeneity = 900.387, $p<.001$). Put simply, if you violate the rules resulting in an accident, you are considerably more likely to die or kill someone else.

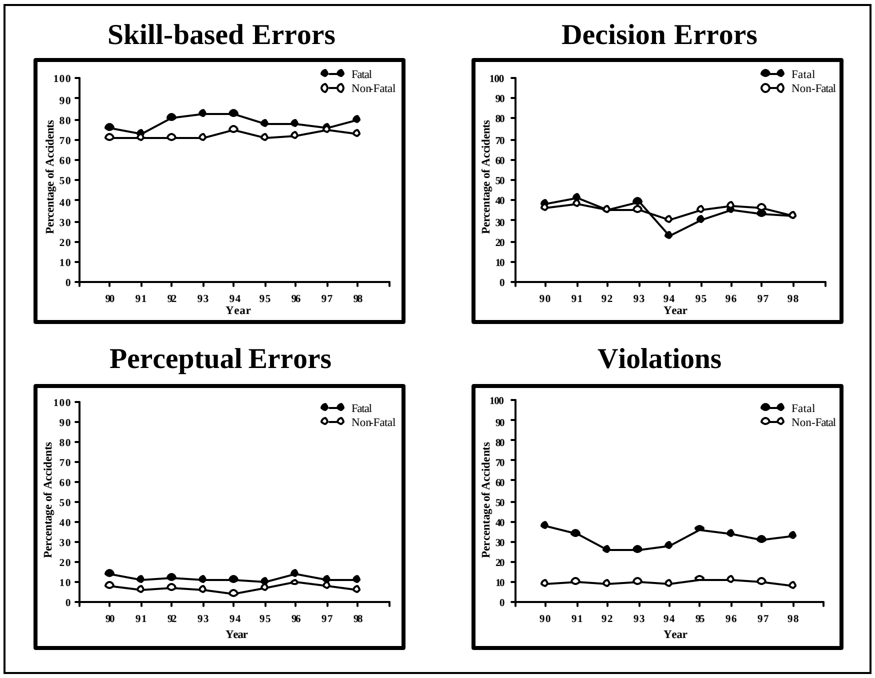

Figure 3. Percentage of fatal (closed-circles) and nonfatal (open circles) GA accidents associated each unsafe act.

Human error associated with CFIT accidents

The preceding analysis of the data represents a "quick look" at the human error issues facing GA. Yet, alone it provides little insight into the pattern of errors associated with any specific type of accident, like CFIT. The next step, therefore was to investigate what differences, if any, existed in the type and frequency of errors committed by aircrew involved in CFIT versus those observed in other types of accidents. An examination of the GA accidents revealed that 1,407 (roughly 10 percent), of the over 14,000 accidents were classified as CFIT by our pilot-raters using the criteria established by the CAST/ICAO Common Taxonomy Team. While the actual number and percentage of accidents associated with CFIT is a new and important finding in and of itself, the larger question was whether there were any differences in the pattern of errors associated with CFIT and the non-CFIT accidents.

An inspection of Figure 4 reveals that the proportion of accidents associated with each HFACS causal category varied markedly between CFIT and non-CFIT accidents. The difficulty was in determining which differences, if any, were actually significant, and more importantly, which were meaningful. Traditionally, nonparametric statistics, like Chi-square, are used to measure the association between two nominal (indicator) variables. However, Chi-square, like many other nonparametric statistics, are fraught with problems where large data sets are involved. That is, as the sample size increases, the more likely it is to find significance where only small, perhaps trivial, differences actually exist.

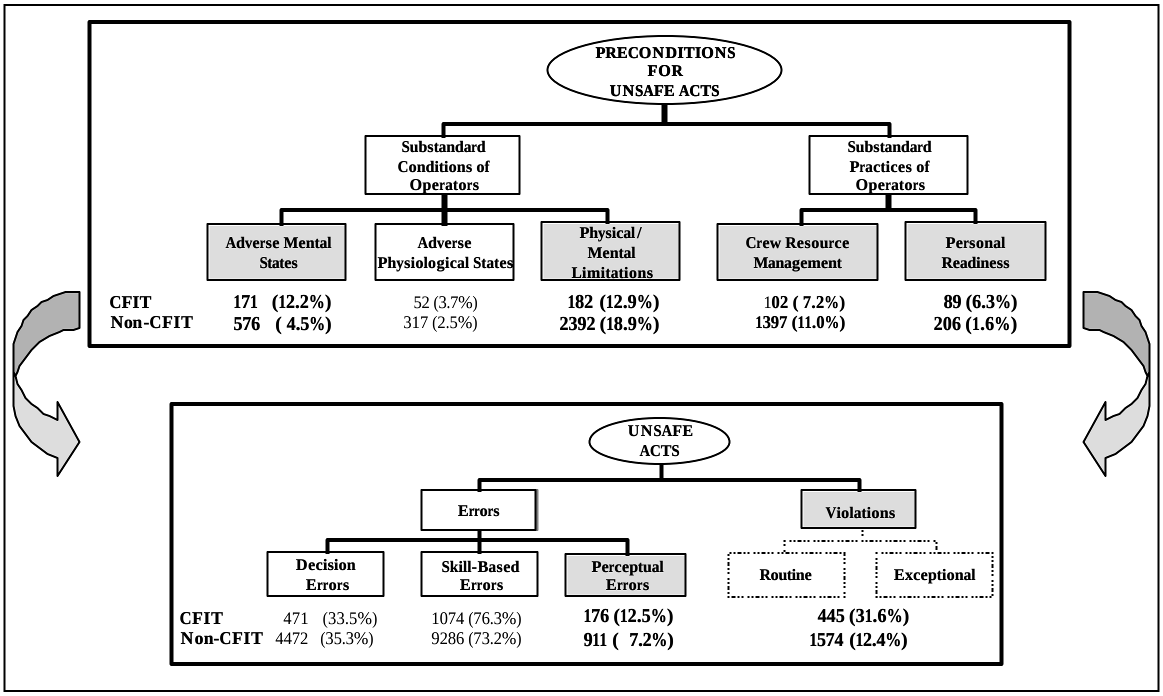

Figure 4. Number and percentage of CFIT and non-CFIT accidents associated with at least one instance of each particular causal category. Statistics associated with violations have been collapsed across the type of violation committed. Significant differences ($p<.001$) are represented by shaded boxes.

One option is to use a measure of association that is not affected by sample size, like the odds ratio. Commonly used in epidemiology, the odds ratio is typically used to measure the *degree* of the association between two variables or the ratio of the odds of suffering some particular fate given certain characteristics. Consider, for example the odds of surviving an automobile accident with or without using a seatbelt. If drivers suffer fatal injuries 20% of the time when they use their seatbelts, the odds of dying in a car accident while wearing a seatbelt are 0.25 (0.2 die with their seatbelt on / 0.8 survive with their seatbelt on). In contrast, 35% of drivers not wearing seatbelts die in automobile accidents, giving odds of 0.538 (0.35 die with their seatbelt off / 0.65 live with their seatbelt off). Thus, the odds ratio is 0.465 (0.25/0.538). In other words, you have a 0.465 times higher chance of dying in an automobile accident with your seatbelt on than without it. Arguably, this is hard to interpret, so with numbers of less than one we typically calculate the inverse of the odds ratio, which in this case equals 2.15 (1/0.465). This means that you would be 2.15 times more likely to die in an automobile accident if you did not wear your seatbelt than if you had worn it.

Another option is to dispense with traditional nonparametric statistics altogether, and compare the differences observed in the percentage data associated with each HFACS causal category for CFIT and non-CFIT accidents against some preset level considered “operationally relevant.” But, who is to say which differences are operationally relevant, and which are not? After all, is a difference between CFIT and non-CFIT accidents of five percentage points more operationally relevant than say three or four percent - or perhaps, one should use a larger percentage like 10 percent? In the end, the decision is subjective and often left to the researcher to defend.

Regardless of whether one uses traditional statistics or simply chooses an operationally relevant difference, there really is no right or wrong answer. Therefore, left without a clear-cut option, we chose to use the more objective approach of nonparametric statistics (Chi square and odds ratios) but with a considerably more conservative *p* value ($p<.001$) than is typically reported in other studies ($p<.05$ is generally regarded as acceptable within the psychological literature). Our intention was to capitalize on the objective power of statistics while minimizing the problems associated with potentially inconsequential findings.

Using this approach, the results of the Chi-square analysis are presented for each HFACS causal category in Table 1. Also included are the corresponding odds ratios with a 95% confidence interval as a measure of the relative risk of CFIT given a particular causal category. For illustrative purposes, the results of the analyses in Table 4 have been translated into Figure 4 by shading the corresponding HFACS causal categories where significant differences existed.

Table 1. Chi-square and odds ratio for CFIT for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval Lower	Upper	
Unsafe Acts of Operators						
Decision Errors	1.792	Ns	0.923	0.822	1.038	ns
Skill-based Errors	6.229	Ns	1.178	1.036	1.341	ns
Perceptual Errors	50.404	p<.001	1.847	1.555	2.193	p<.001
Violations	380.748	p<.001	3.264	2.883	3.695	p<.001
Substandard Conditions of Operators						
Adverse Mental States	146.069	p<.001	2.907	2.427	3.482	p<.001
Adverse Physiological States	7.097	Ns	1.497	1.110	2.017	ns
Physical/Mental Limitations	29.826	p<.001	0.639	0.543	0.751	p<.001
Crew Resource Management	18.916	p<.001	0.631	0.512	0.778	p<.001
Personal Readiness	136.486	p<.001	4.089	3.168	5.276	p<.001

In some ways, the pattern of human error was similar for CFIT and non-CFIT accidents, as skill-based and decision errors were the most frequently cited causes of both. However, important differences did exist. For instance, almost one-third of all CFIT accidents were associated with violations of the rules compared with just over 12% for non-CFIT accidents, yielding an odds ratio of 3.264. Likewise, personal readiness failures (e.g., failing to obtain adequate rest, self medicating, etc.), arguably another type of violation only occurring external to the cockpit, were over four times more likely during CFIT accidents. Adverse mental states (odds ratio = 2.907) and perceptual errors (odds ratio = 1.847) were also more prevalent during CFIT than non-CFIT accidents. In contrast, physical/mental limitations (e.g., the inability to maintain control of the aircraft) and failures of crew resource management were more likely to occur during non-CFIT than CFIT accidents.

The effect of visual conditions on CFIT

When discussing CFIT, many safety professionals have suggested that these accidents typically occur at night or in adverse weather when pilots simply may not be able to see their impending collision with the terrain or obstacles. However, it now appears that more of these accidents occur during VMC (n=867; 61.6%) than IMC (n=501; 35.6%), although the percentage that occurred in VMC was considerably less than that observed for non-CFIT accidents (Figure 5, upper left). Furthermore, it appears that a greater percentage of CFIT accidents occur during the day (n=923; 65.6%) than at dawn or dusk (n=82; 5.8%) or even at night (n=400; 28.4%; Figure 5, upper right).

However, simply looking at lighting conditions without considering the weather, or vice-versa, really only presents part of the picture. Therefore, we combined the weather with the lighting information and examined the percentage of CFIT and non-CFIT accidents occurring during visually impoverished (i.e., accidents occurring either at night or in IMC) and clear daytime conditions. Yet, even when the data were examined in this way (Figure 5, lower panel), nearly as many CFIT accidents occurred in clear daytime conditions (n=685; 48.7%) as during visually impoverished conditions (n=695; 49.4%). While this finding might not have been predicted by those in the GA community, it was not unprecedented given the previous findings of Shappell and Wiegmann (1997a) using US Navy/Marine Corps accident data. In contrast, considerably more non-CFIT accidents occurred in clear conditions.

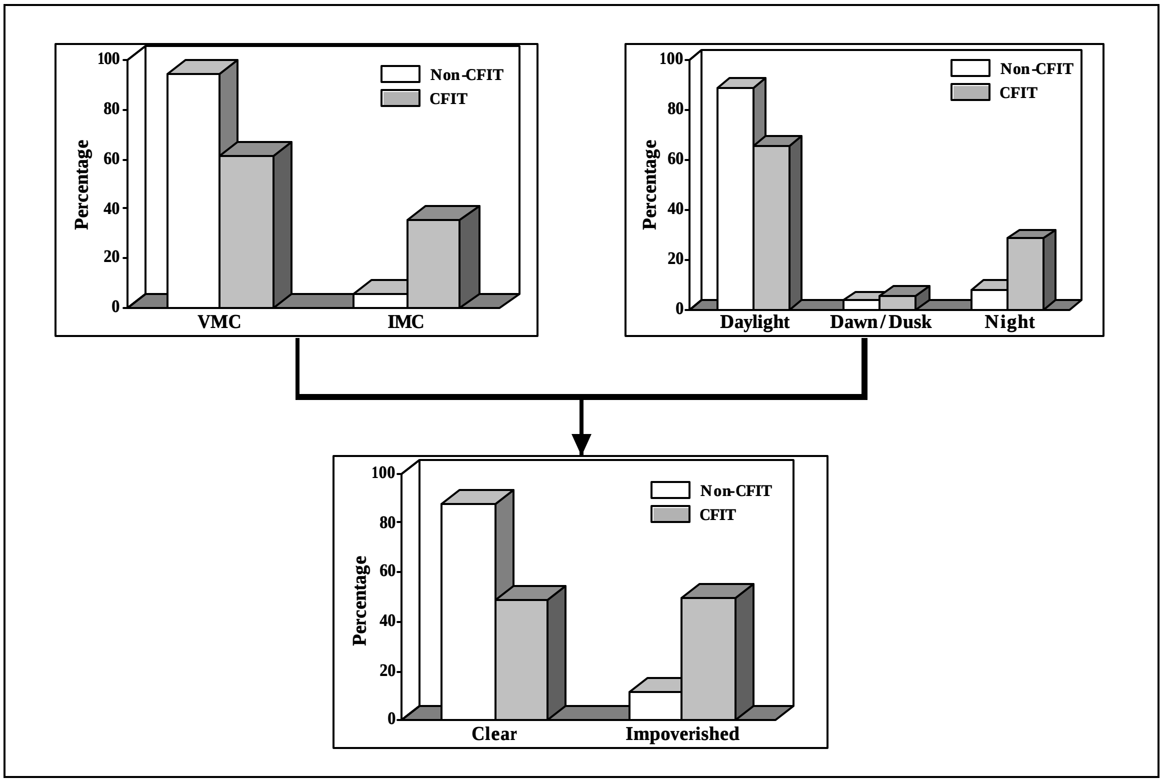

Figure 5. The percentage of CFIT and non-CFIT GA accidents that occurred during selected weather (upper left), lighting (upper right), and visual conditions (lower).

Although there appears to be very little difference in the number of accidents that occurred during clear and visually impoverished conditions, the question remains whether the pattern of human error differed appreciably for the different visual conditions. Indeed, the data presented in Figure 6 suggest that in some ways the underlying causes are intrinsically different. For instance, those CFIT accidents that occurred during visually impoverished conditions were more often associated with violations of the rules, adverse physiological states, physical/mental limitations, and poor crew resource management (Table 2). Perhaps not surprising, aircrew involved in a CFIT accident during visually impoverished conditions were well over six times more likely to have committed a violation of the rules. They were also five times more likely to have been affected by adverse physiological states (e.g., misjudging altitude and spatial disorientation) and more likely to mismanage their resources (e.g., failing to obtain an adequate preflight weather brief or update prior to departure). Indeed, one could almost envision a crew that fails to obtain a weather update prior to takeoff (crew resource management) and then encounters weather enroute. Then, after choosing to continue into IMC when VFR only (violation), they end up misjudging their altitude (adverse physiological state) and collide with the terrain.

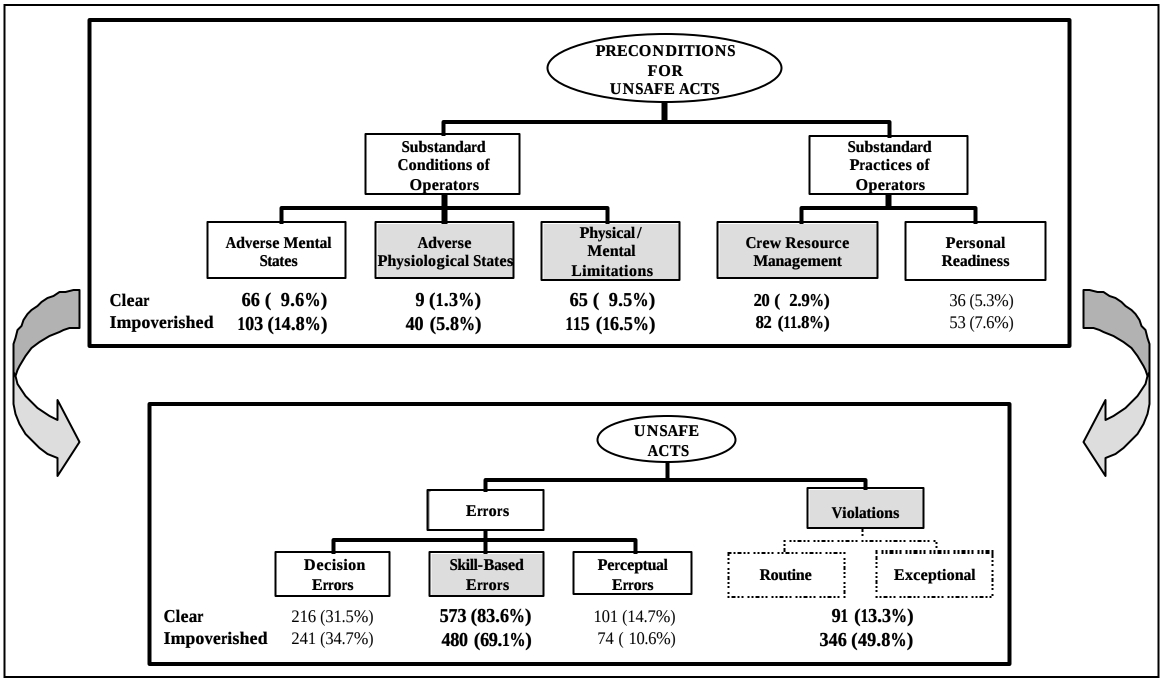

Figure 6. Percentage of CFIT accidents occurring in clear versus visually impoverished conditions associated with at least one instance of each particular causal category. Statistics associated with violations have been collapsed across type of violation committed. Significant differences (p<.001) are represented by shaded boxes.

In contrast to visually impoverished conditions, trying to understand why a pilot would collide with terrain in clear daytime conditions is somewhat more puzzling. However, the odds ratio data may provide a clue. It appears that pilots involved with CFIT in clear daytime conditions are well over two times more likely (1/0.436 = 2.29) to have committed a skill-based error than those involved in other types of accidents. Given that skill-based behavior is often the result of inattention and simple stick-and-rudder skills, perhaps they were either not proficient or simply preoccupied with other things. In either event, the human errors associated with CFIT in clear and visually impoverished conditions are fundamentally different with regard to the types of human error more often associated with it.

Table 2. Chi-square and odds ratio for CFIT occurring during clear versus visually impoverished conditions for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval		
Unsafe Acts of Operators						
Decision Errors	1.539	Ns	1.153	0.921	1.443	ns
Skill-based Errors	40.587	p<.001	0.436	0.337	0.565	p<.001
Perceptual Errors	5.230	Ns	0.689	0.500	0.949	ns
Violations	212.391	p<.001	6.471	4.960	8.444	p<.001
Substandard Conditions of Operators						
Adverse Mental States	8.631	Ns	1.632	1.174	2.267	ns
Adverse Physiological States	19.872	p<.001	4.587	2.208	9.528	p<.001
Physical/Mental Limitations	15.151	p<.001	1.891	1.367	2.616	p<.001
Crew Resource Management	39.732	p<.001	4.448	2.695	7.340	p<.001
Personal Readiness	3.213	Ns	1.488	0.961	2.304	ns

<u>Collision with "terrain/water" versus collision with "obstacles"</u>

There was some concern that a definition of CFIT that equates collision with terrain/water with collision with obstacles might be akin to "comparing apples and oranges," at least from a human factors perspective. To address this concern, we examined the pattern of human errors associated with collision with terrain/water (n=826) and that with obstacles (n=581). An inspection of Figure 6 revealed very few differences between the two types of CFIT, including <u>no</u> differences among the preconditions for unsafe acts. In fact, the only differences were among skill-based and perceptual errors (Table 3). Specifically, skill-based errors were nearly two times more likely (odds ratio = 1.759) when the collision was with the terrain/water. In contrast, collision with obstacles was more often associated with perceptual errors (odds ratio = 1/0.574 or 1.74).

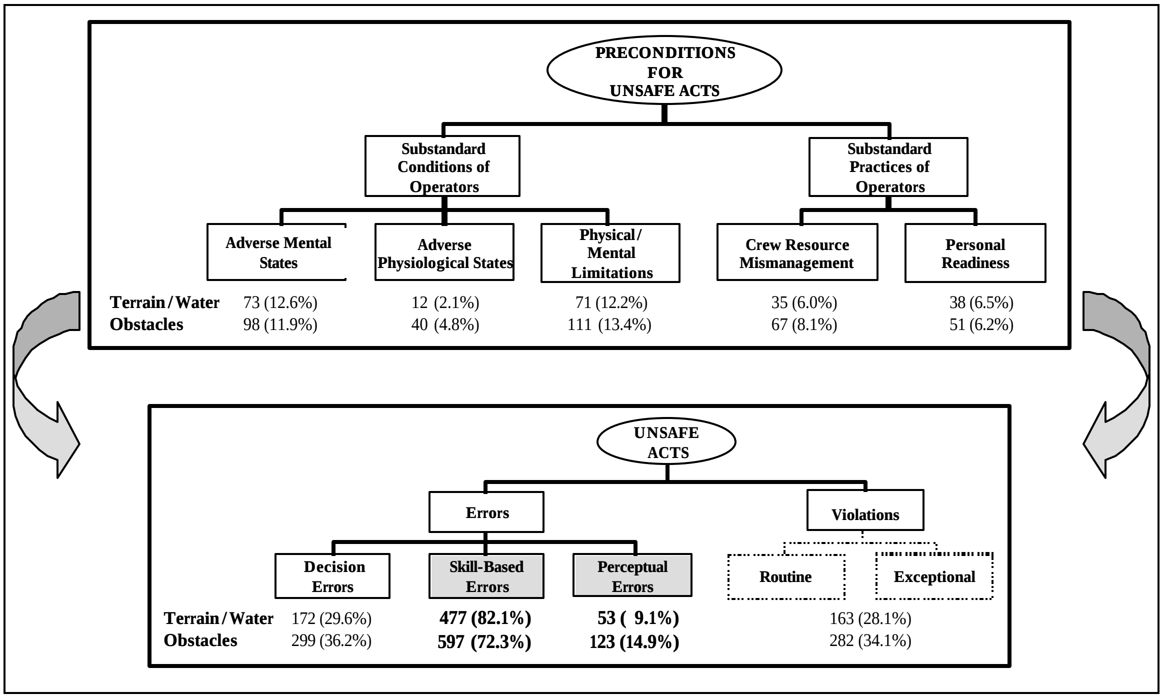

Figure 6. Percentage of collisions with obstacles versus terrain/water associated with the specific unsafe acts of aircrew.

Table 3. Chi-square and odds ratio for type of CFIT for each HFACS causal category.

HFACS Causal Category	Chi-square		Odds Ratio	95% Confidence Interval Upper	Lower	
Unsafe Acts of Operators						
Decision Errors	6.660	ns	0.741	0.931	0.590	ns
Skill-based Errors	18.221	.001	1.759	2.284	1.355	.001
Perceptual Errors	10.372	.001	0.574	0.807	0.408	.001
Violations	5.841	ns	0.752	0.948	0.597	ns
Substandard Conditions of Operators						
Adverse Mental States	0.157	ns	1.067	1.475	0.772	ns
Adverse Physiological States	7.391	ns	0.414	0.797	0.215	ns
Physical/Mental Limitations	0.449	ns	0.897	1.233	0.652	ns
Crew Resource Management	2.210	ns	0.726	1.109	0.476	ns
Personal Readiness	0.077	ns	1.063	1.642	0.689	ns

Regional differences in the patter of human error associated with GA accidents

Of particular interest to those involved with GA safety and training programs was the possibility that differences exist in the types of errors committed by GA pilots depending upon which geographic region of the country one examined. In other words, do GA pilots crash aircraft for different reasons in different regions of the U.S., or is it a "one size fits all" sort of deal? For instance, one might assume that given the often harsh terrain and weather conditions experienced by pilots in Alaska, differences might exist when they were compared with their counterparts in the rest of the U.S. Indeed, some have made that very argument for years – albeit based upon anecdotes and conjecture rather than the accident record. Unfortunately, until now opinion and anecdotes were about all we had to work with. But with the development of HFACS and the completion of the GA analysis we now have a systematic and scientific means to address this issue.

So, with this in mind, we parsed the data set by the region where the accident occurred using the existing FAA regional breakout. The FAA is divided into nine regions as presented above. While one can certainly question whether putting Hawaii in with California, Nevada and Arizona makes sense or question why one state was considered part of Region X but not Region Y or Z, we chose to work within existing FAA regions as a first pass. That being said, what did we find?

Much to the surprise of some, we saw no differences between FAA regions in the relative distribution of errors and violations committed by GA pilots involved in accidents (Figure 7). Even Alaska appears no different than the rest of the U.S. when the data are examined systematically.

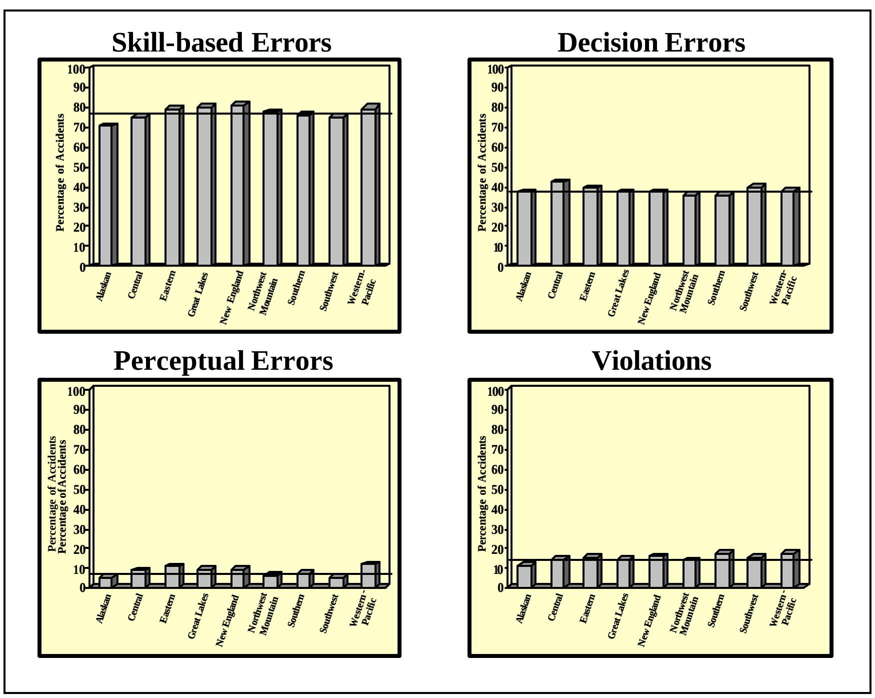

Figure 7. Regional analysis of human error associated with GA accidents using HFACS.

OK, but what if we looked at just fatal accidents. Even then, no real differences jump out at you (Figure 8). Perhaps the New England region is associated with more skill-based and decision errors and maybe the Central region is associated with slightly more violations of the rules – but are these operationally significant? Perhaps not.

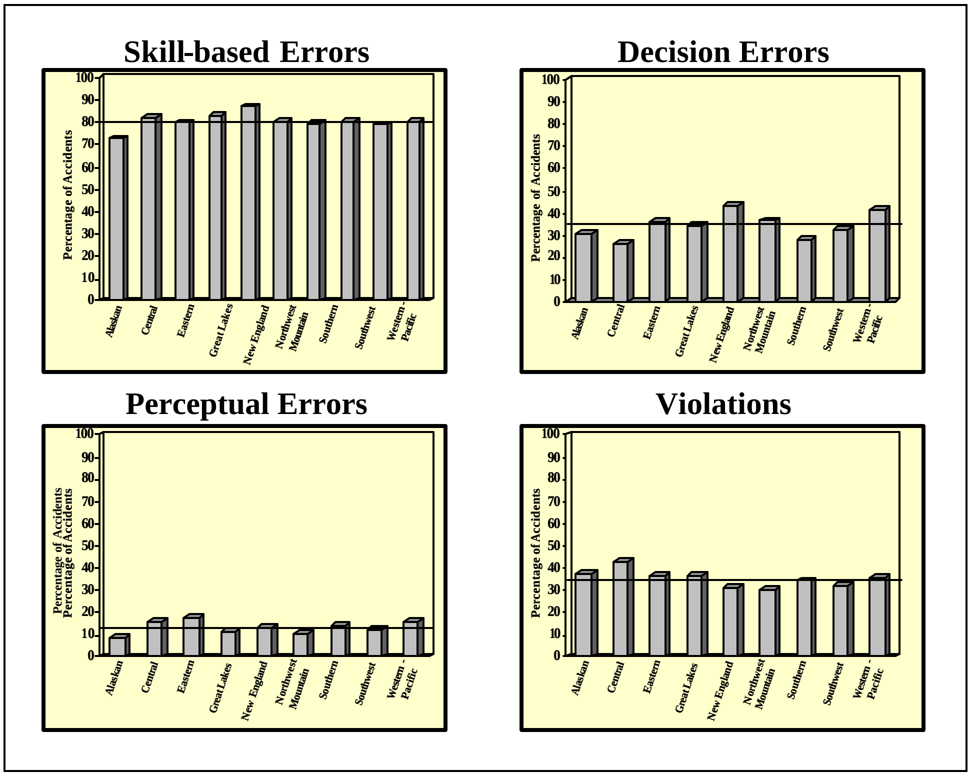

Figure 8. Regional analysis of human error associated with fatal GA accidents using HFACS.

What this tells us is that whether your accident occurred in Alaska or Florida, California or New York, the relative distribution of unsafe acts (errors and violations) committed by aircrew was strikingly similar. Indeed, even those that espouse the "bush pilot" theory of flying in Alaska seem to be off base. While Alaska may witness more accidents, which in turn may be more a function of the fact that folks in Alaska fly aircraft like we take taxis in the continental U.S., the types of errors committed do not appear to vary. This would seem to lend some credence to the old adage that "there are no new ways to crash aircraft, only new pilots."

<u>Impact/Applications</u>: Data generated from the HFACS project has been briefed to a variety of committees and organizations within the FAA, NASA and the NTSB. In each case, the data generated has been incorporated into existing programs to augment or modify goals and plans of that organization. For example, as part of the Safer Skies initiative, Drs. Shappell and Wiegmann were active participants in the Aeronautical Decision Making JSAT (ADM JSAT) and General Aviation Data Improvement Team (GADIT) in Washington, DC. In both instances,

the results of the GA HFACS project have served as cornerstones for human factors data associated with GA accidents and has been integrated into reports out of the committee. In each case, a recommendation has been made to integrate HFACS into the investigative process in the field. As a result, Drs. Shappell and Dr. Wiegmann (Univ. of Illinois) presented their analyses of all General Aviation accidents occurring between 1990-98 to the NTSB (Drs. V. Ellingstad, D. Bruce, and E. Byrne) and ASY-1 on separate days. The intention was to brief the NTSB on the progress thus far and begin discussions on hosting the HFACS data on either the NTSB or NASDAC web sites. Extensive briefings have also been conducted with AFS-800 and ACE-100 (FAA Sponsors of the project). Data from these briefings has been incorporated into several initiatives at AFS-800 and a request has been made for additional analyses in FY02 and FY03.

Technology Transfer: A variety of civilian and military aviation organizations around the world have adopted HFACS. Other non-aviation organizations have adopted HFACS as well. Efforts are underway to adapt HFACS to the medical environment.

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts:

Wiegmann, D., Shappell, S. & Fraser, J. HFACS analysis of aviation accidents: A North American comparison. *73nd Annual Meeting of the Aerospace Medical Association*, 2002.

Wiegmann, D. & Shappell, S. HFACS analysis of accidents involving CFR part 135 nonscheduled air carriers, 1990-1997. *73nd Annual Meeting of the Aerospace Medical Association*, 2002.

Shappell, S., & Wiegmann, D. HFACS analysis of general aviation data 1990-98: Implications for training and safety. *73nd Annual Meeting of the Aerospace Medical Association*, 2002.

Patents Issued or Pending: none

Honors:

- Dr. Shappell and Dr. Wiegmann were awarded the Flight Safety Foundation’s Admiral Luis De Florez Flight Safety Award for their contributions to aviation safety.
- Dr. Shappell and Dr. Weigmann were awarded the William E. Collins “Outstanding Human Factors Publication of the Year” by the Aerospace Human Factors Association.

- Dr. Wiegmann was elected President of the Aerospace Human Factors Association.
- Dr. Shappell is past-President of the Aerospace Human Factors Association

Related Projects:
- Julia Pounds (CAMI) - FAA JANUS Project to harmonize HFACS with EUROCONTROLs HERA framework for use in Air Traffic Control.
- Jim Luxoj (Rutgers University) - NASA funded project that utilizes HFACS data and Bayesian Belief Networks to predict the efficacy of intervention strategies.
- John Schmidt (U.S. Naval Safety Center) - FAA/NASA funded project for the development of maintenance extension of HFACS.
- Doug Wiegmann (U of Illinois) - FAA funded project examining organizational influences on human error.

Project Title: *Reduction of Weather-Related and Maneuvering Flight GA Accidents*

Primary Investigator: Dr. Doug Wiegmann, University of Illinois, Savoy, IL (e-mail: dwiegman@uiuc.edu)

Co-Primary Investigator: David O'Hare

FAA Sponsor Organization: AFS-820 (POC: Anne Graham)
Sponsor's Requirement Statement: Weather related accidents and incidents still remains one of the major causes of general aviation accidents. This research program continues to address countermeasures and advances in training, technologies, and regulations to significantly reduce this GA issue. **Please refer to page 123 for a more detailed description.**

Research Project's Goal: The ultimate goal of this research program is to develop intervention strategies that can be used to promote safer and more effective decision-making in VFR cross-country flight. Such tools can only be effective, however, if they are based on a sound understanding of the behavioral and psychological mechanisms that govern decision-making in VFR cross-country flight.

Best Accomplishment: Served on the ADM JSAT Expert Panel to analyze issues related to pilot decision-making and to generate recommendations for consideration by the JSAT.

Project Summary: General aviation (GA) accident statistics indicate that visual flight rules (VFR) flight into instrument meteorological conditions (IMC), or unqualified flight into bad weather, is a major safety hazard within general aviation. Historically, very little research has been conducted to identify the factors that influence VFR pilots' decisions to risk flying into deteriorating weather conditions. Without an empirical understanding of these factors, decision-making training within pilot training programs has been based largely on common sense and intuition. Hence, such programs have been relatively ineffective in reducing the occurrence of such accidents. To address this issue, the present project involves both archival and laboratory research to empirically explore the factors that contribute to pilots' decision to "press on" into deteriorating weather. To date, one database study and three laboratory studies have been conducted. These studies have all pointed to pilots' situation assessment and previous flight experiences as key factors influencing pilots' decisions to continue VFR flight into IMC. Future research will explore methods for improving situation assessment to prevent accidents, as well as developing methods for reducing the consequences (i.e., improve recovery) of inadvertent encounters with adverse weather.

Scientific and Technical Objectives:

Two studies were conducted to examine the role of pilot experience and self-confidence in diagnostic decision-making ability and perceptions of flight skills. The results of the first study indicated that more experienced pilots' generally considered themselves as having better stick-and-rudder skills than less experienced pilots but more experienced pilots did not feel that they had better diagnostic decision-making skills. The second study involved simulated flight into adverse weather that required pilots to perform a standard 180-degree turn under both VMC and IMC. Results suggest that pilots overestimated their ability to perform this task and that they lacked metacognitive skills to monitor their actual performance while performing the tasks. The relationship between these factors and prior flight experience is still being analyzed. However, preliminary findings suggest that pilots need better training in diagnostic decision-making and that strategies for reducing VFR pilots' over-confidence in their abilities to fly into, and escape from, adverse weather need to be explored.

Technical Approach:
In a typical experiment, participants are introduced to a Frasca 142 flight simulator that is configured as a Cessna 172. The simulator has a full set of instruments as well as a radio stack. All the necessary controls (yoke, rudder pedals, throttle) are also available. An Evans and Sutherland SPX 2400 visual system is used to project a 135° view of the outside visual world. This system is capable of displaying real time weather changes and three-dimensional fixes along the flight route.

After a practice flight (approximately 20 minutes), participants are provided with a checklist, map and flight plan which detailed the route and the fixes along the route they are to fly for the experiment. They are provided with Terminal Aerodrome Forecasts (TAF), an aviation routine weather report (METARS), and Winds Aloft information for the day of the flight. For example, participants may be told that the weather conditions at take-off are above VFR minimums (5 statute miles [sm] visibility, 5000ft MSL cloud ceiling). Winds are forecasted to be from the northwest (310) at 8 knots with a 20% chance of rain later that evening. Participants are given as much time as they need to review the weather information and other flight planning details.

Participants are instructed to treat the simulated cross-country flight like any that they would make in the real world. They are told that they are responsible for monitoring aircraft systems for possible failures, as well as scanning for other possible traffic or changes in the weather. They are also informed that these problems might not necessarily occur. However, in the event that they do decide to divert from the planned flight, they are informed that they could choose any alternate airport that is on the map, including returning to the departure airport. They are instructed to inform the experimenter if and when they decided to deviate from the original flight plan and to press a pre-determined key on the simulator to mark the point in the flight at which this decision was made. The timing and accuracy of their decisions are assessed as well as their ability to perform the chosen course of action.

Following the flight simulation, participants complete a post-experimental questionnaire to examine the participants' assessment of the weather conditions, in terms of visibility and cloud ceiling, at the time the program was terminated.

Results: The results of this research indicate that VFR flight into IMC is due to problems at various points in the decision-making process. Both situation assessment (i.e., weather evaluation) and perceived risk of flight into adverse weather are important factors affecting pilots' choice to press on into deteriorating weather. Previous flight experience also appears to play a role, since experience affects both of these components of a pilot's decision-making process (i.e. situation assessment, risk perception and self-confidence). However, the role of experience is difficult to determine. For example, experience may make a pilot better at diagnosing weather conditions, and hence more experienced pilots may be more likely to divert from flight into adverse weather. However, experience can also make pilots more confident in their abilities, and therefore reduce their perceived risk and promote VFR flight into IMC. Furthermore, there are numerous categories of experience in aviation (total flight hours, cross-country hours, instrument time, etc.). We are therefore, exploring these issues in more detail in current studies.

Impact/Applications: The results of this research will help the FAA sponsor determine the types of intervention strategies that are likely to be effective at promoting safer and better decision making during VFR cross-country flight. Such determinations by the FAA sponsor should be based on a sound understanding of the behavioral and psychological mechanisms that govern decision-making in VFR cross-country flight.

Technology Transfer: none

Journal Articles:

Goh, J. & Wiegmann, D. A. (2001). Visual flight rules flight (VFR) into adverse weather: An empirical investigation of the possible causes. *The International Journal of Aviation Psychology, 11 (4),* 259-379.

Wiegmann, D., Goh, J., & O'Hare, D. (in press). The role of situation assessment and experience in pilots' decisions to continue visual flight rules (VFR) flight into adverse weather. *Human Factors*.

Goh, J. & Wiegmann, D.A. (accepted pending revision). Analyzing the causes of VFR flight into IMC accidents: Implications for aeronautical decision-making theories and training. *Aviation, Space, and Environmental Medicine.*

Books or Chapters: none

Technical Reports:

Goh, J. & Wiegmann, D.A. (2002). Human factors analysis of accidents involving visual flight rules flight into adverse weather. *Aviation, Space, and Environmental Medicine, 73,* 817-822

Wiegmann, D., Goh, J., & O'Hare, D. (2002). The role of situation assessment and experience in pilots' decisions to continue visual flight rules (VFR) flight into adverse weather. *Human Factors, 44*(2), 189-197.

Conference presentations/abstracts:

Wiegmann, D., & Goh, J. (2002). Visual flight rules (VFR) flight into instrument meteorological conditions (IMC): A review of research with an eye toward prevention. *Paper presented at the 73rd Aerospace Medical Association Annual Scientific Meeting*, Montreal, Canada.

Goh, J., Wiegmann, D.A., & O'Hare, D. (2002). The effects of distance traveled and pilot experience on pilot's decisions to continue visual flight rules flight into adverse weather. *Paper presented at the 73rd Aerospace Medical Association Annual Scientific Meeting*, Montreal, Canada.

Goh, J., & Wiegmann, D. A. (2002). Relating flight experience and pilots' perceptions of decision-making skill. *Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society,* Baltimore, MD.

Patents Issued or Pending: none

Honors: Doug Wiegmann was elected President of the Aerospace Human Factors Association (AsHFA). He was also awarded the William E Collins Award for best publication in Human Factors (2001) and the Flight Safety Foundation's de Florez Award for significant contributions to aviation safety (2002).

Related Projects: This project is related to research being done at CAMI on weather displays and ADI failures.

Project Title: *Loss of Primary Flight Instruments During IMC*

Primary Investigator: Dr. Dennis Beringer, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: dennis_beringer@mmacmail.jccbi.gov)

Co-Investigator: Kathleen Roy (AOPA Air Safety Foundation)

FAA Sponsor Organization: AFS-800 (POC: Michael Henry)
Sponsor's Requirement Statement: to identify the probably pilot response to loss of primary flight instruments during IMC and provide recommendations to significant reduce the potential of accidents and incidents. Research should identify training, technology or regulatory solutions. **Please refer to page 114 for a more detailed description.**

Research Project's Goal: The results may have implications for future studies on the presentation of aircraft attitude information in head-up and/or head-based displays, and how back-up instrumentation may be required and used in this context.

Best Accomplishment: Both simulator and aircraft data collections were completed and reported. Results were passed on to AFS for use in an advisory circular. Results were also briefed to Aircraft Certification for possible use in the revision of rules regarding required instrumentation in Part 23 aircraft. Findings were reported to the general aviation pilot population through AOPA publications, and summaries appeared in the popular aviation press.

Project Summary: The purposes of the studies were to determine how effective a back-up attitude indicator would be when substituted for the turn coordinator in Part 23 aircraft, what other combinations of instrumentation might reduce the difficulty of flying with partial-panel instrumentation, and how results obtained in flight simulators compared with results obtained in aircraft. Studies in both simulators and aircraft were completed and the results were compared to evaluate loss potential during vacuum-failure events. The outcome indicated that there is a higher loss potential with high-performance complex aircraft, and that various combinations of instrumentation, particularly those involving the horizontal situation indicator and/or a back-up attitude indicator, could forestall loss of control during vacuum-loss events. Results were reported in the open literature, at professional conferences, and through popular aviation press sources, and were used by AFS for preparation of advisory circular materials. AIR was also examining the results for potential application to Part 23 rules.

Scientific and Technical Objectives: the last 50 years. There are two primary situations where loss of attitude awareness may lead to a fatal accident. The first is when a non-instrument-rated pilot inadvertently or intentionally enters instrument meteorological conditions (IMC), is unable to maintain the attitude of the aircraft, and ultimately enters either a spiral dive or increasingly severe oscillations that ultimately lead to aircraft structural failure. The AOPA Foundation, Inc., funded a study at the University of Illinois Institute of Aviation that was reported by Bryan, Stonecipher, and Aron (1954) in which a procedure was developed to help visual-flight-rules (VFR) pilots who had inadvertently wandered into IMC to return to visual meteorological conditions (VMC). Baseline data were collected at the beginning of the study to determine with what frequency pilots without instrument experience would enter potentially flight-terminating conditions. The 20 pilots ranged in age from 19 to 60 years, had no previous instrument experience, and had a minimum of experience with the Beechcraft Bonanza. Total pilot time ranged from 31 to 1625 hours. In their first exposure to simulated instrument conditions (created by wearing blue goggles in a cockpit with orange plexiglas covering the front and side windows), 19 of the 20 entered a "graveyard spiral" within an average of 3 minutes after losing their contact view of the outside world. The 20th placed the aircraft into a whip-stall attitude. These results were obtained with cockpit instrumentation sufficient to conduct instrument-referenced flight.

The second contributing situation is the one in which instrument-rated pilots in IMC lose their attitude reference through vacuum/pressure system or instrument failure. The majority of the 207,000 airplanes in the general aviation (GA) fleet have vacuum-powered attitude indicators (AIs) and heading indicators. Many of those same airplanes are not equipped with back-up or secondary attitude indicators or a back-up vacuum pump. Therefore, instrument-rated pilots must demonstrate the ability to fly airplanes in "partial-panel" (loss of vacuum instruments) conditions as part of their initial and recurrent training. This usually entails maintaining controlled flight using indications from the pitot/static system instruments (airspeed indicator, vertical speed indicator, and altimeter), electric gyro instruments (turn coordinator), and magnetic instruments (compass). Inasmuch as partial-panel flying is usually simulated by covering up the supposedly "failed" instruments, pilots do not have the opportunity to experience a realistic vacuum failure, in which they would have to detect and diagnose the failure - unless it is an actual emergency. This type of mechanical failure (vacuum system or related instruments) has been documented as a causal factor in only about three accidents per year, which is 11% of all documented spatial disorientation accidents. However, these accidents result in fatalities approximately 90% of the time (Landsberg, 2002; data from the Air Safety Foundation , ASF, database of National Transportation Safety Board accident reports). If one was to look at the combination of a VFR pilot entering IMC and experiencing a vacuum-system failure, thus losing any attitude reference, it is not difficult to imagine the fatality rate being even higher (little data exist, however, on this specific combination of factors). That is to say, if pilots who flew primarily by visual reference had difficulty flying by reference to a full set of instruments, it is likely that they would be completely unable to continue under partial-panel conditions.

These studies were a continuation of a study conducted for the AOPA/ASF by Martinez (2000) and administered by Flight Safety International (FSI) in 2000. Martinez reported on pilot performance following the failure of an aircraft vacuum system in single-engine Cessna 208 and Cessna 210 simulators, with motion disabled. Beringer and Ball (2001), as part of this effort, reported a similar study in fixed-base single-engine Cessna 172 and Piper Malibu simulators, with results comparable to Martinez'.

In the Martinez study, 66.7 % of the 24 test flights resulted in loss of control and 50 % of the flights ended in a crash. Beringer and Ball's results from a sample of 60 pilots showed that 27 % of the 11 pilots flying the Malibu with the electric horizontal situation indicator (HSI) would have exceeded performance limitations of the aircraft or struck the ground. A simulated vacuum-driven directional gyro (DG) was depicted in place of the HSI to represent the majority of low-end GA aircraft for one group, and 83 % of those 12 pilots lost control, exceeded performance limitations of the aircraft, or would have struck the ground. When a back-up AI was depicted in place of the turn coordinator (TC), 33 % of the pilots in that group were unsuccessful in continuing the flight. Best performance was obtained with a back-up AI, HSI and turn coordinator (only 8 % loss). The Cessna 172 pilots, with a warning flag on the AI, fared better, with only one (8 %) loss of control. However, differences in stability between the Malibu simulator and the Cessna simulator (more stable in roll) placed limitations on interpretation. Beringer and Ball recommended replacing the DG and very-high-frequency omni range (VOR) heads with an HSI, freeing up an instrument location for a back-up electric AI.

The Air Safety Foundation and the FAA Civil Aerospace Medical Institute (CAMI) cooperatively developed the reported studies to collect baseline simulator and aircraft data evaluating pilots' skills in dealing with an unannounced vacuum failure in flight for comparison with previous results obtained in flight simulators. The main objectives were to provide data on the effects of various instrument combinations on pilot performance following a vacuum-system failure, and to compare loss-of-control rates between simulators and aircraft. The efforts were in direct response to AFS requests for data regarding the use of a back-up attitude indicator in place of the turn coordinator.

<u>Technical Approach</u>: .

Participants

Forty-one volunteer pilots (40 males, 1 female) were selected from approximately 300 applicants who responded to an announcement on the ASF Web site. The primary goal in the selection process was to choose a wide variety of pilots, regarding demographics and flight experience. Pilots participated without monetary compensation.

Equipment

Aircraft. The two aircraft used were a simple (Piper Archer PA-28) and a complex (Beechcraft Bonanza A36) airplane. Each was equipped with all Federal Aviation Regulation - FAR - required items for a single-pilot IFR flight. Polarized material was placed across the lower portion of the windscreen and left side window of each aircraft so that approximately the lower two-fifths of the windscreen was covered. The Francis hood used to simulate IMC contained the same polarized material in the eye openings, oriented 90° to the windshield material. This arrangement allowed the pilots to see inside the cockpit, but eliminated the outside view immediately above the glare shield.

The PA-28 flights consisted of three groups: (1) Group A - a failure of the AI and the DG, (2) Group B - same as Group A but received 30 minutes of partial-panel instruction in a personal-computer-based aviation training device (PCATD) prior to the flight, and (3) Group C – same as group A but had a failure-annunciator light (vacuum) on the panel. The A36 flights consisted of two groups (see Table 2): (1) Group A – a failure of the AI only, (2) Group B – a failure of the AI and the HSI.

Data recording. Several forms of data were recorded for each flight. Flight performance data were recorded via a Cambridge Aero Instruments GPS Navigator and Secure Flight Recorder. This generated a plan-view map and vertical-profile view of the flight path for the purpose of assessing average and maximum flight-path deviations. A color digital video recording was also obtained during the flight with audio of all intercom/radio communications. The field of view of the camera, which was attached to the cabin headliner behind and to the right of the front left seat, included the subject pilot, key flight instrumentation, and the forward view out of the windscreen. Additionally, the pilot and evaluator each completed a post-scenario questionnaire at the conclusion of the flight .

Archer implementation of vacuum failure. Prior to each flight, an airframe and powerplant (A&P) mechanic disengaged the aircraft's engine-driven vacuum system. Therefore, the AI and DG were fully operational only via the standby vacuum system. During the flight, the evaluator disengaged the standby system via a switch in the cockpit, thereby failing the vacuum-driven instruments in a realistic manner.

Bonanza implementation of vacuum failure. Prior to each flight, an A&P mechanic disabled the aircraft's engine-driven instrument air pressure pump. The AI was powered by the standby system. The HSI is electrically powered, so no maintenance was required before the flights for that instrument. During the flight, the evaluator disengaged the standby air pressure system and HSI via their individual circuit breakers in the cockpit. It is important to note that, because the AI was vacuum-driven and the HSI was electric, this was not a "real world" failure. It would be rare for both vacuum systems *and* one electric instrument to fail during flight.

Procedures and Tasks

Each scenario began with a pre-flight interview and briefing involving the volunteer pilot and the evaluator. Safety information for the flight was discussed, and each volunteer completed a consent form and a flight-experience questionnaire. The pilot was briefed about proper aircraft operation, including airspeed and power settings, and the flight plan was discussed. The volunteers were told they would be evaluated on their execution of IFR procedures. The autopilot was turned off for the duration of each flight.

After the briefing and pre-flight inspection of the airplane, the pilots departed the Frederick Municipal Airport (FDK) in Frederick, Maryland. The evaluator acted as an air traffic controller (ATC), giving the pilot heading vectors for the instrument landing system (ILS) Runway 23 approach at FDK. The purpose of this first approach was to allow the volunteer to practice flying in simulated IMC and to allow the flight data recorder to establish a baseline for the pilot's performance under normal conditions. The approach was discontinued at approximately 800 feet above ground level (AGL). At that time, "ATC" issued a clearance for the pilot to climb to 3,000' and fly a heading of 270º to the Eastern WV Regional/Shepherd Airport (MRB) in Martinsburg, West Virginia.

During the climb after the ILS approach, at a specific standardized point, the aircraft vacuum/pressure pump (and HSI in the Bonanza) was disengaged without the pilot's knowledge, leading to the eventual loss of the aircraft's attitude and heading indicators. The pilot's task was to maintain control of the aircraft, select the best option(s) to pursue, navigate accurately, communicate effectively with ATC, and complete the flight with a safe landing at either the destination or an alternate airport.

The simulated weather conditions were such that FDK was the best alternate airport. "ATC" provided vectors to a point that provided the pilot an intercept heading and altitude to the ILS Runway 23 approach at FDK. If requested by the pilot, "ATC" provided no-gyro vectors above 2,500'. No-gyro vectors consisted of the direction of turn, and when to start and stop that turn. The evaluator took control of the airplane if the pilot at any time maneuvered to a bank angle approaching 60 degrees and increasing, if the aircraft's airspeed was approaching Vne (never-exceed speed) and increasing, if the aircraft was approaching a stall condition, or for any other reason deemed necessary for the safety of the flight. All flights were conducted in weather conditions that would allow the scenario to be completed in VFR conditions. The evaluator acted as pilot in command for each flight relative to flight safety issues

<u>Results</u>:

Response to the vacuum-failure event required two tasks to be performed. First, the pilot had to recognize that a failure of some kind had occurred and correctly diagnose it and, second, the pilot then had to successfully control the aircraft using the flight data remaining. The following sections consider each component in turn

Recognition Time

Time to detect/recognize the failure was measured from the time the failure was initiated to the first verbal report by the participant of something being "wrong." Although some pilots attempted adjustments to the AI prior to verbal reporting, the only consistent scoring point that could be used was the verbal report.

The PA-28 pilots averaged a higher recognition time, with an average of 6.9 minutes for the entire group. The pilots who flew partial-panel on the PCATD prior to their flight recognized the instrument failure more quickly; however, the differences among the Archer groups did not attain statistical significance [$F_{(2,21)}=2.54$, $p>0.1$] (4.9 minutes, vs. 7.6 for the other groups). Neither can comparisons be made between the two aircraft because of potential differences in the rate at which the vacuum/pressure-driven instruments in each failed. The Bonanza pilots who experienced a failure of the HSI as well as the AI recognized the failure in an average of 2.6 minutes, which was significantly faster than the average 4.6 minutes for those pilots who had only an AI failure [$F_{(1,14)}=6.372$, $p<.05$]. The HSI was equipped with a warning flag to announce instrument failure, and this undoubtedly aided pilots in the Bonanza B group.

Flight Performance Data

Outcomes of all flights were categorized as follows:

- Category 1: The pilot had no problem controlling the aircraft. The deviation was less than 20 degrees and 200 feet.
- Category 2: The aircraft remained under the pilot's control, but with more effort than the category 1 pilots. The deviation was between 20 and 40 degrees inclusive and 200 to 400 feet.
- Category 3: The aircraft was barely under control – the pilot was struggling significantly.
- Category 4: The evaluator had to take control of the aircraft. Had this been a real instrument failure in IMC, the flight likely would have resulted in a crash.

Archer. All of the PA-28 pilots were able to maintain control of the aircraft under partial-panel conditions. However, some became disoriented and were not able to successfully execute an approach and landing to the airport. Thirty-two percent of the pilots did not successfully complete the approach (i.e., 68 % were successful).

Archer Procedures. Upon noticing the vacuum system failure, 28 percent of the PA-28 pilots declared an emergency to "ATC" (the experimenter). At the next level of urgency, 68 % notified ATC of the problem without declaring an emergency, but one pilot (4 %) gave "ATC" no notification of the problem. Distraction played a significant role in that 28 % of the pilots covered the failed instruments to prevent distraction or being mislead by the now-failed indicators. The remaining 72 % did not do so and tended to include the failed instruments in their scan, indicating to the experimenter that this was a distracting situation.

Bonanza. Twenty-five percent of the A36 pilots lost control of the aircraft. All four of those pilots (3 males, 1 female) were in Bonanza Group B (loss of AI and HSI). Two of these four were experienced Bonanza pilots, thus the effect is not solely attributable to lack of familiarity with the aircraft type. Sixty-nine percent of the pilots were able to successfully complete a partial-panel approach, including two of the pilots who had lost aircraft control but were given a second chance to fly the aircraft partial panel.

Bonanza procedures. None of the A36 pilots declared an emergency to "ATC," choosing instead to simply notify "ATC" of the problem and request assistance. One pilot (6 %) covered the failed instruments – that pilot had no problem controlling the aircraft, and is classified as a Category 1 flight.

The distribution of loss-of-control flights was such that a chi-square analysis was not appropriate given the number of cells having expected and/or observed frequencies less than five. The distribution of failed approaches by aircraft type was amenable to such an analysis, but there was no significant effect attributable to aircraft type.

Response to Warning Indicators/instruments

Only one (12.5 %) of the Archer pilots in Group C (vacuum annunciator light available) actually noticed the light. Only one (4 %) out of all of the Archer pilots noticed the vacuum gauge at the onset of the emergency. The others simply used it to verify the system failure once the instruments were tumbled. Previous studies (Beringer and Ball, 2001) listed the vacuum-low annunciator light as one of the first failure indications detected by the participants in the conditions where it was available. The present finding is not too surprising, given that the pilots were wearing the Francis hood, which greatly limits peripheral and parafoveal vision, and that the vacuum gauge was located on the right side of the cockpit, well out of the area of vision when viewing the primary instrument cluster. It should also be noted that the vacuum annunciator light was small and not very bright. This suggests that some attention may need to be given to indicator placement and conspicuity.

Pilot Experience Variables

Several questionnaire forms were administered to gather experience data from each pilot. Questions assessed experience with the specific model of aircraft to be flown, certificates/ratings, date of instrument rating, pilot-in-command hours (total and last 90 days), instrument hours (total, last 12 months, last 90 days, and "actual"), instrument training in the last 90 days (last date of partial-panel training, amount of partial-panel training, description of that training), hours flown annually, number of approaches in the last 90 days, and experience using GPS equipment. Only two observations are worth noting. The PA-28 pilots who had more than three instrument flight hours during the 90 days preceding their flight (40 %) were noticeably more proficient. Nine (75 %) flew Category 1 flights and three (25 %) flew category 2 flights. However, it should be noted that no significant correlations were found between pilot experience variables and performance variables, including categorization, for the PA-28 sample. This is undoubtedly due to the small sample size. The only pilot-experience variable that showed a significant correlation with performance (Spearman's rho) was total pilot-in-command (PIC) hours (rho = -.622, p=.01). Practically speaking, a higher PIC total was associated with a greater likelihood of obtaining a better (lower-numbered) category of performance.

Simulator and Training Benefits

Pilots reported that flying the partial-panel trial was a beneficial experience and that they felt better prepared to handle this type of emergency situation in actual IMC after having participated in the study. Those who flew the Elite PCATD flight simulator prior to their aircraft flights indicated that the training helped them. Specifically, they said that they were better prepared to handle an emergency and were already "warmed up" to fly after the training-device practice. Recommendations related to training included encouraging flight schools to have at least one aircraft configured to present vacuum-system failures in flight, providing students with the opportunity to detect and diagnose this failure in a realistic-onset environment. This was proposed in contrast with the present practice of having the instructor place covers over instruments to be deemed "failed" during practice. In addition, it was the majority opinion that pilots need more practice flying with partial-panel instrumentation.

Please include meaningful technical results achieved during the reporting period.

Make significance clear. Emphasize what was learned, not what was done. This should be a summary of significant results and conclusions.

Impact/Applications: These studies directly addressed the issue, at request of AFS, of whether a back-up attitude indicator could be used, in place of the turn coordinator, to allow the safe continuation of a flight after loss of vacuum-driven instrumentation. They also provided baseline data on whether general aviation pilots can effectively maintain control of the aircraft after the loss of vacuum-driven instrumentation. The results directly impacted an advisory circular and may have impact on Part 23 rules.

Technology Transfer: Results of the studies (simulators and aircraft) were used in the preparation of an advisory circular by Flight Standards and were being examined by Aircraft Certification for potential rule changes in Part 23.

Journal Articles: none

Books or Chapters: none

Technical Reports:

Roy, K.M. and Beringer, D.B. (2002). *General aviation pilot performance following unannounced in-flight loss of vacuum system and associated instruments in simulated instrument meteorological conditions.* Technical Report DOT/FAA/AM-02/19. Washington, D.C.: Office of Aviation Medicine

Conference presentations/abstracts:

Beringer, D.B. and Ball, J.D. (2001). When gauges fail and clouds are tall, we miss the horizon most of all: General aviation pilot responses to the loss of attitude information in IMC. In *Proceedings of the 45th annual meeting of the Human Factors and Ergonomics Society*, Santa Monica, CA: Human Factors and Ergonomics Society, 21-25.

Beringer, D.B., Ball, J.D. and Roy, K.M. (2002). Pilot responses to vacuum failure in flight simulators and aircraft, Aerospace Medical Association annual meeting, Montreal, May 6 - 9.

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *Pilot field-of-vision capabilities/limitations*

Primary Investigator: Dr. Dennis Beringer, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: dennis.beringer@faa.gov)

FAA Sponsor Organization: ACE (POC: Frank Bick)
Sponsor's Requirement Statement: to develop human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non-standard installations of avionics devices and other cockpit equipment in general aviation aircraft. The research will provide pilot field-of-vision limitations for design considerations. **Please refer to page 118 for a more detailed description.**

Research Project's Goal: The results of these efforts have provided data concerning the use of HITS displays that need to be extended to other display platforms (head-mounted or head-referenced displays). Thus, these results are being used to guide further research and provide comparative data as well as an index of baseline certification criteria.

Best Accomplishment: Pilot performance data (navigation error, eye movement, airborne target detection) were obtained for baseline (conventional) instrumentation, HDD and HUD HITS presentations and provided to Aircraft Certification for use in pending display-system certification efforts. Results were reported in the open literature and at professional conferences.

Project Summary: A study was conducted to compare pilot eye movements and flight performance attainable using highway-in-the-sky (HITS) format displays in both head-up display (HUD) and head-down display (HDD) configurations and conformal (with outside world) and compressed forms within the HUD, with a baseline conventional-instruments condition. Results were mixed, and the HUD was not clearly superior to the equivalent HDD when comparing flight technical error. Workload appeared to be comparable for the HITS formats but slightly elevated for specific tasks in a baseline condition using conventional instrumentation. The need for a conformal HUD for general aviation operations was not supported for most flight operations, and pilots preferred the HUD over the HDD and the compressed HITS format over the conformal HITS or conventional instruments. Results were reported in the open literature and to Aircraft Certification. Additional preparations were made for investigating the minimum criteria required for head-mounted display (HMD) presentations of these data.

Scientific and Technical Objectives: This requirement is in response to several lines of inquiry, all relating to pilot visual performance. Of primary interest, is the development of certification criteria for highway-in-the-sky (HITS) and other emerging display technologies. Three concerns are present for these displays. First, there is interest in the effective field of view within the GA cockpit and where it is allowable to place head-down displays. The functional field of view literature needs updating to produce usable limits (for certification) for the placement of both primary flight displays (PFDs) and multi-function displays (MFDs). Second, many emerging displays are thought to be quite compelling, and there is concern that pilots may spend too much time fixated upon this particular PFD to the exclusion of other instrumentation and out-the-window scanning. Third, head-up displays have been suggested as a means of reducing the proportion of time that the pilot spends head-down, but, again, preliminary data indicate that despite the physical positioning, scanning is greatly reduced with cognitive fixations on the HUD. This “cognitive capture” has been demonstrated to negatively affect processing of features (other aircraft, etc.) in the real world. In addition to the HUD, devices are now becoming available that allow unrestricted access to overlaid synthetic imagery throughout the pilot's visual field. In fact, the NRC of Canada has already flight-tested one such device intended for civilian use, and another device is being offered by one U.S. avionics manufacturer as an add-on option. These head-mounted see-through display systems (HMDs) will additionally present their own unique problems in terms of contrast, hysteresis (display lag), and cognitive and perceptual capture. Research associated with this task was intended to examine the human factors associated with these displays and devices; address certification questions about the compellingness of HITS displays, critically examine the claims being made for HUDs, compare pilot performance with HITS displays on both HUDs and HDDs (head-down displays) with that observed using conventional instrumentation, and extend the evaluations to head-mounted displays. The object of the task is to provide data to Aircraft Certification for the certification of these display systems and for possible inclusion in Advisory Circulars. Additionally, data provided to Flight Standards should be useful in determining what, if any, training should be required for the use of such systems

Technical Approach:

Experimental Design and Participants

Twenty-six GA pilots, all having more than 100 hours total flight time, participated in the study, with the conditions administered such that both within-subject and between-group analyses could be conducted. Three counter-balanced orders of the three display conditions (head-down compressed, head-up compressed, and head-up conformal) were presented. As a result of each display format appearing first in one of the orders, a between-groups examination could be performed on the first flights only, free of any intra-serial transfer effects. Thirteen pilots, who were still available at the time of the baseline-data request (some had moved out of state), were recalled six months after the initial sessions to fly the conventional instrumentation scenario.

Equipment / Displays

Data were collected using the Advanced General Aviation Research Simulator (AGARS), configured to represent a Piper Malibu, at the Civil Aerospace Medical Institute. Highway-in-the-sky primary flight displays (PFDs) were presented as monochrome (green) so that the head-down presentation would match that of the

HUD. A Kaiser Optics LCD-projection HUD was used for the head-up presentations, while the head-down display was shown on a CRT, emulating a LCD approximately 11 inches across. The conformal version of the HUD showed approximately 22 degrees of the synthetic HITS presentation, while the compressed version squeezed about 40 degrees of the presentation into the same physical display width. The HITS used trough-type (rain gutter) symbology and a velocity-vector symbol to indicate flight-path trend. An Elmar head-mounted infrared eye-tracking device was used to monitor right-eye movements and fixations.

Procedure / Tasks
The session began with a short warm-up flight using conventional instruments. This was followed by a briefing concerning the HITS display and replay of a stored flight, allowing the participant to view HITS displays in operation. The pilot was further briefed concerning the locale for the flight (Albuquerque, NM) and the presence of significant terrain. This was followed by calibration of the eye tracker. Three 20-minute flight profiles followed, using each of the HITS formats once, with a short break between flights 2 and 3. The baseline procedure used a warm-up session with the conventional instrumentation and then one 20-minute flight.

Each HITS flight included a take-off and interception of the pathway, climb to cruise, enroute level flight, descent/approach, and landing, with four major heading changes required during the flight. The direction of required turns changed with each subsequent flight, although the distances flown were the same. Seven airborne targets were presented and pilots were instructed to report any traffic detected. Pilots were also required to perform a probe-reaction-time task. Data collected during the flight included digital flight technical error, eye-gaze point, and cockpit video/audio. A questionnaire was administered during the post-flight debriefing to determine pilots' responses to the HITS display. The baseline flight was similar in many respects but involved a vector to intercept a specified VOR radial inbound (similar to HITS downwind leg), followed by a procedure turn and approach using the ILS.

<u>Results</u>: Flight-performance variables. Examination of course-tracking errors by flights and display configurations indicated that mean errors were very similar in most cases, with the exception of mean horizontal root-mean-square error (RMSE), which was consistently greater for the conformal format. This reflected greater tracking error in the turns due to the loss of view of the path at some point in the turn and cutting inside turns to keep the path in view. This is consistent with the findings of Reising and Snow (2000), who found greater course, altitude, and airspeed errors during curved segments than on straight segments. Error was greatest when the conformal HUD was flown first or last, the former likely due to novelty, the latter most likely a result of having flown two compressed formats first. Comparison of data from the first flight only using a between-groups ANOVA indicated that both horizontal and vertical RMSE differences were significant ($p=.05$). In both cases, the error values for the two

compressed formats were indistinguishable, but both were significantly smaller than for the conformal format.

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Inasmuch as baseline flights used a different basis for guiding the flight path (altimeter, VOR needle; horizontal error measure and guidance indications were angular), displacement errors along the entire route were not considered comparable enough for direct comparison. Blunder errors (overshooting an intercept) were, however, observed to be more frequent using conventional instrumentation, even when intercept headings were given for joining the VOR courseline.

Target Detection Performance

Target 1, the C-130, was detected by nearly every pilot and at better than 4 miles distance, and was thus used as a check that participants were performing the search task. The remaining targets, all small GA aircraft, were used for the statistical analyses. Hit rate and detection distance data were collapsed across the 3 flights for the HDD and HUD conditions and repeated-measures ANOVAs indicated a significant effect of display for both variables (hit rate: $F(2,50)=7.25$, $p<.005$; detection distance, $F(2,50)=6.498$, $p<.005$). Hit rates for the 2 HUD conditions did not differ significantly, but both were reliably different from the head-down condition in post-hoc tests. Similarly, the trend was in the same direction for detection distance, although only the difference between the head-down and the head-up compressed displays attained significance. It is worth noting that targets were frequently not detected in the HUD condition until they actually entered the HUD visual space.
Comparisons with the baseline rates/distances were conducted using data for only the 13 returning participants. Although the trend was similar for detection distance, the difference did not attain significance ($p<0.1$), largely due to variability of scores in the smaller sample. Hit rate differences were significant, however, and the hit rate for the baseline condition was significantly lower ($p<.05$) than for the compressed HUD but not different from the head-down HITS.

Williams (2000) found an overall hit rate for airborne targets using a head-down HITS display format of 0.54, which is not inconsistent with the HDD findings here. However, the findings are at variance with Fadden and Wickens (1997), in that they found a consistently larger advantage for the HUD format; their targets, however, were all the same and the HUD image was not presented on an actual HUD device.

Eye-Tracking Results

Only those subjects who flew the baseline condition are included in the mean percent dwell time calculations. A within-subjects ANOVA for the four defined areas of interest revealed significant main effects of display condition for the percentage of dwell time on primary flight instruments ($F(3,36) = 21.581$, $p<.001$), looking out the window ($F(3,36) = 19.894$, $p<.001$), and time spent looking at other instrumentation and radios ($F(3,36) = 5.646$, $p =.003$). The percentage of dwell time spent looking at other areas was not statistically significant. Pair-wise comparisons revealed significant differences between the HUD conditions (conformal and compressed) and the HDD conditions (HDD and conventional instrumentation). Pilots spent significantly more time on the primary flight instrumentation and significantly less time looking out the windows or at other instrumentation while using either HUD format. There were no significant differences between the HUD conformal and compressed conditions for any of the dependent measures related to visual scanning. Also, there were no significant differences between the HDD condition and the conventional instrumentation for any of the areas of interest. Comparison of the HITS conditions for the full sample showed the same effects.

Probe Reaction Time Results

Probe reaction time (PRT) was assessed at 7 points along the course, both in turns and during the straight course segments. The pilot was to cancel a steady red LED mounted just beneath the glareshield by pressing a lighted key on a yoke-mounted keypad. The pilot was then required to fixate briefly on a flashing LED, in the same location, until that LED was extinguished so that centering of the eye tracker could be assessed. The PRT data contained a number of outliers (RTs greater than 10 seconds), concentrated in the first flights and the conformal HUD condition. These were removed to reduce the skewness, and all subsequent condition means fell between 1.5 and 2.5 seconds. Comparison of conditions indicated no significant differences between display conditions for either analysis with or without the outliers. The only tangible difference was the frequency of extreme scores in the first flight.

Rating Results

HUD versus HDD. Some participants with more time in complex aircraft preferred the HDD location, indicating that it was less disruptive to their scans. Lower-time pilots, however, expressed a preference for the HUD, indicating that they believed it allowed for better surveillance of the surrounding airspace. Overall, the preference was: HUD(17), HDD(5), No preference (1), no data (3). Data for the baseline indicated that most rated the HITS display as being easier to fly than conventional instrumentation (mean of 3.14 versus 2.21 on a scale of 1=difficult to 7=easy, $p=.0574$). However, 4 individuals, all over 30 years of age (34, 47, 50, 52), rated conventional instruments as easier to fly; of those decidedly favoring the HITS, 80% were under 30. Quantitatively, age was negatively correlated with higher ratings for the HITS (-.617) and total instrument hours was also negatively correlated (-.48).

Conformal versus compressed. Overall, the compressed was preferred over the conformal. When examined more closely, the majority of this effect is due to a strong preference for the compressed format during turns. Although the conformal was rated as more acceptable for straight-and-level flight than for turns, it was still rated slightly lower than was the compressed

Impact/Applications: There have been a number of questions raised during certification efforts concerning where primary and secondary instrumentation need to be located and how various terms ("normal field of view", "primary field of view", "secondary field of view") should be defined. The data being generated from these tasks help to define, using pilot visual behavior, where different types of displays may be located without compromising pilot performance (and thus safety), and thus reduce the number of "arbitrary" field-of-view definitions. A specific question had been posed concerning highway-in-the-sky displays and their "compellingness," and the eye-movement data directly addressed this question. These data as a whole can be used to support directly the certified placement of displays in the cockpit and certification efforts involving highway-in-the-sky guidance formats.

Technology Transfer: Data were developed with the Small Airplane Directorate (ACE-111) to further the definitions of primary, secondary, and normal field of view. Data were provided to ACE to specifically address the question of "compellingness" of highway-in-the-sky display formats for ongoing certification efforts. Additional data will be provided in the immediate future for a PFD certification checklist being developed at the Small Airplane Directorate

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *GA Training*

Primary Investigator: Dr. Kevin Williams, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: kevin.williams@faa.gov)

FAA Sponsor Organization: AFS-840 (POC: Tom Glista)
Sponsor's Requirement Statement: to identify potential near-term training improvements that could immediately have a positive effect on the reduction of general aviation accidents. In addition, this research should address training implications of future GA systems such as SATS. **Please refer to page 106 for a more detailed description.**

Research Project's Goal: Research is required to study the training and certification requirements that these new systems will impose on the GA pilot. Such research, to be performed in response to the request of a sponsor from the Flight Standards Service organization (AFS), will allow the development of minimum training standards for these systems and will provide useful information for officials involved in certifying these systems. This research should also support the development of user-interface guidelines for these new systems that will hopefully allow developers to avoid the problems encountered with the introduction of GPS systems.

Best Accomplishment: One research report was generated as a result of this year's efforts. This report summarizes the research at Embry-Riddle Aeronautical University and The University of Ohio outlined below. In addition, a second report is in development that summarizes an experiment conducted at FAA CAMI.

Project Summary: The integration of advanced navigation displays with on-board flight planning displays has enormous potential to increase the safety and efficiency of flight operations within the NAS, especially general aviation operations. While there is potential for these displays to enhance safety by increasing situation awareness, there is also the possibility that a new level of complexity will be introduced in the cockpit that will have a negative impact on safety. Lessons learned from the introduction of GPS systems to the GA cockpit suggests that there are possible trade-offs between the increased navigational capability provided by new technology and the increased complexity that must be handled by the pilot/user of the system. In addition, the lack of a standard user-interface and other interface design shortcomings for GPS units has caused problems for pilots operating those units. With the advent of MFD's much, if not all, of the functionality of the GPS systems will be migrated to these new displays.

Scientific and Technical Objectives: Multifunctional displays (MFD's) will, in the near future, begin to replace current navigational display systems commonly in use in today's GA cockpit. While there is promise that these displays will increase safety by increasing situation awareness, there is also the possibility that a new level of complexity will be introduced in the cockpit that will have a negative impact on safety. Lessons learned from the introduction of GPS systems to the GA cockpit suggest that there are possible trade-offs between the increased navigational capability provided by new technology and the increased complexity that must be handled by the pilot/user of the system. In addition, a lack of a standard user-interface and other interface design shortcomings for GPS units has caused problems for pilots operating those units. With the advent of MFD's much, if not all, of the functionality of the GPS systems will be migrated to these new displays. Research is required to study the training requirements that these new systems will impose on the GA pilot. Such research will allow the development of minimum training standards for these systems. This research will also enable the beginning of a user-interface standardization process for these new systems that will allow system developers to avoid the problems encountered with the introduction of GPS systems.

Technical Approach: .Apparatus

The SmartDeck portion of this experiment was conducted in the Small Aircraft Transportation System (SATS) Lab. The SmartDeck HITS display system simulator was installed in a renovated ATC 810 cockpit shell located in Hangar 2 at the OSU airport. Two display screens were put on the top of the control box that had the pilot's yoke, throttle quadrant, and other simulated controls. To control the airplane, the subjects used a control yoke which was on the left side of the control box, the throttle which was in the middle of the control box and the rudder pedals which were located on the floor of the cockpit shell. There was also an out-the-window screen simulation projected onto the wall in front of the cockpit shell. (need a picture) Other controls could be ignored (flaps, landing gear, etc.).

The SmartDeck HITS display system

The computer program for the new SmartDeck "Highway-in-the-Sky" (HITS) display system was designed by Goodrich. This display system is composed of two heads-down display screens which provide all the information necessary to maintain flight control, navigate, control aircraft configuration, and monitor systems health. The Primary Flight Display (PFD) is on the left (Figure 4), immediately in front of the pilot. The HITS format appears on the PFD. It shows a forward view of the world relative to the aircraft position, as well as aircraft configuration information and basic instrument information. The purpose of the PFD display is to provide the critical information necessary for flying and controlling the aircraft. As such, this display can never be re-configured to portray anything but the PFD information. The PFD Page as displayed on this screen is a display only and has no pilot interaction capability.

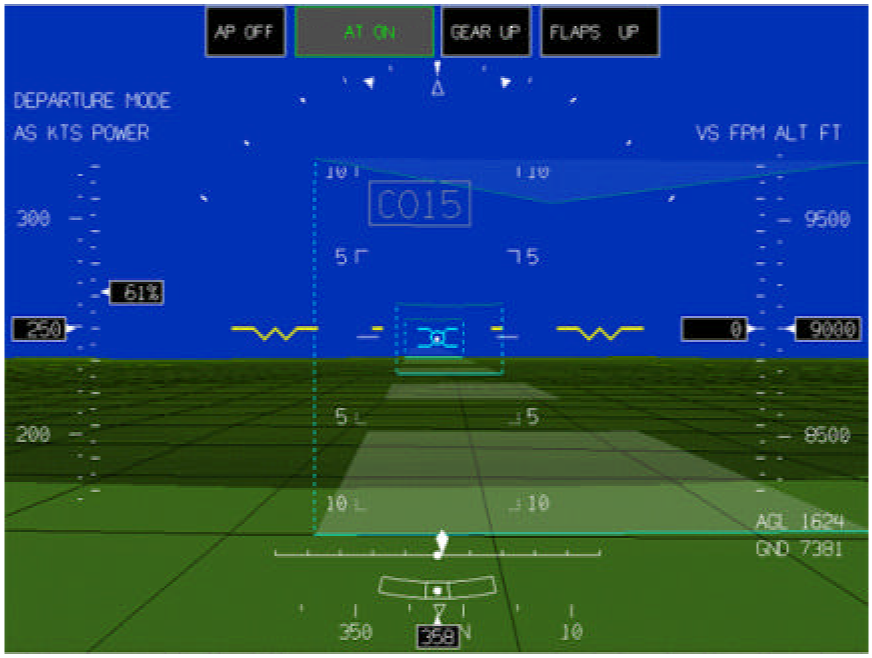


Figure 4: Format of PFD

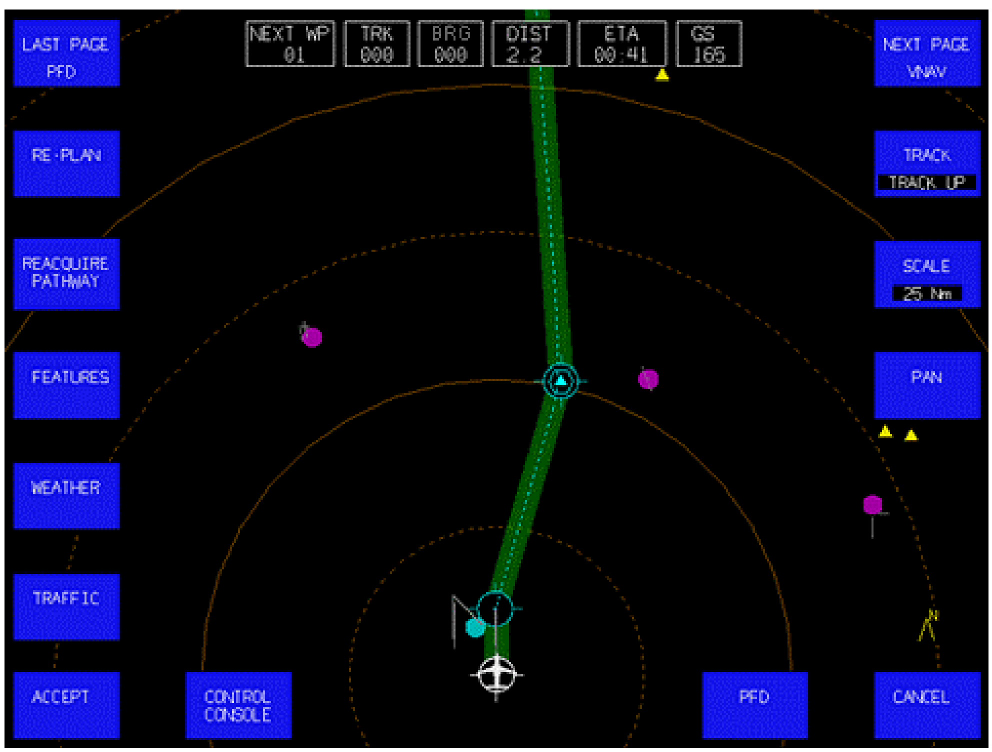


Figure 5: MFD

The second display screen—Multi-Function Display (MFD) (Figure 5) is to the right of the PFD and may be toggled between several interactive pages which provide detailed information related to navigation, systems status monitoring, and various checklists. The information displayed may be highly customized to suit pilot preference, flight mode, and specific situational needs. The MFD screen provides the primary pilot interface to the SmartDeck system using a touch sensitive panel over the display. This screen includes five top-level display pages and a series of submenus. The top-level pages are: a Horizontal Navigation page (HNAV), a vertical navigation page (VNAV), a systems page for three aircraft subsystems (engine, fuel, and electrical), a checklist page, and a redundant PFD Page. The default page at startup is the HNAV page. The other four pages are accessed in round robin fashion using the rectangular blue touch screen buttons. The MFD is also used to display ATC messages and system warning messages. These are delivered both as audible messages and as text in message windows on the MFD.

The HNAV Page provides a bird's-eye view of the flight path over the ground. Looking at this page is like looking at the airplane and its flight path superimposed on a map. The planned route of flight and the airplane's position in relation to this route are shown. As the pilot flies on the pathway using the PFD, s/he will see his or her airplane move forward along the planned route on the HNAV display.

The VNAV Page (Figure 7) shows a profile view of the flight and lets the pilot see his or her airplane's altitude in relation to terrain elevation and planned flight path. As the pilot flies on the pathway using the PFD, he or she will see his or her airplane climb, level off at specific altitudes, and descend on this page.

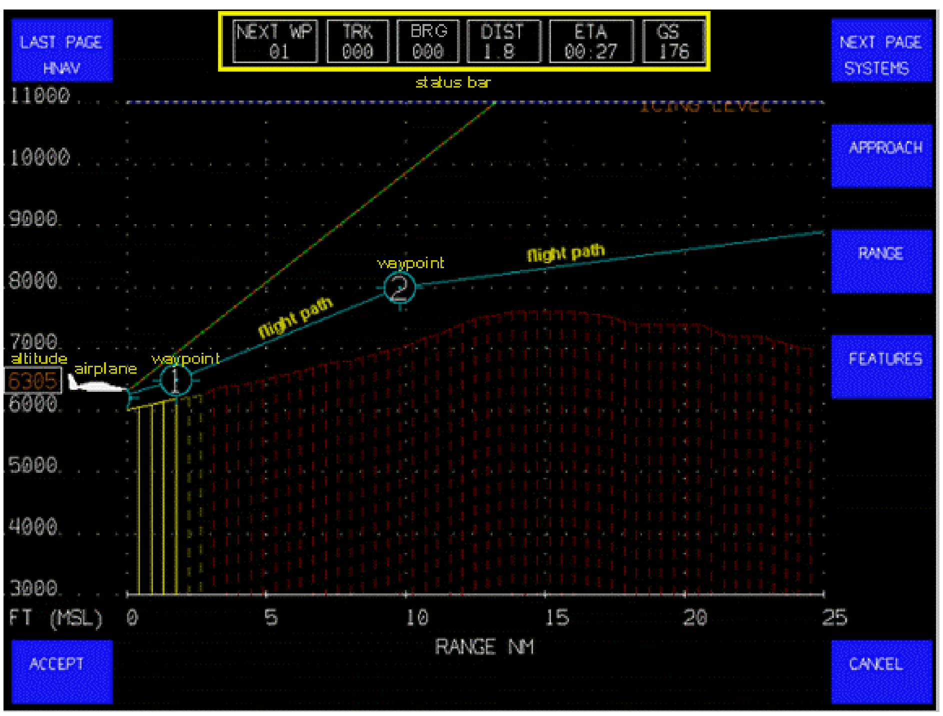


Figure 7: VNAV

When the pilot gets close to the destination, he or she needs to set up an approach for landing at the airport. The pilot can select a runway by starting from the VNAV page. First, the pilot will select a runway on the Approach menu and choose Accept (Figure 8).

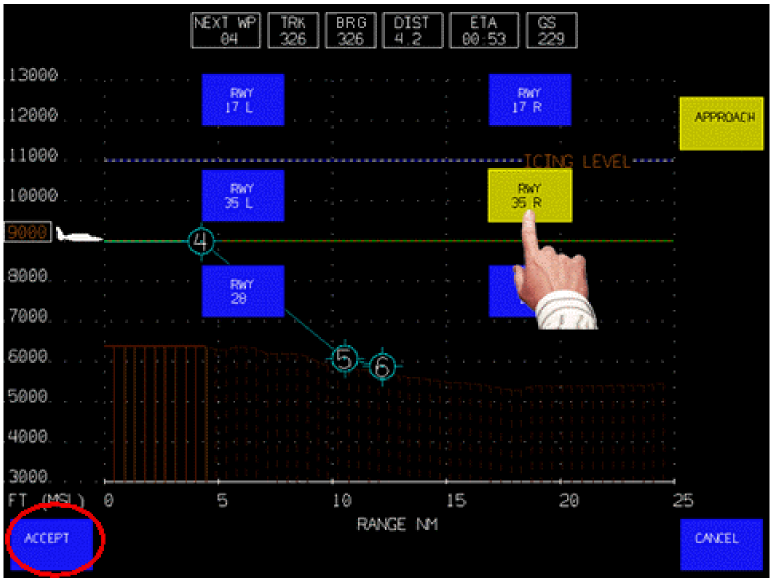


Figure 8: Select an approach

Next, the pilot must return to the HNAV Page and select the PFD menu.

When the pilot chooses Approach Mode, the appearance of the flight course will change to show an approach path designated by a dashed line to the selected runway. The final approach portion of the path is shown by an elongated arrow head shaded on one side (Figure 9). A Maltese cross is shown at the final approach fix (FAF). This is the position at which the pilot should begin the final descent for landing. When the pilot reaches the final approach fix, the trial ended at this point.

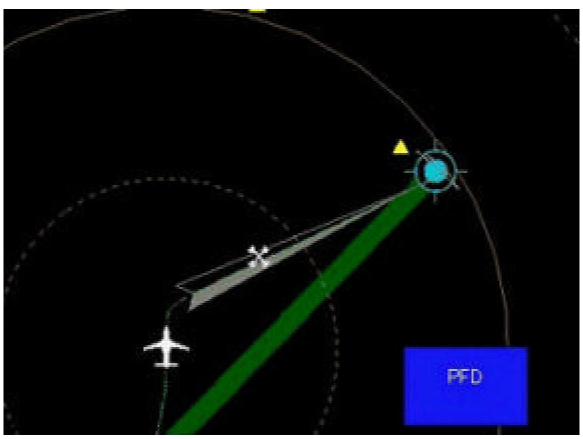


Figure 9: Approach Mode

The pathway on the PFD changes from blue to green to designate the approach course as Figure 10. By steering down the pathway, just as what the pilot needs to do during cruise flight, he or she will be able to fly a precise approach to the touchdown zone of the runway.

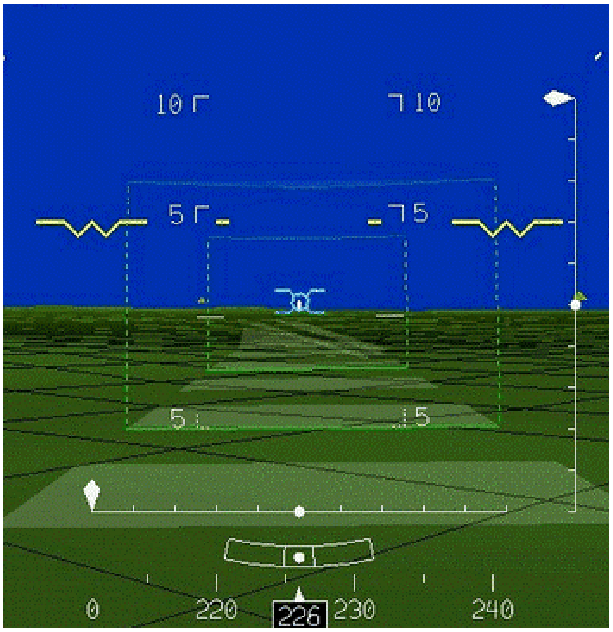


Figure 10: Changed pathway

The Systems Page gives pilots information on the status of equipment in the airplane.

The Systems Page lets the pilot access information about the status of the airplane's engine, fuel system, and electrical system. For example, this page shows a variety of gauges which can help the pilot determine if the engine is working properly as Figure 11. This page was not used in this study.

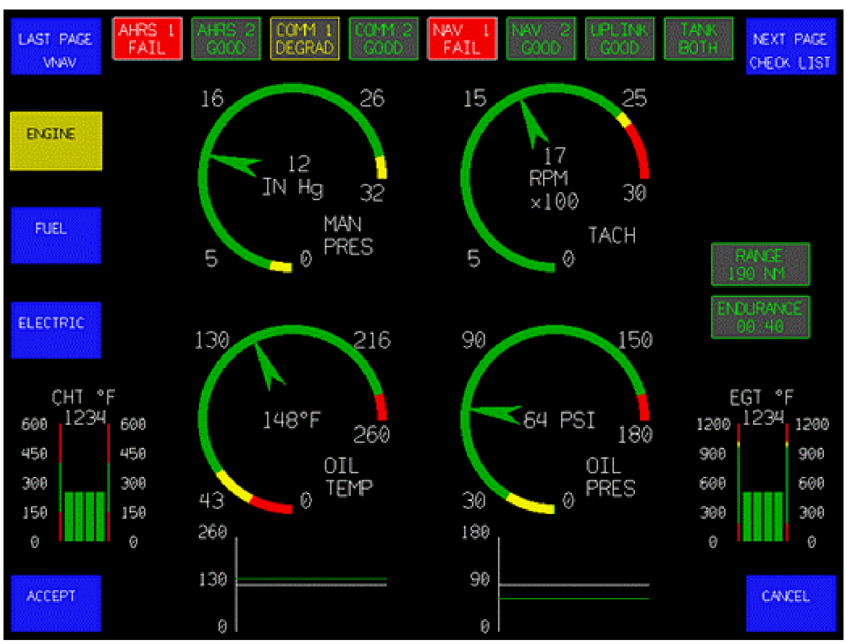


Figure 11: System Page

The Checklist Page (not shown) gives the pilot access to a variety of checklists to follow for performing specific airplane procedures. The pilot can choose checklists for the preflight and routine procedures to be performed during flight, as well as landing, post-fight, and emergency operations. It was not necessary to use this page during the present study

The PFD Page lets the pilot view the Primary Flight Display on this screen. Its purpose is to serve as a backup in case the PFD monitor fails during a flight. Then the MFD can be used instead to display the PFD information. That was not necessary here.

Bendix / King 89B GPS unit in the AST Hawk Flight Training Device (FTD)

The Bendix / King 89B GPS unit in the AST Hawk (FTD) was located in Simulator Lab in Hangar 5, the Flight Education Division at the OSU Airport. The Bendix/King KLN 89B GPS provides user-friendly operation and a graphics display which will help the pilot navigate more easily and more accurately (Figure 12). It has trip planning features, can do air data calculations, and includes other useful features. In addition, the KLN 89B is FAA certified for En route, Terminal, and Non-precision Approach Instrument Flight Rule (IFR) operations.

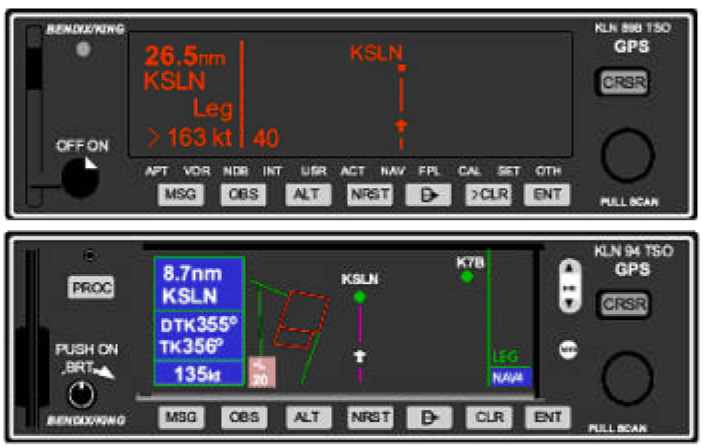


Figure 12: KLN 89B

Experimental Procedures

The experiment was conducted using the AST Hawk FTD and SATS Lab simulator. Participants received training on the use and functionality of the displays and were given one or more practice flights to ensure their familiarity with the displays and both MFD and GPS option selections relevant to this study.

For the experimental task, participants were to plan, enter (using the MFD and/or Bendix/King 89B), and execute an instrument approach to a prescribed airport. During the flight, participants were given tasks that required them to interact with the MFD to gather information about weather, terrain, and traffic in the area. Shortly before beginning the initial approach, participants received a weather message requiring that they use a different runway from the one planned. This required pilots to change the flight plan so that the new approach could be executed. Participants then flew to the new FAF, at which time the scenario was halted and post-run SA surveys conducted.

Scenario

The flight originated over the Aurora airport, designated by the code (01V). The destination airport was Centennial, designated by the code (APA). The filed flight plan departed from Aurora Airpark (O1V), flew direct to Falcon VOR (FQF)—waypoint1, then along a Victor Airway (V95) to the HOHUM intersection. On the way to HOHUM, the pilot would turn to the initial approach fix (IAP) NERXY at the waypoint—TURN1—waypoint2. During the leg from FOF to TURN1, the subject was asked to do two tasks in order to prevent them from being bored. The GPS approach for runway 35 was programmed in. After NERXY—waypoint3, the fourth waypoint is HOHUM, and then the fifth waypoint CASSE, the final approach fix of GPS runway 35. Finally, the pilot will land on runway 35 at APA if they follow the flight plan.

There was also a suggested altitude profile for this scenario which was provided to subjects, depicted on the VNAV page

Depart Aurora Airpark at 11,000ft

Maintain 11,000ft Direct to Falcon VOR (FQF)

At FALCON descend to 10,000ft while on V95 to HOHUM

When turning South off V95 to NERXY descend to 9,000ft

After the clearance to runway28 is issued descend to 8,000ft to NIDLY

Before subjects start to fly, they will be given the weather briefings, which were:
At Aurora (01V): 33010KT 007 BKN 010 OVC 15/14 A2995 (Translated, this meant that at 01V- the wind was coming from 330 degrees at 10 knots. The ceiling was 700 feet and broken, with an overcast at 1000 feet. The temperature was 15 Celcius with a dewpoint of 14 Celcius. The altimeter setting was 29.95 inches of mercury)

At Centennial (APA): 34012KT 006 SCT 008 BKN 010 OVC 15/14 A2994 (Translated, this meant that at APA—the wind was coming from 340 degrees at 12 knots. The scattered clouds were at 600 feet, and the ceiling was 800 feet broken, with an overcast at 1000 feet. The temperature was 15 Celcius with a dewpoint of 14 Celcius. The altimeter setting was 29.94 inches of mercury)

A current Notice to Airmen (NOTAM) was provided, indicating that:
APA ILS35R OTS (Translated, this meant that the Instrument Landing System for runway 35R was out-of-service)

With this scenario, about 4 nm from the second waypoint—TURN1, an ATC message about weather was issued:

"Convective Sigmet 4 Central is valid for 150 nautical miles of Colorado Springs, Severe thunderstorms moving from 270 degrees at 25 knots. Tops to 6 5 0. Hail."

Before arriving at the NERXY intersection, the ceiling was lowered to 600 feet. At 9 miles from NERXY, a canned ATC weather message was issued indicating:

"Ceiling at Centennial has now dropped to 650 feet. Say intentions."

Since now the ceiling is lower than the approach minimum of runway 35R, the pilot needs to change the approach runway to Runway 28 whose approach minimum is 600 feet, which is lower than the approach minimum of runway 28—6660 ft.

The first scenario (factor a_1), indicated in the table 2, is that ATC does not indicate which approach the pilot is to use because they are legally not allowed to do so. The change of approaches must be initiated by the pilot. The subject is expected to say something like:

"Denver Approach, Jet 123, requests GPS 28" to which the ATC specialist would answer:

"Jet 123, proceed direct, Runway 28 GPS Final Approach Fix, NIDLY."

"Jet 1 2 3, Cleared to land, GPS Runway 28."

Table 2: Tasks list for scenario 1

Trigger Location	Event	Trigger	Criteria
10 NM from Second Waypoint	Ask participants for elevation of KAFF	Experimenter, Manual	If they give the correct elevation prior to the next event
6 NM from Second Waypoint	Ask participants to change the range on VNAV page.	Experimenter, Manual	If they changed the range of VNAV page prior to the next event.
4 NM from Second Waypoint	ATC Messages	Press ATC Button5: “Convective Weather Alert” 3: “Traffic Alert for KAFF” 4: “Traffic alert for C015”	None
9 NM from the Third Waypoint	ATC Messages	Press ATC Button6: “Runway change”	Participant indicates intention to change to runway 28
Participant indicates intention	ATC Message	Press ATC Button1: “Cleared for the approach”	Participant correctly completes selection of new runway

The second scenario (factor b_1), indicated in table 3, is that ATC will tell the subject what to do by issuing the above two messages right after the canned ATC weather message. Therefore, the subject doesn't need to make any decisions after receiving the message of ceiling dropping.

Table 3: Tasks list for scenario 2

Trigger Location	Event	Trigger	Criteria
10 NM from Second Waypoint	Ask participants for elevation of KAFF	Experimenter, Manual	If they give the correct elevation prior to the next event
6 NM from Second Waypoint	Ask participants to change the range on VNAV page.	Experimenter, Manual	If they change the range on VNAV page prior to the next event.
4 NM from Second Waypoint	ATC Messages	Press ATC Button5: "Convective Weather Alert" 3: "Traffic Alert for KAFF" 4: "Traffic alert for C015"	None
9 NM from the Third Waypoint	ATC Messages	Press ATC Button6: "Runway change" Press ATC Button 2: "Select an Approach" Press ATC Button1: "Cleared for the approach"	Participant correctly completes selection of new runway

In both cases, after the subject gets the clearance of the runway 28, it was at this point where the subject should start the procedure of changing runway, and follow the new generated pathway leading toward NIDLY, the FAF for runway28.

Right after the subject finished the procedure of changing the runway, the experiment was frozen for as long as 5 to 6 minutes which allowed the subject access workload and SA information presumably without substantial memory decay. It was necessary to make sure that the subject could not see the information on the screen by turning down all the monitors. After the subject completed the survey of workload and the survey I of SA, the experiment was resumed. When the airplane got to the FAF of runway 28, the experiment was frozen again and a different survey—survey II was completed.

Evaluation aids and flight data record

To assist in evaluating each subject's flight performance and SA, every flight scenario was videotaped.

During the flight, data was collected regarding the ability of the pilot to interact with the MFD. Interaction errors (pushing the wrong button, backtracking through the menu structure, etc.) were recorded. In addition, navigation errors relative to the pathway were recorded to ensure that the pilot was maintaining appropriate control of the aircraft during interaction with the MFD.

The flight data recorded during the flight using SmartDeck included:

Data collection frequency is 2 seconds.

Data Item	Units
NEXT WAYPOINT	Waypoint #
LATITUDE	**Decimal Degrees**
LONGITUDE	Decimal Degrees
ALTITUDE	Feet
AC ROLL	Degrees (cw +)
AC PITCH	Degrees (up +)
AC TRUE HEADING	Degrees
AC THROTTLE	0 to 1 (1 = full)
RATE OF CLIMB	Feet Per Minute
AC AIRSPEED	Knots
HORZ PATH DEVIATION	Feet
VERT PATH DEVIATION	Feet
PILOT ACTION	Button Text

The flight data recorded during the flight using HAWK included:

Data Collection Frequency (1 sec)

TIME	Time from the start of data recording
LATITUDE	Sim latitude
LONGITUDE	Sim longitude
HEADING	Sim heading
AIRSPEED	Sim airspeed
ALTITUDE	Sim altitude
PITCH	Sim pitch
ROLL	Sim roll
YAW	Sim yaw
PITCH_ATT	Pitch attitude
HEADING	Heading (magnetic)
P_TOTAL	Total pressure
HP	Pressure height
KCAS	Corrected airspeed in knots
ROC	Rate of climb

RADALT	Radar altitude

Conduct of the Experiment

The experimenter read the Subject Instructions (Appendix B) to the subject which briefly outlined the experimental requirements. Subjects were then asked to complete a consent form (Appendix C). Following confirmation of a subject's intention to participate, each subject was given their copy of the "consent for participation" form, in conformity with the Ohio State University's policy on social and behavioral research risk protection.

The subjects also were asked to provide their personal flying record (total flying hours, pilot in command hours, and so on). The data may provide some insight into those areas of a pilot's background which correlate with good or bad performance. The data on subjects' flying experience can be found in Appendix D.

Subjects were asked to participate both of two experimental sessions. The order of the two experimental sessions was determined by tossing a coin. If the result of the toss was heads, the first session would be flying the SmartDeck avionics in SATS Lab (b_1). Otherwise, the first trial would be in the Hawk (b_2). The first step was to train the subjects on the procedures to be used in updating the SmartDeck avionics navigation display. After the computer training, the subjects were permitted to practice using those functions and to ask whatever questions they had about the system or its operating procedures. When they felt comfortable flying the simulator, the real experiment scenario was conducted, which required the subject to fly the SmartDeck avionics to accomplish a short flight from Aurora (01V) to Centennial (APA). Then the second session was implemented by asking the subject to fly the same route using the HAWK with Bendix/King 89 GPS simulation. If the subject did not have any former experience with Bendix/King 89 GPS system, there was an extra session for training the subject to get familiar with it before the real experiment was run.

After each of the experimental sessions, the subject was asked to complete the first two parts of the SA survey. After the subject finished the survey for the second session, the third part of the survey one was administered.

Finally, the subjects were thanked for their participation in the study.

Hypothesis

The following hypothesis is based upon the rationale present in the previous section.

It was hypothesized that the pilot will have different flight performance with the SmartDeck—HITS display integrated with the MFD than using the conventional displays and the Bendix / King 89B GPS unit.

The independent variable is the two display formats—SmartDeck and the conventional display and GPS unit. The dependent variable is respectively altitude deviation, heading deviation. The experimental hypothesis is that there will be significant difference between these two conditions.

It was hypothesized that the pilot will spend different amount of time changing the approach runway using SmartDeck with using Bendix / King 89B GPS unit.

The dependent variable is task duration: the time that the subject spent changing the runway. Specifically, for SmartDeck, task duration was calculated from the button—"next page" being pressed to the button or the message of runway clearance being issued to "Accept" on MFD after choosing the "Approach Mode" being pressed. For the Bendix/King GPS, task duration was calculated from the subject going to the page "Flight Plan" or the message of runway clearance being issued to the subject coming back to the "NAV" page. The experimental hypothesis is that there will be a statistically significant difference between these two conditions.

It was also hypothesized that the pilot will have different workload by using the display of HITS integrated with MFD with using the conventional displays and the Bendix / King 89B GPS unit.

The independent variable is again display formats—SmartDeck and the conventional displays. One dependent variable is the subjects' workload score.

Results: .The inclusion of new global positioning systems (GPS) in general aviation aircraft has been of concern to the aviation community due to the potential for this new technology to increase workload in general aviation aircraft. A study was conducted jointly by Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida and the Ohio State University (OSU) in Columbus, Ohio, to investigate this issue. Pilots were evaluated on the ability to interact with two display interfaces under high workload conditions. The first interface was an advanced digital avionics system equipped with a GPS-like component in the multi-function display (MFD). The second interface was a traditional general aviation console with an onboard GPS system. Participants were also to interact with these systems with two forms of device inputs: voice and touch screen style input. These systems were expected to show differences in workload on the basis of the type of interface the pilot was confronted with and the method by which they entered data into the system.

Workload was measured through an analysis of participant performance during flight to an approach that required a change due to weather. Flight tracking performance, time to change the flight plan to the new runway, and subjective workload reports provided information about the effects of these different platforms and interfaces on pilots' workload.

Results indicated that the advanced digital avionics system did produce better flight path tracking, faster times to change runways, and a lower subjective workload compared to the more traditional general aviation console.

Impact/Applications: .The information collected in these reports will assist the sponsor in current and future certification and standardization decisions regarding multi-function and perspective flight displays

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports:

Williams, K.W., Ball, J. & Harris, H. (in draft) *Training Requirements for Aircraft GPS Displays: A Comparison of Two Methods*. Federal Aviation Administration, Office of Aerospace Medicine Technical Report.

Doherty, S.M., Atchley-Greene, F., Chang, L. & Chubb, G.P. (2002). *General aviation training: Integration of advanced cockpit displays.* Technical Report Prepared for FAA Civil Aerospace Medical Institute, Oklahoma City, OK, FAA Contract DTFA 02-01-C-09254

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *CFIT/Terrain Displays*

Primary Investigator: Dr. Kevin Williams, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: kevin.williams@faa.gov)

FAA Sponsor Organization: ACE (POC: Jeff Holland)
Sponsor's Requirement Statement: The purpose of this research is to address CIT issues which were identified by the JSIT team. Research will focus on various countermeasures to include training, technology, and science-based regulations to significant reduce the occurrence of general aviation CFIT accidents. **Please refer to page 94 for a more detailed description.**

Research Project's Goal: Results from this research can be used to support other research on cockpit navigation displays. New displays that are beginning to transition to the general aviation cockpit include moving-map/multi-function displays and perspective flight displays that include highway-in-the-sky symbology and synthetic terrain

Best Accomplishment: Three research reports were generated as a result of this year's efforts. The first report briefly summarizes the graphical terrain display design literature. Display concepts and criteria are discussed in reference to their application to navigational tasks and human perception and performance. Supporting bibliographic material is provided for a more in-depth investigation by FAA CAMI researchers. The second report documents the current state of perspective flight guidance displays and identifies potential issues or guidelines associated with them. It includes an annotated bibliography documenting the history, current state, issues, and guidance on highway-in-the-sky flight perspective displays. The third report summarizes the use by pilots of a relative terrain display in real-world flight operations in the region around Bethel, Alaska.

Project Summary: CFIT accidents have been cited as one of the leading causes of fatalities in aviation, in particular general aviation. Unfortunately, little is known about the specific human causal factors associated with these accidents. What is needed is a better understanding of the types of human causal factors associated with CFIT accidents along with any trend information so that the impact of selected interventions can be tracked. This need has been partially addressed by the CFIT Joint Safety Analysis Team (JSAT) which identified several human casual factors associated with CFIT accidents and developed 55 intervention strategies to mitigate the causes. One of the most effective strategies identified by the team was the installation and use of horizontal and vertical situation awareness displays. However, the quality of these displays and their effectiveness in the general aviation sector remains to be determined. Research in this area will be aimed at validating the findings of the CFIT JSAT and assessing the intervention and mitigation strategies the committee identified

Scientific and Technical Objectives: The objectives of this research are to satisfy the requirements of regulation and certification (AVR). A primary objective is to develop and test interventions that will mitigate or eliminate causes of general aviation pilot "errors" and thereby achieve a reduction in aviation accidents and incidents. Human factors information and data gained via that objective will provide a sound scientific basis for the FAA to develop and implement certification and rule making initiatives that will result in gains in aviation safety. Manufacturers have been developing and marketing horizontal and vertical situation awareness displays for some time. The quality of the displays varies significantly. However, with the recent development of less expensive and higher quality color displays, there has been a significant increase in the quantity and sophistication of these systems. Unfortunately, the designs seem to be driven more by intuition, supposition, and marketability than by data. The effectiveness of some of these systems to prevent CFIT accidents is questionable. Consequently, research was needed to determine the minimal amount and type of information that should be presented to develop adequate situation awareness to avert CFIT-related accidents. Some key issues addressed included:

- Horizontal Situation Displays vs. Vertical Situation Displays vs. Both
- Benefits/Detriments for 2-D & 3-D Displays
- Minimum Display Size
- Minimum Level of Detail and Quality of Terrain Depiction
- Type and Form of Displayed Position-Terrain Information
- Color Application Philosophy (e.g., darker colors for lower elevations)
- Desired Visual/Audio Alerts
- Most Appropriate and Effective Cues to Alerting Pilot of an Impending Situation
- Methods of Operation

Appropriate Use of Such Systems

Technical Approach: The Human Systems Information Analysis Center (HSIAC) was asked to generate a Review and Analysis (R&A) of current cockpit terrain display systems research literature and perspective flight display research literature for the Human Resources Research Division of the Federal Aviation Administration (FAA) Civil Aerospace Medical Institute (CAMI). To generate these reviews, a keyword list and search strategy was developed and a search of both government and commercial literature databases was conducted to identify relevant information. The search strategy was employed by professional database researchers using the following in-house, government and commercial databases:

- Abstracts in New Technologies and Engineering (ANTE)
- Aerospace Database
- Applied Social Sciences Index and Abstracts
- Defense Technical Information Center (DTIC)
- Dissertation Abstracts
- EiCompendex
- Federal Research in Progress (FEDRIP)

- IHS International Standards and Specifications
- INSPEC
- National Technical Information Service (NTIS)
- PsycINFO
- SciSearch
- Science Citations
- Transportation Research Information Service (TRIS)

Search results produced over 500 citations and abstracts, some of which were unrelated to the specific objectives of this effort. The abstracts were reviewed by HSIAC analysts to identify the most pertinent literature. Selected documents were obtained to use as source material in the preparation of the reports.

In addition to the generation of these reports, a data collection effort was conducted in the Bethel, Alaska area of pilots using a moving-map display that includes relative terrain information. Use of the relative terrain information was documented and summarized in a report on this data collection effort.

Results: CFIT Display Research Summary:

Two-dimensional displays (i.e., plan- or profile-view) are typically very effective for displaying information along two dimensions, but must rely on some abstract coding or alphanumeric labeling method for representing information in the third dimension. Carefully chosen coding techniques can help improve the intuitiveness of 2D displays. In addition, presenting a display array consisting of both plan- and profile-view images appears to assist in maintaining terrain situational awareness. Still, cognitive processing requirements may be greater when performing tasks that require integrating information across the three dimensions. Three-dimensional perspective displays, on the other hand, appear to be subjectively preferred by many pilots because of their ability to show a highly accurate representation of the out-the-windscreen view. These displays, however, can suffer from visual clutter, and may de-emphasize depth or vertical terrain features when a large field of view image of a three-dimensional environment scene is scaled to fit on a 2D cockpit display.

The paramount issue confronted by designers is how to configure terrain displays with features that best serve the navigational needs of the pilot(s). Developers may be tempted to integrate every available feature so that the forward field of view and the electronic display are close to the same. For shared displays, in which terrain is one of several types of information that can be depicted, information prioritization, discrimination of terrain information, and potential visual clutter are just some of the issues that need to be addressed. The potentially degrading effect of high complexity or "information overload" suggests the need for image simplification without sacrificing navigation performance. These, and many other perception and performance issues, raise several human factors questions of importance to FAA CAMI researchers.

<u>Perspective Flight Display Summary:</u>

Pilots can and do adapt to the display available. The way they perform tasks may differ as a function of the display used. As a result, the use of perspective displays has a distinct impact on pilot performance. For instance, Morello, Knox, and Steinmetz (1977), Adams (1982b), and Hennessy (1995) found that use of a pictorial perspective display resulted in superior accuracy and reduced workload when compared to a conventional multiple display system. Similarly, a Reising, et al. (1995) experiment found that pilots performed better with a pathway HUD than with a standard military HUD symbology. On the other hand, Adams (1983) found that the appropriateness of a perspective display may vary between phases of flight and Beringer (2000) states that perspective formats are not always superior to multiple planar formats. Hennessy received negative comments from participants regarding the lack of numerical data when comparing perspective with conventional flight displays (Hennessy, 1995).

Another user-oriented issue that must be addressed with perspective displays is cognitive tunneling, or the lack of SA that results when an operator over-attends to the display and neglects other important aspects of the visual scene. A tunnel-in-the-sky with a deviation color seems to have both advantages and disadvantages regarding cognitive tunneling. It can improve flight path control, but there is a serous risk that it attracts too much attention, leading to inefficient attention-switching strategies when other tasks are involved.

When using perspective displays, one must keep in mind that integrated displays generally lose the specificity found in individual displays. When asked to fly as accurately as possible, pilots tend to use the information with the highest error gain that can be processed to perform the task. If an additional flight director or predictor is available with a tunnel, the pilot will primarily use this information (Theunissen, 1994).

In addition to user-oriented issues, there are several possible design issues that have emerged with the use of prediction in perspective displays (see Section 3.2.2). For instance, there are three possible ways to generate a prediction (i.e., computer model, regression analysis, and extrapolation). There are also two kinds of prediction that can be used to assess the impact of control inputs based on control input assumptions or "stick assumptions;" online and offline. There are two types of predictor symbols that can be used in perspective displays; point predictors and path predictors. A final issue with the use of prediction in perspective displays is prediction span. Prediction span is the distance or time in the future that is represented by the prediction symbol.

Another issue in designing perspective displays is the frame of reference used. Frame of reference refers to the perspective from which the display represents its information. Egocentric or inside-out frames of reference correspond to immersed viewpoints as if the observer was immersed within the scene. Exocentric displays provide the viewpoint extracted from the scene. In general, egocentric perspective displays have an unstable frame of reference, but demonstrate better tracking performance and require fewer and simpler mental transformations than with exocentric displays. The exocentric perspective provides a fixed frame of reference, but tends to require more mental transformations for the pilot to remain oriented. A study by Wickens, Haskell, and Harte (1989) found that using a inside-out display compared to a outside-in display resulted in better performance and a reduced negative impact on performance as difficulty increased.

While the primary focus of this report is on head down displays, research findings are divided regarding the head-up or head-down placement of perspective displays. For instance, Fadden (1999) found that using a head up display enhanced detection of external events compared to a head-down display when visibility was high. The HUD showed no benefits over the HDD when visibility was low. Ververs and Wickens (1998) and Fadden, Ververs, and Wickens (2001) also found improved performance for perspective displays when using a HUD compared to a HDD. On the other hand, a 1989 study by Reising, Barthelemy, and Harsock found that a 3-D pathway display yielded better performance than a HUD in all conditions.

Another issue with perspective displays is whether or not to use 3-D or 2-D cues. Research has shown that the performance using a 2-D versus a 3-D display may be task dependent. According to Haskell & Wickens, 3-D displays are generally favored over 2-D displays when directly compared (1993). There are also two human factors arguments can be made to support research to use 3-D displays to replace multiple 2-D displays. First, a 3-D display will provide a more “natural” representation of the pilot’s view than a 2-D display. Second, a single 3-D display that integrates several sources of information will reduce the need to mentally integrate these sources of information during a mission. On the other hand, there are some limitations to 3-D displays. For instance, judgments were made more rapidly with a 3-D display but more accurately with a 2-D display (Wickens, et al., 1994). 3-D displays also provide a less accurate representation of depth perception, and are often cluttered. When compared by Andre, et al. (1991), 2-D displays tended to support more accurate flight control than 3-D displays. Three-dimensional displays are often cluttered. A final consideration with the use of a 3-D perspective display is the use of stereo effects (using binocular versus monocular cues). In two studies, Nataupsky and Crittenden (1988) and Zenyuh, Reising, and Walchli (1998) found that 3-D cues improved performance and accuracy over monocular 3-D displays. However, Haskell and Wickens (1993) state that stereoptic effects probably should not be used in perspective displays due to complexity and cost. Future research may help clarify which cues are most effective for perspective flight displays.

In addition to how the information is represented, there has also been research on the way the information is presented to the user. For instance, Hennessy (1995) and Williams (2000) found that there were clear differences in pathway interception depending on which guidance symbology was used. Pilots had less horizontal and vertical error with a follow-me airplane symbology than with a flight predictor, and most (72%) felt like the follow-me airplane symbology made pathway acquisition easier, and was more intuitive and easier to use. It was concluded that the follow-me airplane was the best display for the pilots to use compared to the predictor symbol alone or no-guidance (conventional displays).

When designing the pathway in a perspective display, there are several differing opinions and guidance varies. For instance, Etherington recommends a square tunnel with boxes at 0.20 miles with drop-lines to the ground for use in general aviation applications (cited in Beringer, 2000). Generally, Beringer (2000) suggests that formats providing more relative-elevation cues (i.e., channel or tunnel) are more effective than pavestone styles in presenting accurate altitude control information in the absence of auxiliary quantitative error indices. They also provide better off-axis cues in the absence of other guidance data for reacquisition of the pathway. They appear to have improved dimensionality from most viewing angles, while pavestones can appear as a line at some angles.

Regarding the representation of the path/tunnel, Theunissen (1994) states:

- Size influences the magnitude of the velocity cues perceived. The greater the size of the displayed information, the slower the perceived velocity.
- The width of the lines should be inversely proportional to the distance from the viewpoint. As the path gets further away, the lines representing its edges should become more narrow.
- The path in the distance may contain too many pixels as the lines come together, this can be alleviated by controlling the intensity of the pixels in question.

On the other hand, Smallman, Schiller, and Cowen (2000) found that track size did not influence accuracy. As a result, it is unclear whether path size influences accuracy.

When designing the flight path, special attention must be taken with the cross-section frames because of the impact they can have on the effectiveness of the display (Theunissen, 1994). Issues with cross section frames include:

- They provide motion cues,
- Too many cross sections results in cluttered display,
- Too few results in lack of cueing, and
- Time between frames is proportional to the relative velocity between the aircraft and flightpath (i.e., the faster the aircraft is flying, the more quickly the cross section frames pass by).

When illustrating effects to improve ground-tracking, Smallman, Schiller, and Cowen (2000) found that using drop-line/shadow cues improved ground tracking performance by 100 percent compared to displays with no pathway-to-ground cues. When drop-lines were compared to drop-shadows, participants performed best on the localization task using drop lines compared to drop-shadows. Additional benefits to the drop-line over drop-shadow are additional cues include improved altitude judgements and decreased workload with increased display symbol density. Drop-lines can also be further augmented with tick marks at varying intervals (e.g., 1,000 or 5,000 feet) to increase the accuracy of altitude judgements.

When addressing the display of weather information in the cockpit, there are three issues that must be considered; scanning, cognitive integration, and clutter. Displays that provide all the weather information a pilot needs are generally too noisy and cluttered. However, separate displays require the pilot to integrate the data mentally, which increases workload. While remaining an unresolved trade-off, one solution to retaining information while still reducing clutter is to design the display with varying intensity between resource domains, or lowlighting. This would allow the user to focus attention on different sources of information while reducing screen clutter (O'Brien, 1993).

Overall, there are numerous design and guidance issues with respect to perspective displays that remain to be clarified. Perhaps future research will help resolve some of the disparate results found in the literature.

Bethel Data Collection Summary:

Terrain Database Inaccuracies

An incomplete terrain database can lead to a dangerous situation. One of the pilots noted during an interview that some “mud volcanoes” did not appear in the terrain database or on the map page. Since these terrain features rise up to over 600 feet, they pose a danger to pilots that might not be aware of their exact position, especially in low visibility conditions. However, it should be noted that the inaccuracy of the database could not be verified.

Incorrect Barometric Pressure Reports

The relative terrain mode can be inaccurate if the current altimeter setting is input incorrectly or not at all, or if pressure changes drastically during the flight, thereby rendering the altimeter setting incorrect. A second problem, mentioned by one of the pilots during an interview, is that the barometric pressures noted at certain locations are often inaccurate because of the sparse availability of reporting stations in the area. Another problem area involving barometric pressure is that pilots are required to input barometric pressure in both the GPS and MFD separately, as well as the altimeter display, which increases pilot workload and the chance for human error.

Increased Navigational Awareness

Despite the above-stated negative safety implications of how these displays were used, many positive points were brought out in the interviews and questionnaires. One statement made by the pilots was that the moving map display increased their awareness of terrain and airports during flight. The moving map display is thought to be especially useful for maintaining awareness of the location of a runway under low-visibility conditions. The map display was also helpful for locating runways that had never been visited or had been visited rarely. Another way in which the moving map display assisted in navigation was in helping the pilot to distinguish between mountain passes that look very similar out-the-window.

Pilots filling out the self-administered questionnaire reported that relative terrain information was used approximately 10% of the time, on average. Individual usage varied from 0% to 100%. The finding that pilots did not use the terrain information very often makes sense, given that most of the flying done in the area is under visual flight rules. Pilots stated that, when they were somewhat unfamiliar with an area or unsure of the location of the correct pass, they would call up the Terrain mode (or use the Custom mode with relative altitude displayed) to isolate the correct pass. This was particularly helpful when visibility was limited and it was more difficult to see distinguishing terrain features. Once inside a pass, it was reportedly not unusual to experience decreasing visibility to the point that all visual references with the surrounding terrain would be lost. The extreme case of loss of visual contact with the ground would occur when the snow-covered ground and clouds would cause a “whiteout” condition where everything outside of the aircraft looked white. One pilot reported that the Capstone equipment essentially saved his roommate’s life when he inadvertently entered a whiteout condition while flying through a pass. His roommate told him that he selected the terrain page and flew through the pass, staying within the yellow color-coded area on the display.

When asked about the effect that the equipment had on conventional navigational skills, one pilot stated that his skills had significantly improved as a result of using the Capstone equipment. His reasoning was that the GPS display gives you an instant picture of the required wind correction angle to hold a course (i.e. Wind correction angle = current heading - current track when current track = desired track). The only way to accomplish that with ground based navigational displays is by "bracketing" a course until you eliminate the drift. This "precise" experience with GPS navigation helps the pilot make better estimates of drift correction when relying solely on ground aids. Also, at distances over 30 miles from the station, a course line to or from a VOR becomes wider than a GPS course line to the same location. Because CDI sensitivity is generally set to 5 miles for en route GPS navigation, a pilot could see a GPS CDI that is slightly off-center when the VOR CDI is fully centered. The converse of this is true near the VOR because the VOR course is narrower than the same GPS course. These differences could be significant when precise navigation is required to avoid obstacles. Pilots with GPS experience might make better decisions because they are more likely to be aware of the limitations of both forms of navigation

<u>Impact/Applications</u>: The information collected in these reports will assist the sponsor in current and future certification and standardization decisions regarding CFIT displays. The information can also be generalized to other navigation displays, including multi-function displays and perspective flight displays

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports:

Williams, K.W., Yost, A., Holland, J. & Tyler, R.R. (in press) *Assessment of advanced cockpit displays for general aviation aircraft – the Capstone Program*. Federal Aviation Administration, Office of Aerospace Medicine Technical Report.

Wourms, D.F., Johnson, S.J., & Cunningham, P.H. (2001). *Human systems analysis of cockpit terrain displays, volume I: Final report.* Human Systems Information Analysis Center (HSIAC), AFRL/HEC/HSIAC. Wright-Patterson AFB, OH, Report # HSIAC-RA-2001-005.

Wourms, D.F., Johnson, S.J., & Cunningham, P.H. (2001). *Human systems analysis of cockpit terrain displays, volume II: Final report*. Human Systems Information Analysis Center (HSIAC), AFRL/HEC/HSIAC. Wright-Patterson AFB, OH, Report # HSIAC-RA-2001-006.

Rench, M.E., Wilson, C., Johnson, S., Chadwell, E. & Cunningham, P.H. (2002). *Flight perspective displays, Volume I: Final report*. Human Systems Information Analysis Center (HSIAC), AFRL/HEC/HSIAC. Wright-Patterson AFB, OH, Report # HSIAC-RA-2002-002.

Rench, M.E., Wilson, C., Johnson, S., Chadwell, E. & Cunningham, P.H. (2002). *Flight perspective displays, Volume II: Final report*. Human Systems Information Analysis Center (HSIAC), AFRL/HEC/HSIAC. Wright-Patterson AFB, OH, Report # HSIAC-RA-2002-003.

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: Priorities, organization, and sources of information accessed by pilots in various phases of flight

Primary Investigator: Dennis Beringer, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: dennis.beringer@faa.gov)

Co-Primary Investigator: Roger Schvaneveldt (Arizona State U.)

FAA Sponsor Organization: Frank Bick (ACE-111)

Sponsor's Requirement Statement: Develop a systematic analysis of the information required by pilots in various phases of flight. To specify what information is needed, when it is needed, and how pilots conceive of the organization of the information. **Please refer to page 122 for a more detailed description.**

Research Project's Goal: It is expected that the results of these efforts will be used to create and validate tools for Aircraft Certification that can be used to evaluate various forms of flight information systems in terms of their information content and organization.

Best Accomplishment: Weather information priorities by phase of flight were established for pilots classified as experienced and novice and were reported in the literature and to the sponsors (and NASA AWIN). Prioritization schemes were formalized in a checklist and used to evaluate several flight information systems for data organization and content with the cooperation and assistance of a major avionics manufacturer.

Project Summary: The purpose of the effort was to determine what information pilots require by phase of flight and in what prioritization. The intent was to provide a framework for organizing data, in flight information systems, that would allow decluttering of multifunction displays through prioritization of data by phase of flight. This would allow for a more meaningful organization of the data according to the pilots' mental models of how the information items were related. The second phase of this study was completed, in conjunction with the NASA AWIN program, relative to weather information requirements in the cockpit, and was reported in the open literature and at a NASA-sponsored aviation weather meeting. The third phase of the study was also completed, being a validation of the utility of this hierarchical structure of data, found in the first phase, for evaluating and ranking multifunction display systems portraying flight and weather information. The final project report was delivered and a draft OAM tech report was authored.

Scientific and Technical Objectives: Recent trends in aircraft instrumentation/data systems have been towards electronic integrated displays and systems. This "integration" is not always an actual fusion of data from multiple sources into a single display presentation but is often more the combination of multiple display formats or "pages" within a single multifunction display (MFD). In many cases, the system is capable of displaying many more pages than the display surface can present simultaneously. Therefore, some means are necessary to allow controlled access to those data and displays that are most relevant at any given point in the flight. Beyond the initial question of how one should format the data for presentation are the issues of data prioritization and the breadth of coverage required for different flight phases. Additionally, it is necessary to consider if and how one might automate prioritization and presentation schemes. One study has shown that allowing pilots to selectively suppress or declutter instrument approach plates (IAPs) increased performance, and study participants preferred the decluttering system (Mykityshyn, Kuchar, & Hansman, 1994).

Design decisions about what to display at particular moments in time would benefit considerably from a thorough analysis of the various required elements of information (aircraft position, weather, engine status, communications, etc.) and their properties (priority of the information, source of the information, quality of the information, etc.) by phase of flight (e.g., preflight, taxiing, take-off, cruise, approach and land-ing). Together with data revealing how pilots organize these information elements, such an analysis would assist efforts toward the integration of information in displays and prioritization and layering of information elements. For example, displays designed with critical information available at the right time in a meaningful organization should be of great assistance to the pilot who is actively controlling the aircraft. Andre and Wickens (1991) demonstrated how an integrated perspective-view cockpit display could reduce mental work-load while increasing situational awareness. Well-designed displays should also help establish and maintain the situational awareness of the pilot when automated systems are in control.

Research in supervisory control (Sarter & Woods, 1992, 1994) indicates that the increased capabilities and autonomy of new automated systems have increased the difficulty of maintaining mode awareness in the modern cockpit.

Comparison with Task Analysis

A long-standing goal in the analysis of aircraft systems has been to thoroughly analyze the tasks involved in flying aircraft (Roscoe, 1980). The usual approach analyzes goal-directed activities in terms of goals to be accomplished, subgoals used to index progress towards the goals, and the component actions required to achieve those goals/subgoals (cf., Sutcliffe, 1997). A limitation of this approach in the context of aviation is that the specific component actions required of a pilot to achieve goals/subgoals are largely determined by the nature of the technology in the aircraft. In the worst possible case, every significant change in cockpit systems calls for a distinct and separate task analysis.

If one abstracts these actions to some degree, however, one can reduce the number of distinct task analyses required, but this higher level of examination moves the analysis from the task/action level toward the goal level. For example, we could use “set 10 degrees of flaps” instead of “move the flap lever to the 10-degrees mark,” but in doing so, we have technically moved from specifying an action to specifying a subgoal. It seems clear that goals remain more constant across technological differences than actions. Even with extreme degrees of automation in aircraft, most goals of flight remain the same as they were with pilots in control. Still, we should be able to provide a more thorough analysis of the various phases of flight than simply specifying the goals (and subgoals) of each phase and still have some generality across technologies.

In addition to goals remaining relatively constant across technological changes, the critical information pertaining to flight also remains relatively constant. For the pilot actively controlling the aircraft, it is obvious that different information elements are critical at different times during a flight, but it is also true that even when the aircraft is being flown by automated systems, the same information elements are critical. Although semi-automated systems may be controlling much of the behavior of the aircraft, the pilot must make decisions concerning the safe continuation of the flight based upon relevant information concerning the aircraft, its systems, and the flight environment. Moreover, for pilots to maintain (or to quickly attain) good situation awareness, they must have access to and be aware of these critical information elements whether they are actively in control or not. It is also reasonable to assume that pilots' mental models of flight depend upon having the appropriate information elements present when needed. Incorrect information entering into the model is a very likely precursor to an incident or accident resulting from good pilot intentions based upon bad data.

The objectives of this work, then, were to determine pilots' information needs in the cockpit by phase of flight and pilot experience level (greater experience implying a more developed mental model) and the prioritization of those flight-related data by flight phase and pilot experience.

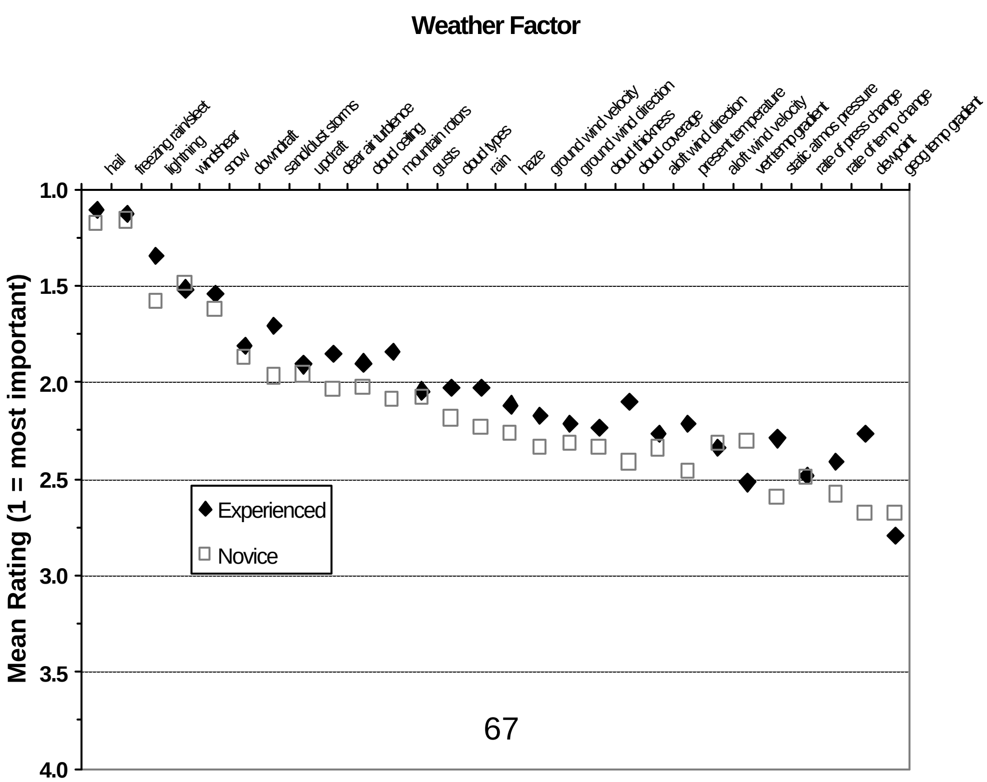
<u>Technical Approach</u>: For the weather-related phase of the study, a weather-information taxonomy was developed grouping weather information into several categories related to potential effects on pilot and aircraft performance. These included: clouds, precipitation, temperature, air movement (winds, turbulence, convection), pressure, and obscurations of vision. A listing of the variables associated with each of these categories appears in Table 1. These variables were then combined with phases of flight to form a matrix, which was incorporated into a questionnaire form to be used by raters/pilots.

Participants were solicited both in person and indirectly through a major university. A large segment of the sample (56 flight instructors) was from a major university aviation program. Participation was arranged by the chief pilot for instruction and the questionnaire was administered during a required meeting of flight instructors. The remainder of the sample consisted of pilots contacted by one of the experimenters. A set of instructions and a sample questionnaire were included with each of the questionnaire forms. The sample showed how numbers should be entered for several fictitious items not appearing in the real questionnaire form (an attempt to avoid biasing later responses to the questionnaire). The respondents were instructed to rate each of 28 weather information factors for each of 11 phases of flight (Table 1).

Participants were asked to assign the following ratings, indicating if a factor's rating changed between VFR and IFR flight by using two numbers separated by a slash: 1 = critical and/or frequently accessed, 2 = important and/or usually accessed, 3 = relevant and/or sometimes accessed, and 4 = not relevant or rarely accessed. Data were collected and entered into Excel files for analysis. Most pilots did not differentiate in their ratings, and for those who did it was for only a few weather factors. Whenever differences in IFR and VFR ratings were encountered, the lowest rating value (highest importance) was used for the analysis. Statistics for total flight hours for the full sample were as follows: Mean total hours = 1885 hours, median total = 400 hours, maximum = 20,000 hours, minimum = 70 hours.

Results: Initial categorization used 1000 hours as the criterion for an "experienced" pilot as in a previous study by these authors (Schvaneveldt, et al., 2001), producing 26 experienced and 45 novice pilots. An additional set of analyses was conducted using 500 hours as the breakpoint, and it produced a nearly equal distribution of pilots between groups (33 experienced, 38 novice). Although the total of pilot flight hours is only a rough index of "experience," this was an exploratory investigation and the division criterion was considered appropriate for a first-pass examination of the data. The resulting groups were characterized by the following statistics for total flight hours: Novice – mean = 286, median = 290, maximum = 420, minimum = 70; Experienced – mean = 3727, median = 1500, maximum = 20,000, minimum = 500. This latter division will be the basis of the analyses discussed herein, space not allowing a comparison of both categorizations

Overall ratings. Figure 1 shows a comparison of the ratings by factor and averaged across flight phases for both groups. These data are ordered from most important to least important according to the mean ratings across all pilots.



It can be seen that experts tended to rate the majority of the weather information factors as more important overall than did the novices (75% of factors). Eleven percent was rated in the other direction, and 14% was rated essentially the same between groups. Only the rating of *dewpoint* emerged as significantly different for the collapsed scores.
Figure 1. Mean ratings of weather information importance across all phases of flight for experienced and novice pilots.

Note that the top-rated items (averaged across phases of flight) all involve items related to precipitation or convective activity, factors which are likely to affect visibility or the continued safe flight of the aircraft (freezing rain, hail). Hail, freezing rain/sleet, and lightning were all rated less than 1.5. The drop in scores is most evident from the first factor through mountain rotors, with the second group being wind shear, snow, downdraft, and sand/dust storms (1.5 to 1.75), followed by updraft, clear-air turbulence, cloud ceiling, and mountain rotors (1.75 to 2.00). The decrease from this point on is less extreme, with less than a point separating the 11th from the 28th factor.

Changes by flight phase. The second point of interest is how these ratings change as a function of phase of flight. Ratings of experienced pilots were examined to determine which information was deemed most important for each flight phase, and how these priorities shifted. These mean ratings are listed in Table 2. Factor ratings considered "critical" for more than half the sample are shaded (<1.6) whereas those that were clearly rated as important (1.6 to 2.0), on the average, by all respondents have been boxed. All rating values of 2.0 or less are in bold type. It is clear that a number of factors that are critical or important during takeoff, climb, descent/approach, and landing are seen as less important during cruise (e.g., cloud ceiling, snow, wind shear, etc. More specifically, an examination of Table 2 reveals that several of the factors are rated as important (2) or critical (1) for only specific phases of flight. This can be seen in such pairs as climb and transition to cruise, transition to cruise and cruise, and descent and approach. Thus, the potential number of prioritization filters could be reduced from the possible 11 to something much less.

The number of factors rated to be at least "important" varies across flight phases, going from a high of 22 during pre-flight planning to a low of 8 during transition to cruise (see last row of Table 3). Thus the density of required information will shift considerably across flight phases, being at its lowest during climb, take-off and cruise (8 to 12 factors) and being at its highest during flight-planning activities (22 and 19 factors). There is also a rise during descent, approach, and landing (15 to 18 factors). These figures appear to be closely related to workload ratings for different phases of flight as obtained in other studies (e.g., Corwin, 1992), and thus information requirements may be useful as a priori indicators of anticipated workload. These figures are also somewhat correlated with accident rates as tallied by phase of flight Schvaneveldt, et al., 2001), and thus can serve as another potential a priori index of where we need to focus our attention in designing effective flight information and navigation systems.

Table 2. Mean ratings of weather factors for experienced pilots by phase of flight, scores coded as: clearly critical (<1.6) bold/shaded; clearly important (<2.1) bold/italicized/boxed.

	Pplan	JBD	Taxi	T-O	Climb	T-C	Crs	IFP	Desc	App	Land
Cloud ceiling	**1.4**	**1.5**	2.6	***1.6***	2.1	2.3	2.3	***1.7***	***1.9***	**1.4**	2.1
Cloud thickness	***2.0***	2.1	2.7	2.2	2.1	2.6	2.5	***2.0***	***2.0***	***1.8***	2.6
Cloud coverage	***1.6***	***1.9***	2.6	2.1	2.2	2.4	2.3	***1.8***	***1.9***	***1.8***	2.5
Cloud types	***1.8***	***2.0***	2.5	***2.0***	***2.0***	2.1	***2.0***	***1.8***	***2.0***	***1.8***	2.3
rain	***1.9***	***1.8***	2.2	***2.0***	2.2	2.3	2.3	***1.9***	***1.9***	***1.8***	***2.0***
Freezing rain/sleet	**1.1**	**1.1**	**1.2**	**1.1**	**1.2**	**1.2**	**1.1**	**1.0**	**1.1**	**1.1**	**1.2**
hail	**1.1**	**1.0**	**1.2**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.2**
snow	**1.5**	**1.4**	1.6	**1.5**	***1.8***	***1.8***	***1.6***	**1.4**	**1.5**	**1.4**	**1.5**
Present temp	2.1	2.3	2.6	2.3	***2.0***	2.4	***2.0***	***1.9***	2.2	2.2	2.4
geog_temp gradient	2.5	2.6	3.0	2.8	2.8	2.9	2.9	2.6	2.8	2.8	3.0
vert_temp gradient	2.3	2.4	2.9	2.6	2.4	2.6	2.7	2.2	2.4	2.4	2.8
Rate temp change	2.2	2.5	2.8	2.5	2.2	2.5	2.4	2.2	2.2	2.3	2.7
dewpoint	***1.9***	2.1	2.5	2.4	2.4	2.6	2.4	***1.8***	2.2	2.2	2.4
grnd_wind direction	**1.5**	***1.7***	***1.7***	**1.4**	2.8	3.2	3.2	2.4	2.8	2.1	***1.6***
Aloft wind direction	***1.8***	2.6	2.9	2.5	2.1	2.2	***2.0***	***1.8***	2.2	2.2	2.6
Grnd wind velocity	***1.6***	***1.6***	***1.8***	**1.5**	2.8	3.1	3.1	2.4	2.6	***2.0***	**1.4**
aloft_wind_velocity	***1.8***	2.5	2.8	2.6	2.2	2.3	***1.9***	***1.9***	2.4	2.4	2.9
Clear air turblence	***1.6***	2.1	2.5	***2.0***	***1.7***	***1.8***	***1.6***	***1.6***	***1.7***	***1.7***	2.1

gusts	1.9	2.0	2.1	1.7	2.1	2.6	2.6	2.3	2.1	1.7	1.4
Mountain rotors	1.5	1.8	2.5	1.9	1.9	1.9	1.6	1.5	1.8	1.9	2.0
downdraft	1.7	2.0	2.2	1.6	1.8	2.1	2.1	1.7	1.8	1.4	1.5
updraft	1.8	2.0	2.3	1.8	1.8	2.2	2.2	1.8	1.9	1.6	1.6
lightning	1.4	1.3	1.6	1.3	1.3	1.3	1.4	1.4	1.4	1.2	1.2
windshear	1.3	1.7	1.9	1.3	1.5	1.8	1.9	1.5	1.4	1.2	1.2
Static atmo_press	2.1	2.3	2.5	2.3	2.4	2.4	2.4	2.2	2.3	2.1	2.2
Rate press change	2.2	2.4	2.7	2.4	2.7	2.6	2.5	2.3	2.6	2.4	2.5
haze	1.9	2.0	2.3	2.2	2.2	2.4	2.4	2.1	2.1	1.9	1.8
sand/dust storms	1.6	1.8	1.9	1.7	1.7	2.0	1.9	1.7	1.6	1.5	1.4
# rated important	*22*	*17*	*8*	*16*	*12*	*8*	*12*	*19*	*15*	*18*	*15*

Experienced/Novice differences. Recall that only *dewpoint* was rated significantly differently by novices and experienced pilots overall. However, the separate analyses of factors by flight phase produced 19 factors rated as significantly more important by experienced than by novice pilots (all differences were in this direction), and these are shown in Table 3 as are the results of t-tests. Given that this was an exploratory study, we felt that it was more valuable to err on the side of being oversensitive to differences and thus no corrections (e.g., Bonferroni) were used. It is worth noting that freezing rain/sleet, hail, and lightning were consistently rated very highly (1.6 or less) across all phases of flight, undoubtedly as indices of areas of severe threats to flight safety. It is interesting to note that fewer factors were rated significantly differently in the 1000-hour breakpoint analysis, and that only 4 of the significant differences were common to both categorizations. However, the unequal n and variability of ratings undoubtedly contributed to the outcomes in that categorization. The differences in some cases (factors under Taxi, for instance) resulted from factors being rated as considerably less important in one phase of flight than in others, but the drop in importance was greater for the novice than for the expert pilots. Average novice rankings can be obtained by adding the values in Table 3 to the appropriate cells in Table 2.

Table 3. Significant differences resulting from t-tests between experienced- and novice-pilot ratings by flight phase.

Phases of Flight

Weather factors	Pre	Dep	Taxi	T-O	Cl	I-P	De	Land
Cloud_ceiling			0.7	0.5				
Cloud_thickness			0.8*					
Cloud_coverage			0.7+	0.8*				
Cloud_types			0.6					
Rain						0.4	0.5	
Hail								
Snow		0.3						
Present temperature					0.4	0.4		
Dewpoint	0.4					0.7*		
Ground wind direction	0.7*							
Aloft wind direction								0.6
Ground wind velocity	0.5					0.7		
Static atmos pressure			0.5					
Sand/ dust storms								0.5

Unmarked differences are $p<.05$; + $p<.01$; * $p<.005$. All differences show experienced pilot ratings higher in importance (lower numerically) than novice ratings. P = preflight, Dep = just before departure, T-O = Take-off, Cl = climb, I-P = inflight planning, De = descent.

Impact/Applications: The application of the data derived from this study will allow for a more standardized assessment by Aircraft Certification of how data are organized and accessed in flight information systems. The impacts are most likely to be seen in certification checklists, advisory circulars, GAMA and SAE documents, and potentially in rules for Part 25 and/or Part 23

Technology Transfer: The data are being made available to Aircraft Certification with the hope that the evaluation aid that was developed will both aid ACS in evaluating flight information systems for their data organization and content and influence avionics manufacturers to move towards a more standardized internal organization and representation of the data in flight information systems

Journal Articles: Schvaneveldt, R. W., Beringer, D. B., and Lamonica, J. A. (2001). Priority and organization of information accessed by pilots in various phases of flight. *International Journal of Aviation Psychology, 11(3),* 253-280.

Books or Chapters: none

Technical Reports: Schvaneveldt, R.W., Beringer, D.B., and Leard, T.M. Evaluating Aviation Information Systems: The role of information priorities. Project final report on contract DTFA-02-02-P-13325, September 2002. (Draft OAM TR)

Conference presentations/abstracts: Beringer, D.B. and Schvaneveldt, R.W. (2002). Priorities of weather information in various phases of flight. In *Proceedings of the 46th Annual meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: Human Factors and Ergonomics Society, 86-90.

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *JSAT ADM Panel*

Primary Investigator: David Hunter, Office of Aerospace Medicine, Washington, DC (email: david.hunter@faa.gov)

Co-Primary Investigator: none

FAA Sponsor Organization: Michael Henry (AFS-800), JSAT ADM

Sponsor's Requirement Statement: to use identify potential data sources to identify causes of general aviation human error accidents as well describe potential remedies. The outcome of the research should be to develop and standardize methodologies for identifying, defining, and monitoring human error based incidents and accidents. **Please refer to page 123 for a more detailed description.**

Research Project's Goal: Develop and validate a standardized methodology for conducting accident investigation in which human error is cited as the cause or contributor to the accident.

Best Accomplishment: List of interventions aimed at reducing general aviation accidents attributable to poor aeronautical decision-making

Project Summary: Poor decision-making by pilots has been identified as a major factor in the cause of general aviation accidents. Estimates of the proportion of accidents associated with poor decision-making range from 30% (Wiegmann & Shappell, 1997) to 50% (Jensen, 1995). . As an example, poor decisions result in pilots initiating flights under adverse conditions, continuing flights in the face of deteriorating conditions or operating aircraft beyond their limits. To address these issues a Joint Safety Analysis Teams (JSATs) was chartered by the Administrator to develop new means of preventing these types of accidents. The ADM JSAT was composed of representatives from the FAA, National Weather Service, Volpe National Transportation System Center and industry members representing HAI, GAMA, NBAA, AOPA and SAMA. In order to identify potential interventions in this highly technical area, a panel of human factors experts was formed, consisting of individuals drawn internationally. These panel members were well-known researchers and authorities, who have previously conducted and published extensive research in the area of aeronautical decision-making within the general aviation domain. Panel members included: Dr. David O'Hare (The University of Otago, New Zealand), Dr. Mark Wiggins (The University of Western Sydney, Australia), Dr. Monica (The University of Tromso, Norway), Dr. Richard Jensen (Ohio State University), Dr. Doug Wiegmann (University of Illinois), and Dr. Robert Mauro (The University of Oregon).

This panel met in Alexandria, VA in February 2002 and was charged by the ADM JSAT to devise a comprehensive and detailed set of interventions that would, based on the current state of knowledge in psychology and human factors, improve the decision-making by general aviation pilots. To accomplish this goal, the panel used a variety of techniques. Prior to the meeting, the panel members reviewed current scientific literature on aeronautical decision-making and related topics. They were also provided a video depiction of a fictitious general aviation accident. This video followed the decision-making processes of an inexperienced general aviation pilot as he prepared for and conducted a flight that presumably led to a crash. The video depiction provided a richness of information not present in the narrative, as well as factual descriptions provided by the NTSB, and served as a focus for discussion.

Each panel member provided a proposed list of interventions that would address the decision-making errors evident in the video. During the panel meeting, these initial interventions were elaborated upon, and additional interventions were identified. To further focus the panel's discussions and to ensure that interventions were related to actual (as opposed to fictitious) accidents, the panel members also reviewed the accidents analyzed by the JSAT. From this process, a list of approximately 120 potential interventions was produced and a report describing those interventions was provided to the ADM JSAT

<u>Scientific and Technical Objectives</u>: List of interventions

<u>Technical Approach</u>: Scientific panel reviewed extant literature and relevant accident narratives and produced list of recommended interventions

<u>Results</u>: Produced technical report which specified over 100 interventions based on current scientific literature on this area

<u>Impact/Applications</u>: The ADM JSAT used the list of interventions as its recommended solutions. These interventions will now be implemented by FAA and industry

<u>Technology Transfer:</u> none

<u>Journal Articles</u>: none

<u>Books or Chapters</u>: none

<u>Technical Reports</u>: none

<u>Conference presentations/abstracts</u>: none

<u>Patents Issued or Pending</u>: none

<u>Honors:</u> none

<u>Related Projects</u>: none

Project Title: *Developing and Validating Human Factors Certification Criteria for Cockpit Displays of Traffic Information Avionics*

Primary Investigator: Dr, Esa Rantanen, University of Illinois at Urbana-Champaign, Savoy, Illinois, (email: rantanen@uiuc.edu)

Co-Primary Investigator: Wickens, Chistopher, University of Illinois at Urbana-Champaign, Savoy, Illinois

FAA Sponsor Organization: Colleen Donovan (AIR-130)

Sponsor's Requirement Statement: to develop and validate criteria for constraining false and nuisance alerts for cockpit displays of traffic information (CDTI), based on what is known about other alerting algorithms and human performance issues with alerting systems, trust, situation awareness and workload. Where objective criteria are not possible, subjective means may be recommended provided they are established to be reliable and valid measures. **Please refer to page 98 for a more detailed description.**

Research Project's Goal: An exhaustive review of existing literature is a prerequisite for all research efforts, and the one we are performing can—and should—be used as a foundation for any future studies on CASs and associated human factors issues, augmented with results subsequent to our project as necessary. However, a far more important contribution of our literature review is identification of areas where no empirical research can be found and where future research efforts should therefore be directed.

The concept of human factors certification of diverse complex and safety-critical technologies is not a mature one. The anticipated outcome of this project—a framework for human factors certification of CDTIs—has therefore a potential of serving the certification process of future versions of CASs as well as becoming a template for development of similar certification criteria for other systems and technologies.

Best Accomplishment: We have commenced the literature search and review on three distinct areas: (1) Human factors certification literature and standards and guidelines across domains, (2) literature against which the premises and hypotheses—explicated in the research proposal and in part 3 "Concise Research Summary" of this report—will be evaluated, and (3) literature on CDTI and other conflict detection and alerting algorithms.

We have also commenced the design of an experiment investigating unaided pilot performance in airborne conflict detection. We are developing taxonomy of plausible two-aircraft conflict geometries, based, in part, upon FAA Air Traffic Control Handbook 7110.65. We have also developed a CDTI interface in which conflicts can be readily created with a wide range of geometries, and where critical parameters of time to closest passage and separation at closest passage are automatically computed. Our emphasis now is in developing prototypes of conflict geometries and a methodology for pilots to express conflict likelihood at varying look-ahead times. The pilot-in-the-loop simulation data generated from this experiment will provide baseline data on the geometric factors that impose highest workload on the pilots, as well as any inherent biases that might be found.

Project Summary: This project was started on August 23, 2002. This report hence summarizes the first three months' work on it.

The purpose of the study is to develop a framework for human factors certification of cckpit displays of traffic information (CDTIs). This framework, to be completed during the first year of the study, will also provide a foundation for further research efforts during the anticipated second and third years of the project.

Our work has commenced based on the following premises: (1) Collision avoidance systems (CASs) with a zero false alarm rate (FAR) and 1.0 hit rate (HR) do not exist nor can they be built; this limitation is inherent to all prediction efforts in a probabilistic world, rather than a result of algorithms or computing power. (2) To certify such imperfect technology, emphasis must be placed on human performance issues, including determination of factors that affect operators' trust, workload, and situation awareness (SA) when interacting with CASs, development of guidelines for mitigation of the adverse effects of imperfect technology, and development of methodologies for measurement of human performance in both simulated and operational environments. (3) It is not possible to determine a fixed threshold for "acceptable" FAR due to the complexity of constructs such as trust and workload and the innumerable factors affecting them as well as the diversity of the operational environments and settings in which alerting systems are used. (4) More important than to establish fixed criteria for FAR and HR (or for other metrics such as PPV) is to research the question of FAR tolerance and factors that mitigate the detrimental effects of false alarms, including pilots' situation awareness, understanding of the alerting algorithms, display design, alert resolution, and congruence with other alerting systems. (5) The respective roles of TCAS and CDTI should be carefully researched**,** along with their relationship with the similar systems (e.g., CA, URET) in the ATC domain. (6) Finally, human factors issues of CDTI should be examined in the context of the free flight environment together with the role of ATC.

To guide the initial literature search and review, we formulated four main hypotheses based on the above premises: (1) The operators' tolerance for false alarms can be increased by improving their general awareness of the traffic situation on one hand, and the accuracy of their mental model of the algorithms of the collision alert system on the other. (2) False alarm tolerance can be improved by increasing the resolution of the alert (dichotomous alert—no alert vs. an alert on a continuum from low to high conflict probability). (3) The operators' performance can be significantly improved by displaying probabilistic information to them in a form that is easy to perceive and understand and that can be readily used in their tasks. (4) Finally, congruence of planning and conflict detection algorithms of CDTI and ATC automation tools will impact the performance of both pilots and controllers.

Parallel to the literature review focusing on the above hypotheses we have reviewed literature on existing CDTI conflict detection and resolution (CD&R) algorithms. We have continued to expand upon the review of airborne algorithms provided originally by Kopardekar and Mogford (2002), identifying some studies that were not contained in their review and examining the original papers that were the focus of that review. Our review has focused explicitly on the following questions for each algorithm/study: (1) What are the range of parameters and variables considered in conflict prediction/detection (e.g., conflict angle, common vs. separate altitudes, intent, look-ahead or "prediction span"). Our particular interest is in the specific assumptions that different algorithms make, regarding the growth of uncertainty of trajectory (and conflict potential) over time. (2) To what extent do the algorithms explicitly acknowledge the tradeoffs between misses and false alarms in issuing alerts? To what extent do they articulate the manner in which other design parameters (e.g., look-ahead time) will make this tradeoff more or less severe? (3) To what extent have the algorithm designers provided Monte-Carlo conflict simulation data to test the accuracy of their predictions? (4) To what extent have designers, implicitly or explicitly, considered the impact of misses and false alarms on the trust and responsiveness of the human operator? (5) To what extent have designers attempted to balance the costs of misses and false alarms in either designing "optimal" alerting systems (e.g., Yang and Kuchar, 1997), or proposing multi-level alerts (Johnson et al, 1997)? (6) To what extent have algorithm designers presented actual pilot-in-the-loop data regarding pilot response to alarm false alarms and misses, and subsequent pilot trust/reliance on the alerting data?

Finally, we are developing an experimental plan to investigate unaided pilot performance in conflict detection. The pilot-in-the-loop simulation data generated from this experiment will provide baseline data on the geometric factors that impose highest workload on the pilots, as well as any inherent biases that are found

Scientific and Technical Objectives: This project has four main objectives, directed by the premises and research hypotheses described before. These objectives are:

(1) Review of relevant literature. The literature review will focus on several critical areas, including empirical human factors results relevant to alerting systems, certification standards, requirements and guidelines related to false alerts and alerting criteria, comparison of the alerting algorithms of TCAS, CDTI, CA, and URET and examination of their congruence with pilots' and controllers' tasks and mental models, previous ASRS analyses on alerting system related incidents to determine if yet another ASRS analysis is warranted, and literature

on human factors certification for guidelines for development of certification criteria for CDTIs. We will also seek to identify other data sources (e.g., from demonstrations and simulations or from operational environments) that would allow for further examination of relevant human factors issues outside of a laboratory.

(2) Development of a framework for human factors certification of CASs. This Objective will be accomplished by synthesizing the findings of the literature review into a framework for human factors certification of CASs in general, and certification of CDTI in particular. This framework will include examination the roles of a number of automatic alerting systems (GPWS, TCAS, wind shear alert, URET, CA) and the impact of these on the respective certification criteria of the alerting systems, a comprehensive evaluation of available measures of machine, human, and human-machine system performance as they pertain to collision avoidance systems, and development of experimental designs and protocols aimed at investigation of the most critical issues relevant to human factors certification of CDTIs and to address possible controversies in the alerting system literature.

(3) Development of a cognitive model of unaided conflict prediction. This model will be based on a laboratory experiment to be conduced during the spring of 2003 and it is intended to reveal the pilot vulnerabilities that are in greatest need of automation support and suggest design solutions to provide such support. The experiment will also suggest, by implication, the pilot vulnerabilities to unreliable predictions. This latter goal is based on the assumption that more difficult cognitive predictions will induce greater reliance upon automated assistance, and have as a result more serious consequences when the predictor is incorrect and the pilot must suddenly rely upon the raw data to estimate future trajectories. Fundamental to the research effort will be modeling the pilots' judgment of time to contact as these judgments are made on a pair of aircraft moving across a CDTI. Our model will predict the sorts of errors (random and systematic) that pilots make when trying to judge when a single aircraft will cross a point in the airspace and when (and whether) two aircraft will occupy that point at the same time. The model will explicitly incorporate the factors that make these judgments more—or less—difficult. Understanding of pilot performance with respect to their ability to make accurate judgments on collision risk based on CDTI information sans automated alerts will be critical in assessing the pilots' performance in response to alerts, both false and real. Such understanding will allow for prediction of mistrust caused by too many false alarms as well as prediction of complacency resulting from highly reliable systems or very low conflict base rates. Therefore, this experiment must be seen as a prerequisite to the development of any human factors certification criteria for CASs.

(4) Development of a plan for further research A detailed research plan will be developed to continue the research based on the findings and results of the first year effort. As this plan will be based on the literature review completed during

the first year, its focus will be on empirical research. We will develop experimental designs and protocols to investigate the questions that have not been sufficiently answered by previous research and that are most relevant to the human factors certification efforts of CDTIs as well as identify data sources for evaluation of CDTI and human performance in operational settings. The ultimate goal of the research will be to provide the FAA with sufficient knowledge and tools to make informed certification decisions of collision avoidance systems and to develop procedures for their safe and efficient use.

Technical Approach: An exhaustive literature review will be conducted, focusing on three distinct areas: (1) Human factors certification literature and standards and guidelines across domains, (2) literature against which the premises and hypotheses (as stated above) will be evaluated, and (3) literature on CDTI and other conflict detection and alerting algorithms. Synthesis of this literature will form the basis of the framework for human factors certification of CDTIs.

We will conduct a pilot-in-the-loop experiment to investigate unaided pilot performance in airborne conflict detection. Based on the results of this experiment, a cognitive model of unaided conflict prediction will be developed. This model will be used to determine areas of greatest need of automation and pilot vulnerabilities to unreliable predictions, predict pilot errors in judging conflict probabilities, and allow for prediction of mistrust caused by too many false alarms as well as prediction of complacency resulting from highly reliable systems or very low conflict base rates.

We have developed a CDTI interface in which conflicts can be readily created with a wide range of geometries, and critical parameters of time to closest passage and separation at closest passage are automatically computed.

We will attempt to simulate the outcomes of different CD&A algorithms at various parameter settings and conflict geometries to determine the variability in their respective conflict detection performance and the impact of the outcomes on human performance. Towards this end, we are developing taxonomy of plausible two-aircraft conflict geometries, based, in part, upon FAA Air Traffic Control Handbook 7110.65. This taxonomy will allow for systematic sampling of all possible conflict situations for simulations and comparison of performance of different algorithms and CASs.

Results: (1) Literature review in support of the hypotheses: Despite extensive literature search, only one paper relevant to (in support of) hypothesis 1 (operators' tolerance for false alarms can be increased by improving their general awareness of the traffic situation) has been found, by Cotté, Meyer, and Coughlin (2001), and only four papers relevant to (in support of) hypothesis 2 (false alarm tolerance can be improved by increasing the resolution of) by Gupta, Bisantz, and Singh (2001), John and Manes (2002), Sorkin, Kantowitz, and Kantowitz (1988), and Manalosis and Parasuraman (2000). These results, although preliminary, indicate the amount of work yet to be done to develop empirically supported guidelines for human factors certification. They also provide guidance for further research efforts during the second and third years of this project.

(2) Literature review on conflict detection and alerting algorithms: In most materials reviewed, the specific algorithm used in the CDTI is not named or referenced. Thus, it is not always clear if the CDTI is using an existing validated algorithm or one that was created specifically for the experiment. When the algorithm or conflict detection logic is mentioned, the data is often incomplete (due to the part-task nature of the studies, limited resources, limited integration, limited conflict orientations, etc). No experimental, pilot-in-the-loop papers, which discuss false alarm findings or effects on pilots, have been found, and none that specifically address false alarms as an independent variable. In general, there appear to be two philosophies of dealing with false alarms: Minimize false alarms by plotting an SOC curve of probabilities of successful vs. unnecessary alarms, then setting a probability value that maximizing P(SA)s while minimizes P(UA)s (Kuchar et al.), and minimize false alarms by setting the look-ahead scope of the alerting logic to 5 minutes, purported to provide enough time to detect and resolve conflicts, while reducing time-based uncertainty in the trajectories (NLR/Hoekstra). In reviewed articles about algorithm philosophies equations for how the airspaces (protected zones, conflict zones, no-go zones, etc) and trajectories are derived, how uncertainties and probabilities are calculated, and how false alarms are calculated and minimized are provided. Most of these articles validate the algorithm model via Monte Carlo simulations. Relatively few of the algorithms have been put into operational systems and validated in field conditions, or realistic laboratory conditions. It is probable that we can model at least some of the algorithms that have not before been implemented in CDTIs. This work has allowed us to augment conflict algorithm comparisons based on Kopardekar et al. (2001) by addition of the HIPS column information, and additions to the Kuchar column of specific NASA CDTI-related information.

(3) Work on the experimental design is well under way, with taxonomy of conflict geometries and development of a CDTI interface nearly complete.

Impact/Applications: This project will provide the FAA with sufficient knowledge and tools to make informed certification decisions of collision avoidance systems and to develop procedures for their safe and efficient use.

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device, and an Airplane in Conducting Instrument Proficiency Checks*

Primary Investigator: Henry L. Taylor, University of Illinois at Urbana, (e-mail henryltaylor@bellsouth.net)

Co-Primary Investigator: Tom Emanuel, Esa Rantanen, Donald Talleur

FAA Sponsor Organization:

Sponsor's Requirement Statement:

Research Project's Goal: The study will directly compare the performance of pilots receiving an IPC in a PCATD, a Frasca FTD, or an Airplane (IPC #1) with performance in an airplane (IPC #2). The comparison of performance in a PCATD to that in an airplane will investigate the effectiveness of the PCATD as a device in which to administer an IPC. Currently, the PCATD is not approved to administer IPCs. The comparison of performance in a Frasca and the airplane will determine whether the current rule to permit IPCs in a FTD is warranted. Finally, we will compare the performance of pilots receiving IPC #1 in an airplane and IPC #2 in an airplane with a second Certified flight instructor, instruments (CFII). This comparison will permit the determination of the reliability of IPCs conducted in an airplane.

Best Accomplishment : The following are the three best accomplishments during the first year of the study. All equipment required for the study was acquired. This included two FAA approved Personal Computer Aviation Training Devices (PCATDs) and one FAA approved Frasca 141 flight training device (FTD) with a generic single-engine, fixed gear, fixed pitch propeller performance model. The FTD is approved for instrument training towards the instrument rating, instrument recency of experience training, and IPCs as well as for administering part of the instrument rating flight test. Performance measurement systems have been developed for the PCATD and for the Frasca. Two 180 hp Beechcraft Sundowner aircraft (BE-C23) which have a single engine, fixed-pitch propeller, and fixed under carriage will be used as aircraft for IPC#1 and IPC#2. Two flight data recording systems for the Sundowner aircraft were updated using the latest Wide Area Augmentation System (WAAS).). A technical report entitled *IPC Data Logger (a Flight Data Recorder):Operation Manual, Change 1*,(ARL-02-2/FAA – 02-1) was forwarded to the COTR February 13,2002. This report describes the updated system.

A pool of 166 instrument pilots have been recruited for the study. A total of 55 instrument pilots have started the study, and of these, 27 have completed the stud

Project Summary: Two flight data recording systems for the Sundowner aircraft were updated using the latest Wide Area Augmentation System (WAAS). The details of this update were documented in a technical report entitled *IPC Data Logger (a Flight Data Recorder):Operation Manual, Change 1*, (*ARL-02-2/FAA – 02-1),* which was forwarded to the Contracting Officer's Technical Representative (COTR) February 13,2002.

A mail survey to determine interest for participation in the study was mailed to all instrument pilots within a 75-mile radius of Champaign, IL. A total of 272 instrument pilots responded with a statement of interest. A Pilot Experience and Biographical Data Questionnaire which collected information about the pilot's experience and instrument currency status (see Appendix I in the semi-annual report dated April 10, 2002) was mailed to the 272 instrument pilots who expressed interest. A total of 204 pilots returned the questionnaire. Of these 272 instrument pilots, 166 are considered available for the study. A total of 82 pilots are current, 10 are within 1 year of currency, 30 are between 1-2 years and 44 are 2 years or more out of currency. These pilots form the pool of potential subjects for the study.

A cognitive task analysis was performed to investigate the areas where check pilots would most benefit from objective pilot performance measures. The analysis consisted of a questionnaire, which asked the check pilots to rate each element in each segment of an IPC flight by its (1) difficulty to observe, (2) criticality for overall evaluation of pilot proficiency, and (3) its sensitivity to differentiate between good and poor pilot performance. The results showed that while there were substantial differences between the experienced and inexperience instructors' ratings, the "top ten" elements in each category were in close agreement. The efforts to develop objective performance measures will concentrate on these maneuvers and maneuver elements.

As of September 30, 2002 a total of 55 instrument pilots had started the study. A total of 226 pilots have been scheduled for all types of sessions. The following table shows the sessions run as of 9/30/2002:

Sessions Run:

Air-fam*	44
PCATD-fam*	41
Frasca-fam*	41
IPC#1	32
IPC#2	27
P-Training	15
F-Training	25
A-Training	1
All	226

types:	
# of Subjects Started	55

Familarization (fam)

Of the 226 sessions completed, there have been 126 familiarization (fam) flights, (44 airplane fam flights, 41 PCATD fam flights and 41 Frasca fam flights). Thirty-two subjects have completed the IPC # 1 flight, and 27 subjects have completed the IPC #2 flight. When the pilots complete the IPC#2 flight they have completed the study. There have been a total of 41 training flights.

Scientific and Technical Objectives: To maintain instrument currency, instrument pilots must track courses, complete six approaches and perform instrument holding procedures every six months. This recency of experience may be performed under either simulated or actual instrument meteorological conditions (IMC)to satisfy the requirement. The simulated recency of experience requirements may be conducted in an airplane or an approved FTD with a Certified Flight Instructor, Instrument (CFII). If an instrument pilot fails to meet the recency of experience requirements within the six-month period, the requirements can be met within the following six months to regain instrument currency. If an instrument pilot fails to meet recency of experience requirements within a 12-month period, an instrument proficiency check (IPC) must be accomplished with a CFII for the pilot to regain instrument currency.

The specific objective of the project is to compare instrument pilot performance of an IPC performed in a PCATD, a FTD, and an airplane (IPC #1) with a second IPC in an airplane (IPC #2) to evaluate the effectiveness of the PCATD and the FTD in conducting an IPC flight. Parallel to these efforts, the project will develop and analyze performance measures derived from an airborne Flight Data Recorder (FDR) as well as from similar data from the PCATD and FTD. These measures will allow us to examine in detail various aspects of pilot performance and identify particular strengths and weaknesses associated with the particular training devices.

The study will directly compare the performance of pilots receiving an IPC in a PCATD, a Frasca FTD or an Airplane (IPC #1) with the performance of pilots in an airplane (IPC #2). The comparison of performance in a PCATD to that in an airplane will investigate the effectiveness of the PCATD as a device in which to administer an IPC. Currently, the PCATD is not approved to administer IPCs. The comparison of performance in a Frasca and the airplane will determine whether the current rule to permit IPCs in a FTD is warranted. Finally, we will compare the performance of pilots receiving IPC #1 in an airplane and IPC #2 in an airplane with a second Certified flight instructor, instruments (CFII). This comparison will permit the determination of the reliability of IPCs conducted in an airplane. Comparison of the PCATD, Frasca FTD, and airplane as an IPC platform is contingent on measures of pilot performance. In addition to the CFII scores (on the dichotomous pass/fail scale), we will evaluate the subjects' performance on the IPC in their respective devices based on objective and quantitative performance measures, derived from data recorded by the FDR or the training devices (FTD and PCATD

Technical Approach:
Subjects. A total of 105 subjects are scheduled to be used in the study (35 subjects in each group; FTD, PCATD and airplane). Based on past experience, some subjects will fail to complete the study. Consequently, we plan to recruit additional instrument pilots above the desired 105. The pilots fall into one of three categories of instrument currency: 1) instrument current; 2) within one year of currency; and 3) outside of one year of currency but within two years of currency. The subjects will receive a familiarization flight in the FTD, the PCATD and the airplane prior to being assigned to an experimental group. A randomization process is being used to balance the order of the familiarization flights. Following the familiarization flights, subjects will be assigned to one of the three groups (FTD, PCATD and airplane) with a constraint that the three currency categories are balanced among the groups.

The following outlines a modified approach to subject assignment. Since our goal is to maximize the balance on the subject currency factor, we will recruit subjects who are instrument current initially and use the table below as an assignment matrix. Each replication has the six possible assignment orders given the three experimental groups (PCATD, Frasca, Airplane).

PCATD= P
Frasca= F
Airplane= A

Replication	1	2	3	4	5	6
	PFA	FAP	APF	PAF	FPA	AFP
	FAP	APF	PAF	FPA	AFP	PFA
	APF	PAF	FPA	AFP	PFA	FAP
	PAF	FPA	AFP	PFA	FAP	APF
	FPA	AFP	PFA	FAP	APF	PAF
	AFP	PFA	FAP	APF	PAF	

Equipment. Two FAA approved PCATDs and one FAA approved Frasca 141 FTD with a generic single-engine, fixed gear, fixed pitch propeller performance model are being used in the study. Performance measurement systems have been developed for the PCATD and for the Frasca. The FTD is approved for instrument training towards the instrument rating, instrument recency of experience training, and IPCs as well as for administering part of the instrument rating flight test. Two 180 hp Beechcraft Sundowner aircraft (BE-C23) which have a single engine, fixed-pitch propeller, and fixed under carriage will be used as aircraft for IPC#1 and IPC#2. Two flight data recording systems for the Sundowner aircraft have been updated using the latest Wide Area Augmentation System (WAAS).

Procedure. The 105 pilots participating in the study will receive a VFR familiarization flight in each of the following: FTD, PCATD and airplane. They also receive a review of the aircraft systems and instrumentation in each device. Following the familiarization flights, subjects will be randomly assigned to one of the three groups (FTD, PCATD and airplane) with a constraint that the three currency categories will be balanced among the groups. All instrument pilots receive a baseline IPC flight in either the FTD, PCATD and airplane (IPC#1) according to which group they are assigned. IPC#1 is flown with a CFII who acts both as a flight instructor and as an experimental observer.

The subjects will be given an IPC in their respective equipment (IPC #1) and then all subjects will be given a second IPC in the airplane (IPC #2). The subjects will be required to refrain from instrument flight following IPC #1 until IPC #2 is completed. They must also agree not to use a PCATD or a FTD for instrument training during this period. Some potential subjects who are more than two years out currency may require training to prepare them for the IPC. We will provide an average of six hours training equally distributed among the FTD, PCATD and airplane to prepare them for the IPC. Table 1 depicts the experimental design in greater detail.

Table 1: Experimental Groups and Sessions

Sessions

GROUP	Familiarization Flight	Initial IPC flight (IPC#1)	Final IPC flight (IPC#2)
Airplane	In Sundowner	IPC flight in Sundowner	IPC flight in Sundowner
Frasca	In Frasca	IPC flight in Frasca	IPC flight in Sundowner
PCATD	In PCATD	IPC flight in PCATD	IPC flight in Sundowner

The IPC is a standardized test of the instrument pilot's instrument skills. The types of maneuvers, as well as completion standards for an IPC, are listed in the instrument rating practical test standards (PTS) (U.S. Department of Transportation, 1998). A flight scenario, that follows the current guidelines for the flight maneuvers required by the PTS, is used for the IPC. This scenario is used to collect baseline data and to establish the initial level of proficiency for each subject who participates in the project.

The IPC #1 flight contains seven maneuvers (VOR approach, holding pattern, steep turns, unusual altitude recovery, ILS approach and ATC procedures, communication and a partial-panel non-precision approach). The CFIIs for the IPC#1 flight use a form that was designed to facilitate the collection of three types of data (Phillips, Taylor, Lintern, Hulin, Emanuel, & Talleur, 1995). First, within each maneuver there are up to 24 variables (e.g., altitude, airspeed) which are scored as pass/fail indicating whether performance on those variables met PTS requirements. Second, the flight instructor judges whether the overall performance of the each maneuver was pass/fail. Third, the CFII records if the overall performance of the subject met the PTS for the IPC.

The instructors who administer the IPC#1 flight have been standardized on the scenario to be flown and the scoring procedure. After a period, not to exceed two weeks, all subjects fly a final IPC (IPC#2) in the aircraft to assess instrument proficiency. IPC#2 is conducted by a different CFII than IPC#1, and the CFII for IPC#2 is blind to both the group to which the subject belongs and to the subject's performance on IPC#1. In terms of maneuvers, IPC#2 is identical to IPC#1. This final session contains all required maneuvers that a pilot must satisfactorily complete in order to receive an endorsement of instrument proficiency. Completion of IPC#2 marks the end of a subject’s involvement in the experiment.

Results: The percentage of instrument pilots who have failed IPC#1 has exceeded the expected percentage. There has been no difference between groups. The number of subjects is not adequate to draw any conclusions at this time.

Impact/Applications: This study will provide information concerning the effectiveness of a PCATD, an FTD and an airplane in conducting instrument proficiency flights. It will also provide data concerning the proficiency of instrument current pilots.

An analysis of the data collected as of 9/30/2002 is shown in the following table.

		IPC#1					IPC#2			
Group	N	Pass	%	Fail	%	N	Pass	%	Fail	%
Aircraft	*9*	2	22%	7	78%	*8*	3	38%	5	62%
FTD	*10*	2	20%	8	80%	*8*	4	50%	4	50%
PCATD	*12*	2	17%	10	83%	*11*	5	45%	6	55%

		IPC#1					IPC#2			
Currency	N	Pass	%	Fail	%	N	Pass	%	Fail	%
Current	*26*	7	27%	19	73%	*25*	8	32%	17	68%

Within 1 year										
Within 1-2 years										
2-5 years (Frasca)	*2*	0	0%	2	100%	*1*	0	0%	1	100%
2-5 years (PCATD)	*3*	0	0%	3	100%	*2*	2	100%	0	0

		IPC# 2 Pass	Fail	Total
	Pass	1	5	6
IPC# 1	Fail	10	11	21
	Total	11	16	

<u>Technology Transfer</u>: none

<u>Journal Articles</u>: none

<u>Books or Chapters</u>: none

<u>Technical Reports</u>: Lendrum,L. Taylor, H.L., Talleur, D.A., Emanuel.T.W., Jr. IPC Data Logger (A Flight Data Logger) Operations Manuel, Change 1.*Technical Report ARL-02-2/FAA-02-1*, February, 2002. Savoy, IL.

<u>Conference presentations/abstracts</u>: none

<u>Conference Papers:</u> none

<u>Conference Abstracts:</u>

Emanuel, T.W., Jr., Taylor, H. L., Talleur, D.A., and Rantanen , E. M. (2002). Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device, and an Airplane in Conducting Instrument Proficiency Checks. *Research Roundtable, University Aviation Association Annual Meeting*, Orlando, FL., September 13, 2002.

<u>Patents Issued or Pending</u>: none

<u>Honors:</u> none

<u>Related Projects</u>: none

Appendix II

Human Factors General Aviation Research Requirements

Research requirements exist in the AAR-100 interactive management database that allows program managers to track research requirements for each Federal Aviation Administration sponsor.

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Requirement ID: 872

Sponsor Organization: ACE POC: Jeff Holland

Requirement Title: Capstone Phase II Usability Assessment

Funded Requirement:

- FY02:
- FY03:
- FY04:
- FY05:

Requirement Statement: The Capstone Program is in the process of equipping 150-200 aircraft in the Juneau, Alaska with advanced avionics as a mitigation strategy for CFIT, mid-air collisions, and bad weather avoidance. The avionics that will be installed in the aircraft in the Juneau area is similar to that which was installed in the Bethel area except that this avionics suite will include a primary flight display (PFD) along with a similar multifunction display that is currently installed in the aircraft operating in Bethel, AK. The primary flight displays include a standard presentation of air data (airspeed, altitude, etc) seen on most other PFDs. However, the Capstone displays shall include a perspective view of terrain, a "highway-in-the-sky" depiction for navigation guidance, and traffic. The installation will be unique in that low to medium end aircraft having previously equipped with analog gauges and dials will be retrofitted with a "glass panel" display system and certified for IFR operations. The research question that is being asked is what is the impact of this avionics on the flight operations in the Juneau area. Within that question, their sub-questions that will be investigated surrounding training adequacy, equipment usability, and the overall effectiveness of the avionics.1292

Background: In an effort to improve flight safety in Alaska, the Federal Aviation Administration (FAA) has been conducting an assessment of new cockpit avionics for general aviation (GA) aircraft. The assessment is being performed under the FAA's Alaska Capstone Program. Phase I of the program focused its efforts in and around the town of Bethel, located in the southwest region of the state. The avionics system, developed by UPS Aviation Technologies, consists of a multi-function display unit, the Apollo MX-20, and an accompanying Global Positioning System (GPS) display, an Apollo GX-60. Phase II of the Capstone Program is currently ramping up in the Southeast corner of Alaska, centered around the city of Juneau. Phase II avionics consist of both a combination moving-map/flight planning display, similar in capability to the Phase I display, and a primary flight display that includes a perspective terrain, highway-in-the-sky and traffic. The Phase II displays will be certified for IFR operations as well. Since this is the first implementation of these types of display in a real-world setting, and using a large number of aircraft, research is needed to look at the usability and effectiveness of these displays. Certification and training requirements need to be established, and human factors issues regarding these displays need to be identified.

Output: Two research objectives are proposed for this effort. The first research objective is to travel to the Juneau area and interview pilots using the Capstone Phase II equipment. Instruments will be developed to collect information from the pilots regarding training and human factors issues, and to assess the use of the displays in an operational environment. Quarterly visits are proposed so that information can be collected across a range of environmental conditions. The second research objective is the performance of a usability study in a simulated environment. A flight research simulator will be used so that off-nominal conditions (i.e., high workload) can be introduced to the pilot without endangering the safety of the pilot. In addition, single-pilot operations can be studied across a range of pilot experience levels to see the effect of these displays on the general pilot population. Data collected from both of these research efforts will be analyzed and summarized in a set of reports. These reports will detail human factors, training, and safety issues related the use of these displays. Information from these reports will be used to establish training and design guidelines for the displays.

Regulatory Link: Human Factors Issues for ADS-B Applications, Volume 4: Flight Safety, Revision A

Requirement ID: 615

Sponsor Organization: AFS POC: Mike Henry

Requirement Title: Casual factors of accidents and incidents attributes to human error

Funded Requirement:

- FY02: Yes
- FY03: Yes (modified requirement)
- FY04:
- FY05:

Requirement Statement: This requirement objective is to use identify potential data sources to identify causes of general aviation human error accidents as well describe potential remedies. The outcome of the research should be to develop and standardize methodologies for identifying, defining, and monitoring human error based incidents and accidents.330

Background: Intent is to provide better recording of human factors aspects of accidents so that subsequent analyses can more accurately depict the true underlying causal factors.

Output: Develop and validate a standardized methodology for conducting accident investigation in which human error is cited as the cause or contributor to the accident. This effort must produce a product that does a much better job in the assessment of incidents attributable to human error in the cockpit/flight deck.

Regulatory Link: a. Supports Safer Skies through Areonautical Decision Making (ADM) JSAT b. AOA (FAA) Strategic Plan (1998-2003) Mission Goal:Safety. Key Strategies "to enable the goal to include identification of root causes of past accidents; and (2) use a more proactive analytical approach, with new data sources, to identify key risk factors and intervene to prevent potential causes of future accidents" (Page 13). c. FY2001 Performance Plan: Focus Area: Accident Prevention. "Aviation Human Factors to coordinate human factors research, development and based on detailed causal analysis" (Page 2) d. AVR Performance Plan:Reduce General Aviation fatal accidents (pg 2). Contribute to aviation safety by developing policies,standards, programs, and systems to reduce the number of aviation accidents and incidents related to human factors (pg 9)

Requirement ID: 613

Sponsor Organization: ACE POC: Jeff Holland

Requirement Title: CFIT/Terrain Displays

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: purpose of this research is to address CIT issues which were identified by the JSIT team. Research will focus on various countermeasures to include training, technology, and science-based regulations to significant reduce the occurrence of general aviation CFIT accidents.272

Background: Project Entails: Controlled flight into terrain (CFIT) accidents have been cited as one of the leading causes of fatalities for general aviation (GA) flyers. A CFIT accident occurs when an airworthy aircraft, under control of a pilot, is flown into terrain, including water or obstacles, with inadequate awareness on the part of the pilot of the impending accident. In response to the high rate of occurrence and fatalities, the FAA formed a Joint Safety Analysis Team to investigate the causes of GA CFIT accidents. The team analyzed over two hundred reported CFIT accidents for a two-year period (1996-1997). The team identified numerous casual factors that contributed to the occurrence of the accidents. Considering these casual factors, the team developed 55 intervention strategies that had some potential to mitigate the casual factors. One of the most effective strategies identified by the team was the installation and use of horizontal and vertical situation awareness displays. Manufacturers have been developing and marketing horizontal and vertical situation awareness displays for quite some time. The quality of the displays varies significantly. However, with the more recent advent of less expensive and higher quality color displays, there has been a significant increase in the quantity and sophistication of these systems. Unfortunately, the designs seem to be more driven by intuition, supposition and marketability than by data. The effectiveness of some of these systems to prevent CFIT accidents is at best questionable. Research needs to be conducted to determine the minimal amount and type of information that should be presented to develop adequate situation awareness to avert CFIT related accidents. There are a number of key issues that need to be addressed: „h Horizontal Situation Displays versus Vertical Situation Displays versus Both „h Benefits/Detriments for 2-D & 3_D Displays „h Minimum Display Size „h Minimum Level of Detail and Quality of Terrain Depiction, „h Type and Form of Displayed Position-Terrain Information „h Color Application Philosophy (darker colors for lower elevations), „h Desired Visual/Audio Alerts. „h Most Appropriate and Effective Cues to Alerting Pilot of an Impending Situation „h Methods of

Operation „h Appropriate Use of Such Systems The information from this research could be used by the CFIT JSIT to weigh and prioritize implementation strategies. It could also serve as "best practices" guidance to manufacturers of position-terrain awareness systems, it could provide a measure to compare new systems against in terms of best practices and undesirable features.

Output:

Regulatory Link: a. AOA (FAA) Strategic Plan (1998-2003) - Mission Goal: Safety. By 2007, reduce U.S. aviation fatal accident rates by 80 percent from 1996 levels (pg. 13). Focus areas: Accident Prevention, General Aviation Initiative addresses CFIT, weather, runway incursions, loss of control, and decision-making (pg. 14). b. FAA FY2000 Performance Plan - Reduce the General Aviation Fatal Accident Rate (pg.16). c. AVR Performance Plan - Goal B-1, reduce fatal aviation accident rate attributed to human error.

Requirement ID: 767

Sponsor Organization: AFS POC: Mike Henry

Requirement Title: Credit for Instrument Rating in a Flight Training Device

Funded Requirement:
- FY02: Yes
- FY03: Yes
- FY04: Yes
- FY05: Yes

Requirement Statement: This information is required for the revision of FAR 61-141, specifying the credit hours for which various Flight Training Devices (FTDs) may be used in lieu of actual flight.175

Background: Modern flight training devices provide a more effective and safe training experience than aircraft. Instructor and student discuss, perform, and review specific maneuvers in a quiet environment, without the distractions of danger of other aircraft, weather, etc. FTDs provide emergency procedures often not posible in an aircraft. Further, the quality of flight training will be more uniform if the most credit is reserved for the most capable devices, and less credit granted for less capable machines. By adjusting the flight credit allowance per the varying capabilities of FTDs, the FAA shows that it recognizes qualitative differences inthe training experience. It is anticipated that a regulation change may provide incentive for further FTD development and use, and an increase in training effectiveness and efficiency. SubTasks: a. Evaluate all seven levels of FTDs, recategorizing them as necessary by shared characteristics (i.e., fidelity fo physical/visual/flight replication) b. Develop a system for measuring and recording a range of pilot performance within the areas of aircraft handling, navigation, and emergency procedures. c. Measure the performance levels of students from each of the seven FTD categories. d. Determine the pont at which performance levels in an aircraft meet pilot certification standards???

Output: Final report that provides guidance as to what specific maneuvers (initial private and initial instrument training) can be completed in the FTD and/or PCATD in lieu of flight time. Provide guidance as to whether FTD and/or PCATD can be used for recurrent training and instrument proficiency checks in lieu of flight time.

Regulatory Link: none

Requirement ID: 681

Sponsor Organization: AFS POC:

Requirement Title: Develop HF methodology for GA certification issues

Funded Requirement:
- FY02: No
- FY03: No
- FY04:
- FY05:

Requirement Statement: Develop methods of compliance to existing rules by establishing evaluation methodology for human factors design criteria.Analyze existing human factors guidelines e.g. GAMA publication No. 10, RTCA Moving Map MOPS, TSO for GPS equipment, etc. and establish appropriate evaluation methodologies for those recommended practices.326

Background: The method of showing compliance with human factors-related regulations often involves the collection and analysis of pilot subjective data. Frequently, one or more pilots will evaluate aspects of the crew interface and determine whether, in their opinion, it met or did not meet the regulatory requirements. The approaches and procedures used by evaluation pilots to conduct these evaluations differ significantly in structure, form, and content. In some cases, pilots will simply sit in the cockpit and look around at the different areas for problems. Other pilots will use a more structured, line-oriented flight training approach that simulates the performance of flight-related tasks for the evaluation. Additionally, based on pilot individual differences, particularly in the areas of experience and training, some system aspects may be closely scrutinized while other areas may be completely overlooked. Consequently, the results and conclusions derived from these different approaches and individuals can vary considerably. Recommendation: Structured, detailed subjective pilot evaluation methods need to be developed to ensure evaluations are comprehensive and effective. In particular, subjective evaluation approaches need to be developed to show compliance with Part 23 human factors-related regulations: 23.771, 23.773, 23.777, 23.779, 23.1301, 23.1311, 23.1321, 23.1322, 23.1331, 23.1367, 23.1381, and 23.1523. Research should be conducted to:· identify approaches that have been historically used to conduct such subjective evaluations,· determine the merits and etriments of these different approaches, and . develop and validate an approach that may be used by te FAA and applicants to conduct means of compliance evaluations for the aforementioned regulations.

Output:

Regulatory Link: none

Requirement ID: 860

Sponsor Organization: AIR POC: Colleen Donovan

Requirement Title: Developing And Validating Criteria for Constraining False & Nuisance Alerts For Cockpit Display Of Traffic Information Avionics

Funded Requirement:
- FY02: Yes
- FY03: Yes
- FY04: No
- FY05:

Requirement Statement: The objective of this project is to develop and validate criteria for constraining false and nuisance alerts for cockpit displays of traffic information (CDTI), based on what is known about other alerting algorithms and human performance issues with alerting systems, trust, situation awareness and workload. Where objective criteria are not possible, subjective means may be recommended provided they are established to be reliable and valid measures. These criteria are to be included as minimum requirements in the RTCA Minumum Operational Performance Standards document or an FAA Technical Standard Order for CDTI. Both of these documents are used by avionics manufacturers to develop their systems, and FAA aircraft certification specialists who evaluate the systems. The project should be focused on developing these objective and subjective measures as minimum certification criteria, based on research and data, for approving the Free Flight technologies known as Cockpit Displays of Traffic Information (CDTI). The CDTIs may be either stand-alone units or as part of an integrated ADS-B CDTI/Traffic Collision Avoidance System (TCAS).1148

Background: It can be argued that the efforts to modernize the NAS and enhance both capacity and safety of the nation's air transportation system are presently technology-driven and that human factors contributions to these efforts have fallen behind the demand. The reason for this situation is apparent: The task environments in which the personnel ultimately responsible for the safe and efficient functioning of the NAS (i.e., pilots, airline dispatchers, air traffic controllers and –managers) work have increased in complexity with increase in automation applications. Consequently, scientific investigation of the impact of new technologies has become increasingly difficult due to the escalating number of variables and their interactions in the present operational environments and the shift from overt performance (i.e., manual control) to predominantly covert behavior (i.e., supervisory control) of the operators. Several constructs that attempt to describe the complex and mostly covert behaviors have been introduced. The most significant of these is situation awareness (SA), but trust and workload associated with automation are of concern as well. The measurement of these constructs is problematic, yet of critical importance. May want to insert something here talking about the numerous problems with alerting systems and false alerts- impact on human performance- pilots turn them off, ignore them (boy who cried wolf) etc. This research will span a period of three years, with three distinct phases. Each phase may be considered individually for support, but the latter phases will depend on successful completion of the previous phases. Phase 1 and the first year efforts will focus on data gathering and understand how similar issues were solved with other flight deck alerting systems, such as TCAS, enhanced ground proximity warning systems (EGPWS) and wind shear alerts. This phase will include exhaustive review of the certification standards, requirements and guidelines related to false alerts and alerting criteria published in RTCA MOPS and TSOs for the systems mentioned above. The background and basis for the currently published standards should also be examined, as well as research literature pertaining to human performance issues with alerting systems associated with situation awareness, trust, and workload. The interactions of these constructs will also be examined, with an objective of identifying common underlying structures or mechanisms. This will include a review and evaluation of the Aviation Safety Reporting (ASRS) literature associated with TCAS problems, as well as other TCAS issues in order to uncover lessons learned. Special emphasis will be paid to the three “key references” listed at the end of the paper, as a potential means to develop certification standards to enable the evaluation of traffic collision alerting systems (e.g., CDTI ADS-B, TIS, and TCAS). These key reference papers propose the use of Signal Detection Theory (SDT) methodology as a means to evaluate alerting systems and separate the impact of various decision biases. SDT can be used to study the impact of changes to the decision threshold, and also the impact of changes to the a priori base rate events in the real world. The authors of these key references establish the importance not only of high hit rates and low false alarm rates, but also of the importance of high posterior probabilities of a true alarm. Additionally, they also propose a means to access the impact of these changes, despite the fact that only a handful of airplanes are equipped with ADS-B/CDTI systems, and thus it is difficult to determine the base rate information for these events, which is required to determine the posterior probabilities. Thus, one path of pursuit towards objective criteria to evaluating the CDTI alerting system is by attempting to apply the methodologies proposed and developing recommended certification criteria for the alerting systems hit rates, false alarm rates, and posterior probabilities. This methodology may prove effective in developing objective criteria for evaluating the appropriateness of an alerting system on the “trust/use/misuse/abuse” dimension. Additional methodologies and criteria would need to be developed to evaluate the situation awareness and workload dimensions.

Output: Year 1 1. Documentation review: a) empirical human factors results relevant to alerting systems, available in the public domain (journal articles, conference proceedings, and government reports); b) certification standards, requirements and guidelines related to false alerts and alerting criteria published in RTCA MOPS and TSOs for cockpit alerting systems; c) comparison of the alerting algorithms of TCAS, CDTI, CA, and URET and examination of their congruence with pilots' and controllers' tasks and mental models; d) previous ASRS analyses on alerting system related incidents to determine if yet another ASRS analysis is warranted; e) literature on human factors certification for guidelines for development of certification criteria for CDTIs; f) identification of other data sources (e.g., from demonstrations and simulations or from operational environments) that would allow for further examination of relevant human factors issues outside of a laboratory. 2) Examination of the roles of cockpit alerting systems. This subtask will examine the roles of a number of automatic alerting systems (GPWS, TCAS, wind shear alert) and the impact of these on the respective certification criteria of the alerting systems. 3) Development of measures and criteria for collision avoidance system evaluation. This subtask involves a comprehensive evaluation of available measures of machine, human, and human-machine system performance as they pertain to collision avoidance systems, identification of primary and secondary measures, and evaluation of empirical support for the latter. We will also examine possible sources and justification for criteria for the measures. 4) Develop designs and protocols for experiments. Based on findings from the literature review, we will develop experimental designs and protocols aimed at investigation of the most critical issues relevant to human factors certification of CDTIs and to address possible controversies in the alerting system literature. 5) Conduct Experiment 1. The goal of this component of the project is be to develop a cognitive model of the features of unaided conflict prediction, that is, pilot prediction made without the aid of intelligent automation.

Regulatory Link: none

Requirement ID: 871

Sponsor Organization: ACE POC: Jeff Holland

Requirement Title: Effectiveness of ADS-B Displays for Part 91 VFR Pilots

Funded Requirement:

- FY02: No
- FY03: No
- FY04:
- FY05:

Requirement Statement: Interviews with the Bethel, AK pilots using the government provided advanced navigation displays incorporating automatic dependent surveillance – broadcast (ADS-B) has provided significant insight into the impact of this technology on their flight operations. The impact has been mostly positive while some system features have been identified as needing improvement. This information will assist in the transition of this kind of technology to the rest of the country. Pilots participating in the Capstone I project were all Part 135 pilots, flying almost every day of the year. The majority of these pilots fly over 100 hours each month. Ninety-five percent of these pilots are instrument rated. However, less is known about the impact of this kind of technology on the Part 91 pilot population. Part 91 pilots fly much less often and a significant portion of this population does not have an instrument rating. In addition, the Part 91 population is a diverse population having a wider range of total flight experience and ages. Research is needed to establish the impact of these displays on the Part 91 pilot population, specifically low-hour, VFR pilots. The research from this study will attempt to identify potential human factors issues which should be considered during the development of future displays.1323

Background: In an effort to improve flight safety in Alaska, the Federal Aviation Administration (FAA) has been conducting an assessment of new cockpit avionics for general aviation (GA) aircraft. The assessment is being performed under the FAA's Alaska Capstone Program, which has focused its efforts in and around the town of Bethel, located in the southwest region of the state. The avionics system, developed by UPS Aviation Technologies, consists of a multi-function display unit, the Apollo MX-20, and an accompanying Global Positioning System (GPS) display, an Apollo GX-60. In addition, each aircraft is equipped with a Universal Access Transceiver (UAT), which is a remote-mounted (i.e., outside of the cockpit) radio that provides datalink communication between the aircraft and a ground station or from one aircraft to another like-equipped aircraft. Participants in the assessment are Part 135 airline operators and pilots in the Bethel area. Approximately 150 GA aircraft have been equipped with the advanced avionics equipment. The Capstone displays provide pilots with a moving-map display that shows ownship (display of own aircraft) position, traffic, weather, and planned route of flight. Despite the excellent information collected from the Capstone Program to date, several questions remain unanswered. One of these questions is the impact of this kind of display on pilots that do not fly for a living. Most Part 91 pilots fly fewer hours, vary widely in their level of training and experience, and do not consistently maintain their flight skills. These factors can alter the effectiveness of these displays for maintaining situation awareness and safety.

Output: The proposed research will look at the effectiveness of ADS-B displays for Part 91 pilots. The research will focus on pilots that are only VFR rated and include a wide range of total flight hours and ages. Other studies have already addressed IFR, higher time pilots. Pilots will evaluate the system while flying the CAMI research flight simulator. The simulation will include the use of the moving-map display, relative terrain information, and traffic information. Weather features will not be considered in this simulation due to technical constraints associated with simulation. Results of the research will document human factors issues relative to use of these displays by Part 91 pilots under low visibility conditions (still VFR) and under high workload conditions. Results of the research will help to define design guidelines for this kind of a display and help to define “adequate” training requirements for this population of pilots.

Regulatory Link: Human Factors Issues For ADS-B Applications, Volume 4: Flight Safety, Revision A

Requirement ID: 682

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Establish certification requirements for the use of helmet-mounted display technology in General Aviation

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: As new advanced technology is being transferred from military applications to general aviation environments there needs to be appropriate certifications standards developed to guide aviation system designers as well as FAA certification personnel. The research should examine existing standards and assure they are accurate for the GA environment as well identify any gaps and provide appropriate data to resolve these gaps.424

Background: Current technology now allows head-mounted displays to be used in ways that mimic head-up displays, but that are much more flexible and do not have line-of-regard or viewing-box limitations. Systems have already been deployed for military applications, and it is clear that the emergence of lower-cost options in this field are already being capitalized upon for entertainment and personal computing.Research is already being done in applications for the civil cockpit, and it will not be long before systems are being brought forward to be considered for certification to replace HUD devices. It is desirable that standards and certification requirements be in place prior to the first submissions rather than allowing the first device on the market to set the standards, avoiding the experiences already seen with the flood of multifunction displays that arrived on the scene recently. To this end this task will involve the examination of existing data on head-mounted devices with an emphasis on the behavioral/performance consequences of design variables. To the degree that data are not available for certain questions, experimentation will be employed to fill these gaps in knowledge and add to the body of data available for defining certification requirements. Certification methods using these data also need to be developed.

Output:

Regulatory Link: none

Requirement ID: 887

Sponsor Organization: AFS POC: Bob Wright

Requirement Title: FAA/Industry Training Standards (FITS)

Funded Requirement:

- FY02: No
- FY03: No
- FY04:
- FY05:

Requirement Statement: A number of people from industry, academia, and the Federal Aviation Administration believe that the general aviation training programs do not have the flexibility to adapt to the wide variety of aviation technology (e.g., GPS, multifunction displays with moving map navigation, and traffic, weather, and terrain avoidance systems) that has recently emerged in the national airspace. With older technology systems, it did not matter who built the system since they all functioned and looked similar. However, with new technology, systems that perform similar functions may not look alike and pilot interaction with these systems may be completely different. Consequently, a "one-size-fits-all" approach to training may no longer be adequate. FAA/Industry Training Standards (FITS) will attempt to overcome the limitations of existing training programs by working in collaboration with industry to develop new and innovative training methods to ensure that pilots are trained and maintain proficiency in aircraft that contain new technology. New training methods emphasize improved risk management, training and education, and proper use of new technology.1155

Background: Within the past five years, avionics manufacturers have developed a large number of general aviation products to improve pilots" situational awareness. Although these products are advertised to enhance safety and efficiency, there are a number of skeptics who question the utility of these products. In fact, many in the general aviation community believe that some of these aviation products are training intensive and present complex human factors issues that must be resolved to obtain the full safety benefits or, in some cases, to avoid creating new safety issues. The purpose of the FAA/Industry Training Standards (FITS) program will be to develop a flexible but robust general aviation training programs that can be tailored to integrate different technologies into any aircraft platform.

The FITS training program would be web-based documentation repository that would contain the FAA/Industry training standards most up-to-date information to support general aviation guidelines, standards and certification, and other materials. The FITS database would contain training standards for specific technologies by aircraft type. For example, a flight instructor preparing an instrument student would access the FITS website and select the instrument training module standard that matches the aircraft type and avionics installed in the aircraft. The FITS instrument-training program would contain real-world scenarios based on problem solving and case study examples with defined metrics for evaluation on aeronautical decision making, information management and risk management.

Output: Near term products:
Establish web site that will distribute FITS information, Establish template for FITS products, Publish Advisory Circular on FITS, Aviation safety inspector training and guidance, Designated examiner guidance.
Future Products:
Transition training, Type specific aircraft training, Type rating training, Special training (i.e. R-22, MU-2), Recurrent training, Currency requirements, Equipment training (i.e. GPS, HITS, MFD/PFD), Specific avionics equipment training, Ab-initio training for professional pilots, Ab-initio training for non-professional (enthusiast) pilots, First officer training, Designated examiner/FAA inspector training, Flight instructor renewal, Possible 14 CFR part 135 training

Regulatory Link: none

Requirement ID: 626

Sponsor Organization: AFS POC: Tom Glista

Requirement Title: General Aviation Training

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: This requirement outlines the need for a thorough review of general aviation training. Not only is research required to identify potential near-term training improvements that could immediately positive effect a reduction of general aviation accidents but also the research should address training implications of future GA systems such as SATS.345

Background: This research initiative will address General Aviation (GA) pilot training and required improvements that support increased pilot skills and a resultant reduced accident rate. The premise of the research is that improved airman training represents a near-term, cost-effective and meaningful method of intervention into the causative chain of events that have been identified as leading causes of GA accidents. It also suggests that new aircraft systems and capabilities providing traffic avoidance, direct routing, weather cockpit displays and other improved technologies will not be introduced in sufficient quantities in new aircraft or as retrofits to the current GA fleet in time to significantly reduce the accident rate by the year 2007. The research will directly support the AVR mission as articulated in their FY1999 Performance Plan as well as those issues addressed by the Safer Skies program. The research will also directly contribute to the FAA Strategic Plan and FY 2000 Annual Performance Plan whereby a reduction in the aviation accident rate has been identified as a major goal. Specifically, the training research will be designed to accomplish the following: • Reduce GA accident rates through improved pilot training, by focusing on areas identified as known, leading, causative accident factors (Safer Skies) • Ensure GA pilots are trained to fully utilize the capabilities of new aircraft systems as they retrofit and transition to those new systems • Ensure the development of new GA aircraft systems is conducted in consideration of the human factors and training issues involved • Support the development of appropriate airman evaluation and certification methods in consideration of new and emerging technologies. • Support on-going FAA initiatives including Safer Flight, Safe Flight 21 and other programs where reduced GA accident rates are included in program goals and objectives • Reduce the time and cost of ab initio airman certification while extending the amount of instrument training provided to all pilot applicants This research initiative will leverage the work previously accomplished under the NASA / FAA Advanced General Aviation Transport Experiment

(AGATE) program. It will address improved training technologies and techniques in today's (2000) GA operational environment as well as the probable attributes and characteristics of GA operations in the mid-term (2007) and far term (2024) where the new AGATE aircraft and the emerging Small Aircraft Transportation System (SATS) respectively will provide improved aircraft systems and NAS interface for improved flight safety. In addition, it supports the goals and objectives of the NASA Safety Program as it regards reduced GA accident rates. The research will focus initially on near-term training improvements where immediate positive effects on reducing the GA accident rate may accrue. This focus will include current aircraft systems and technologies, as well as current and projected pilot training methods, curriculum and airman evaluation practices. The emphasis here will be on the implementation of new training processes and methods that will reduce the GA accident rate without the introduction of new aircraft systems or technologies. This initial research is critical as the implementation and use of new aircraft systems will be an incremental effort until aircraft operating those systems represent a significant percentage of GA operations. Therefore, identifying and implementing near-term training and human factors improvements will be the best avenue in achieving any meaningful, near-term reduction in GA accident rates. We will specifically investigate new training in the areas of CFIT, weather, loss of control and pilot decision-making. Once a baseline of data is developed concerning today's GA training and operational environment, the research program will turn its attention to new aircraft systems identified for implementation in the AGATE aircraft including the Primary Flight Display (PFD), which includes the "Highway-In-The-Sky" virtual VFR system, the Multi-Functional Display (MFD), Single-Lever Power Control Systems and other increased capability. The research will identify the appropriate training and evaluation methods for these new systems to ensure full advantage is taken of their capability to reduce GA accident rates through improved pilot understanding and system familiarity. The research will additionally identify the training implications of the SATS system including the need to train pilots in the use of improved NAS information sharing and system interfaces (NAS 4.0 or better), as well as the operation of new "smart" airports and aircraft systems. The identification, development and implementation of new, improved aircraft systems and technologies, as well as improved NAS system interfaces and support capabilities, will provide the basis for reduced GA accident rates. The effectiveness of these new systems however, and the ability to achieve reduced accident rates in today's GA operational environment, will only be realized if improvements and innovation in training methods and procedures accompanies the technical systems effort. Without such emphasis, the effectiveness of new systems will be severely reduced and near-term accident rates may continue at the same level for years to come.

Output:

Regulatory Link:

Requirement ID: 868

Sponsor Organization: AFS POC: Mike Henry

Requirement Title: Human error and general aviation accidents: A comprehensive, fine-grained analysis using HFACS

Funded Requirement:

- FY02: previously "Causal factors of accidents and incident attributed …"
- FY03: Yes
- FY04:
- FY05:

Requirement Statement: The Human Factors Analysis and Classification System (HFACS) is a theoretically based tool for investigating and analyzing human error associated with aviation accidents and incidents. Previous HFACS research performed at both at the University of Illinois and the Civil Aerospace Medical Institute (CAMI) has been highly successful and has shown that HFACS can be reliably used to analyze the underlying human factors causes of both commercial and general aviation accidents. Furthermore, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents. Key members of the FAA (e.g., AFS-800) and several committees chartered to address general aviation safety (e.g., Aeronautical Decision Making (ADM) JSAT and the General Aviation Data Improvement Team (GADIT)) have acknowledged the added value and insights gleaned from these HFACS analyses. However, these individuals and committees have directly requested that additional analyses be done to answer specific questions about the exact nature of the human errors identified, particularly within the context of general aviation. The purpose of the proposed research project, therefore, is to address these questions by performing a more fine-grained HFACS analysis of the individual human causal factors associated with fatal GA accidents and to assist in the generation of possible intervention programs.1453

Background: Humans by their vary nature make mistakes; therefore it is unreasonable to expect error-free human performance. It is no surprise then, that human error has been implicated in a variety of occupational accidents, including 70% to 80% of those in civil and military aviation (O'Hare, Wiggins, Batt, & Morrison, 1994; Yacavone, 1993). In fact, while the number of aviation accidents attributable solely to mechanical failure have decreased markedly over the past 40 years, those attributable at least in part to human error have declined at a much slower rate (Shappell & Wiegmann, 1996). It appears that interventions aimed at reducing the occurrence or consequences of human error have not been as effective as those directed at mechanical failures. Clearly, if accidents are to be reduced further, more emphasis has to be placed on the genesis of human error as it relates to accident causation.

The predominant means of investigating the causal role of human error in aviation accidents remains the analysis of accident and incident data (Shappell & Wiegmann, 1997). Unfortunately, most accident reporting systems are not designed around any theoretical framework of human error. Indeed, most accident reporting systems are designed and employed by engineers and front-line operators with limited backgrounds in human factors. As a result, these systems have been effective at identifying engineering and mechanical failures, whereas the human factors component of these systems are generally narrow in scope. Furthermore, even when human factors are specifically addressed, the terms and variables used are generally ill defined and the data structures poorly organized. Postaccident databases are therefore not conducive to a traditional human error analysis, making the identification of intervention strategies onerous (Wiegmann & Shappell, 1997).

What is required therefore, is a general human error framework around which new investigative methods can be designed and existing postaccident databases restructured. However, previous attempts to apply error frameworks to accident analysis have met with encouraging, yet limited, success (O'Hare et. al., 1994; Wiegmann & Shappell, 1997). This is due primarily to the fact that performance failures are influenced by a variety of human factors that usually are not addressed by traditional frameworks. With few exceptions (e.g., Ramussen, 1982), human error taxonomies do not consider the potential adverse mental and physiological condition of the individual (e.g., fatigue, illness, attitudes, etc.) when describing errors in the cockpit. Furthermore, latent errors committed by officials within the management hierarchy, such as line managers and supervisors are often not addressed, even though it is known that these factors directly influence the condition and decisions of pilots (Reason, 1990). Therefore, if a comprehensive analysis of human error is to be conducted, a taxonomy that takes into account these multiple causes of human failure must be offered.

A comprehensive Human Factors Analysis and Classification System (HFACS) has recently been developed to meet these needs (see Figure 1). This system, which is based upon Reason's (1990) model of latent and active failures addresses human error at each of four levels of failure: 1) unsafe acts of operators (e.g., aircrew), 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences. The HFACS framework was originally developed for the U.S. Navy and Marine Corps as an accident investigation and data analysis tool. Since its original development however, HFACS has been employed by other military organizations (e.g., U.S. Army, Air Force, and Canadian Defense Force) as an adjunct to preexisting accident investigation and analysis systems. To date, the HFACS framework has been applied to over 1,000 military aviation accidents yielding objective, data-driven intervention strategies while enhancing both the quantity and quality of human factors information gathered during accident investigations (Shappell & Wiegmann, 2001).

Other organizations such as the FAA and NASA have explored the use of HFACS as a complement to preexisting systems within civil aviation in an attempt to capitalize on gains realized by the military. These initial attempts, performed both at the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably used to analyze the underlying human factors causes of both commercial and general aviation accidents (Shappell & Wiegmann, 2001; Wiegmann & Shappell, in press). Furthermore, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents. Indeed, AFS-800, the Aeronautical Decision Making (ADM) JSAT and the General Aviation Data Improvement Team (GADIT) have acknowledged the added value and insights gleaned from these HFACS.

To date, however, these initial analyses using HFACS have generally been performed at a global level and several questions remain concerning the underlying nature and prevalence of different error types. In fact, AFS-800, the ADM JSAT, and the GADIT committees have directly requested that additional analyses be done to answer specific questions about the exact nature of the human errors identified, particularly within the context of general aviation. Some of these questions are:

1. What are the exact types of errors committed within each error category? In other words, how often do skill-based errors involve stick-and-rudder errors, verses attention failures (slips) or memory failures (lapses)?

2. How important is each error type, or how often is each error type the “primary” cause of an accident? For example, 80% of accidents might be associated with skill-based errors, but how often are skill-based errors the “initiating” error or simply the “consequence” of another type of error, such as decision errors?

3. How do the different error types relate to one another, or with other HFACS variables? Are there connections between the categories that, if known, could improve intervention development?

4. Do accidents that occur in different geographical regions or training facilities within the U.S. have different error patterns or trends?

5. What can be done to intervene given the information that is now available, and what more might be done with the additional refined data? Answers to these questions are not available in the database as it currently exists. Therefore, additional fine-grained analyses of the specific human error categories within HFACS are needed to answer these, and other questions that may arise, and to target problem areas within general aviation for future interventions.

<u>Output</u>: The proposed research project, therefore, is in response to these questions and requests made by AFS-800, the ADM JSAT, and the GADIT committees. Specifically, the goal of this project is to perform a comprehensive

and systematic analysis of the individual human causal factors associated with fatal GA accidents. As a joint effort between researchers at the University of Illinois and the FAA's Civil Aerospace Medical Institute, the HFACS framework will be used to perform fine-grained analyses of GA accident data to explore the nature of the underlying human errors associated with these events. The results of these analyses will then be used to map intervention strategies onto different error categories to determine plausible prevention programs for reducing GA accidents. Results will be provided to appropriated FAA officials and committees for consideration. Ultimately, this project will represent the next step in the development of a larger civil aviation safety program whose ultimate goal is to reduce the aviation accident rate through systematic, data-driven investment strategies and objective evaluation of intervention programs.

Regulatory Link:

a. Supports Safer Skies through Areonautical Decision Making (ADM) JSAT

b. AOA (FAA) Strategic Plan (1998-2003) Mission Goal:Safety. Key Strategies "to enable the goal to include identification of root causes of past accidents; and (2) use a more proactive analytical approach, with new data sources, to identify key risk factors and intervene to prevent potential causes of future accidents" (Page 13).

c. FY2001 Performance Plan: Focus Area: Accident Prevention. "Aviation Human Factors to coordinate human factors research, development and based on detailed causal analysis" (Page 2)

d. AVR Performance Plan:Reduce General Aviation fatal accidents (pg 2). Contribute to aviation safety by developing policies,standards, programs, and systems to reduce the number of aviation accidents and incidents related to human factors (pg 9)

Requirement ID: 873

Sponsor Organization: AFS POC: Garret Livack

Requirement Title: Human Factors Considerations For The Certification of Moving Maps Displays on EFB Devices

Funded Requirement:
- FY02: No
- FY03: No
- FY04:
- FY05:

Requirement Statement: The research proposed shall attempt to address specific issues surrounding AVR's human factors concerns related to relaxing the EFB Advisory Circular certification requirements for EFBs displaying moving maps. The research plan will include documenting the human factors issues, developing the appropriate research plan and the execution of the plan for issue resolution. Results of the research will also demonstrate the efficacy of implementing airport surface moving maps on an EFB device as a mitigation strategy for runway incursions. The research will involve both simulation and flight-testing at the Mike Monroney Aeronautical Center in Oklahoma City, OK.664

Background: The recent released Advisory Circular, AC 120-76, "Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Computing Devices", has caused a great deal of concern within the industry community due to certification requirements specified for the display of moving maps. The AC specifies that EFB devices containing moving maps (with own ship) must be certified as Class 3 (highest level of EFB certification). In addition, the AC specifies that interactive enroute charts, SIDS, STARS, Approach Plates, etc. can only be implemented in systems that are certified as Class 3. A number of airlines feel that these specifications are technically unreasonable and will raise the price of these products to a level where they cannot afford these products. Industry would like to see the AC relaxed to accommodate the above mention features in an EFB certified as Class 2. AVR has expressed a willingness to look at this issue and has committed to working with industry to address this concern. The AVR issues span across several discipline areas that include engineering, software, human factors, and flight operations. The research that is proposed shall attempt to address specific questions surrounding AVR's human factors concerns for moving maps on EFB devices certified as Class 2. Runway incursion mitigation is one of the highest priorities within the FAA. Safe Flight 21 is very much involved in the development airport surface moving map displays and would like to see airport surface moving maps implemented on both in-panel displays and EFB products. The research proposed would supplement data from NASA and other research institutions that support the notion of an airport surface-moving map as a viable mitigation strategy for runway incursions.

However, this research concentrates on the implementation of a surface map display on an EFB.

Output: Resolve some, if not all of the issues expressed by AVR concerning the relaxation of certification requirements for EFBs. The results from this research will help AVR to make a determination as to the appropriate certification level. In addition, data found will test the validity of the concept of implementing airport surface moving maps on an EFB device for the mitigation of runway incursions.

Regulatory Link: Advisory Circular, AC 120-76, “Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Computing Devices”

Requirement ID: 625

Sponsor Organization: AFS POC: Mike Henry

Requirement Title: Loss of Primary Flight Instruments during IMC

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: This requirement objective is to identify the probably pilot response to loss of primary flight instruments during IMC and provide recommendations to significant reduce the potential of accidents and incidents. Research should identify training, technology or regulatory solutions.281

Background: Most single-engine general aviation airplanes are not equipped with redundant attitude or heading indicators and loss of information from these instruments during IFR flight, constitutes a genuine emergency. The emergency situation may be exacerbated by the fact that the majority of vacuum-powered instruments in General Aviation airplanes do not alert pilots when their indications become unreliable. When these instruments or their vacuum sources fail, they often fail slowly and many pilots continue to follow their indications longer than they would if an abrupt failure were to occur. Once a failure is detected, the pilot must transition to partial-panel flight, ignoring the failed instruments. Realistic instrument failure cannot be simulated in most training aircraft. Flight instructors simulate loss of attitude and heading indicators by covering instrument faces. This practice alerts students to the simulated condition and makes the transition to partial panel much easier. Realistic instrument failure can be simulated in ground-based simulators and training devices. However the element of surprise may not be as great because pilots expect failures in the simulator. Although partial-panel training is required for certification and partial-panel skills must be demonstrated during practical tests, many certificated pilots are not prepared for in-flight instrument failure. Crashes are periodically attributed to loss-of-control following instrument failure.

Output:

Regulatory Link:

Requirement ID: 866

Sponsor Organization: AFS POC: Anne Graham

Requirement Title: Low Visibility and Visual Detection

Funded Requirement:
- FY02:
- FY03:
- FY04:
- FY05:

Requirement Statement: The purpose of this project is to develop research and educational materials that will help reduce accidents caused by 4 related problems: 1) continued flight into reduced visibility, 2) failure to detect targets, 3) failure to utilize resources, 4) need for improved education and training for problems 1-3. A review of the current literature indicates that accidents related to visibility account for a large portion of the total fatalities in aircraft. Visibility issues range from continued flight into instrument meteorological conditions (IMC) resulting in controlled flight into terrain (CFIT), runway incursions and ground-based accidents during low visibility conditions, and midair collisions with ground-based objects or other aircraft. These mid-air collisions are often due not only to reduced visibility, but also to background conditions that camouflage or mask the target and impede detection, and indeed many of these accidents occur in clear skies. In most situations there appears to be a failure on the part of the pilots to recognize unsafe visual conditions and take appropriate action. In addition, reports indicate that in many cases, pilots of accident aircraft did not avail themselves of available technology, either advanced equipment installed in the aircraft, or ATC services. Further research aimed at understanding visual limitations under conditions of low visibility and decreased detection is needed. Such research would include optimizing strategies for employing available technology and services. Results from this research will form the basis for education materials designed to improve pilot recognition and performance under non-optimal visual conditions, and ultimately reduce accidents related to poor visual conditions.1770

Background:
Problem 1: VFR into IMC
Some of the most difficult safety issues currently being addressed by the FAA include accidents in which reduced visibility or failures to visually detect other aircraft or ground-based targets played a major role. In 1989, the “Final Report on an Informal Panel on General Aviation Safety Submitted to J. Lynn Helm” identified VFR into IMC as the leading cause of fatal crashes. Night VFR minimums were increased and other interventions implemented, but the problem still exists. Interventions that focus on improved pilot training concerning weather related decision making are critical in reducing fatalities. A review, of poor

visibility CFIT crashes in Alaska since 1980, indicates that pilots failed to transition to an emergency operation or radio for help. Most appear to be attempting visual flight until impact.

<u>Problem 2: failure to detect targets</u>
Similarly, the midair and ground collision rates involving GA aircraft remains unacceptably high. Reports of collisions both in the air and on the ground indicate that the pilots were typically unaware of decreasing visibility or camouflage effects from the background and report never having seen the target until too late. One prime example is the failure of pilots top detect other airborne traffic. Ironically this situation often happens in clear weather. The major cause of this failure is camouflage or masking effects of high contrast backgrounds, such as snow on mountains, or buildings in an urban landscape (please see examples in accompanying video). One of the primary cues for detection of targets is motion. However motion cues are of little help when targets are on a direct collision course since there is no relative motion in this case. The strategy of frequently changing course direction frequently may improve target detection in these cases.

The current recommended target scanning technique is based on the assumption that target detection always occurs with the central (foveal) area of the retina. This assumption ignores the specialized processing that occurs in the paracentral and peripheral areas of the retina that are optimized to detect transient change (motion and flicker). It is possible that modifications of the recommended scanning techniques to more efficiently utilize motion detection capacities will improve detection when combined with intentional course changes under conditions of target masking. More research on this topic is needed.

<u>Problem3: failure to utilize resources</u>
A lot can be said in favor of the new technologies associated with the Capstone project as well as traffic avoidance systems. However, widespread use of this equipment is most likely to be a long time coming and prohibitively expensive for many GA operators. Additionally, as we saw in the recent Kennedy crash, having sophisticated technologies on board does not assure they will be used properly. The more airman know of the limitations for both man and machine under non-optimal visual conditions the more likely they will avoid the situation or will be prepared to handle it.

<u>Problem 4: pilot education</u>
Despite the seriousness of the current situation, information about physiological and psychological responses to deteriorating weather conditions or reduced visual cues and detection is not widely disseminated. The aviation industry has been primarily focused on how to prevent pilots from entering visibilities below VFR minimums, yet it happens and fatal accidents occur. Basic and applied research with an aim toward improving training practices concerning operations in conditions of reduced visibility and detection is important. More information will

help the pilot, who is faced with challenging visual conditions to better cope with this predicament.

Output: Years 1-3

1. There is a lack of data on pilot performance under varying task loads in reduced visibility conditions. Data on this topic could be used to develop advisory circulars or to develop training modules, which would make pilots aware of their limitations and the difficulty of flying and navigating while in reduced visibility at low altitudes and when targets may be efficiently hidden by background conditions. The specific product that is needed is a report that quantifies the relationships between pilot performance, task load (as indicated, for example, by aircraft speed and altitude) and visibility.
2. There is a need to improve pilot decision-making during potential collision and CFIT situations. One common model of pilot decision-making portrays the decision-making process as a continuous loop. On the other hand, in a high task load environment like low altitude and low visibility operations a "discontinuous decision-making" model would most likely be of value. The specific product needed is a report that evaluates currently used poor weather decision models, such as Bensyl, American Journal of Epidemiology, December 2001 or Controlled Flight Into Terrain: A Study of Pilot Perspectives in Alaska, Larry Bailey, Civil Aeromedical
3. Even with advanced display technology, like weather and terrain displays on board, inadequate decision making could result in and an accident. In a low visibility and low altitude environment the man-machine interface is critical. Little is known about the advance technology equipment training and proficiency needed to contend with a VFR into inadvertent IMC situation. The specific product that is needed is a report that specifies inadequate techniques and the techniques that experienced pilots have found to be effective in dealing with these conditions. Information of that nature could be incorporated into pilot training programs, much as current emergency procedures are practiced.
4. It is important to educate pilots as to optimal strategies for avoiding accidents in conditions of reduced visibility and where background terrain or objects interfere with the ability to detect possible targets. The specific product needed is an educational video (or CD ROM) that illustrates the problem of low visibility and target detection and the appropriate strategies for reducing the probability of collision or CFIT. Data from the reports generated by Output 1, 2 and 3 above, would be incorporated into and form the basis of this product.

Regulatory Link: Safer Skies: Goal to Reduce of Fatalities, Reduction of CFIT accidents, Reduction of Weather Related Accidents, and Improving Pilot Decision-Making.

Requirement ID: 614

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Pilot field-of-vision capabilities/limitations

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: The research objectives of this requirement is to develop human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non-standard installations of avionics devices and other cockpit equipment in general aviation aircraft. The research will provide pilot field-of-vision limitations for design considerations.356

Background: Update of field-of-view data with the express purpose of defining display location boundaries that correspond to established desing eye positions for GA aircraft. Existing guidance is based upon the head held in an erect fixed position, which is not representative of actual operation. New data needs to be generated based upon realistic head position. Also data must be gathered in a context of actual operational tasks and constraints, to address more than just physiological considerations. Degraded modes of operation should also be considered. This research is sorely needed to provide human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non standard installations of avionics devices and other cockpit equipments.

Output: A reduction in pilot error and alleviation of pilot workload resulting from improved installation considerations of and interaction with various cockpit devices.

Regulatory Link: a. AOA (FAA) Strategic Plan (1998-2003)-Mission Goal: Safety. Supports the DOT Strategic Goal of Safety. Key Strategies include Research to study issues and technologies (especially Human Factors) to improve policies, procedures and equipment(pg.13). It also supports the Focus Area of Accident Prevention by addressing Flight crew/vehicle interface and interaction issues (pg. 15) b. FAA FY2000 Performance Plan-Reduce the General Aviation Fatal Accident Rate. c. AVR Performance Plan-Goal Targeting Performance Areas "Contribute to aviation safety by developing policies and/or standards, programs, and systems to reduce the number of aviation accidents and incidents related to Human Factors."

Requirement ID: 869

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Primary Flight Displays, terrain, overlays/layers, perspective displays

Funded Requirement:

- FY02: No
- FY03: Yes
- FY04:
- FY05:

Requirement Statement: The intent of this research requirement is to identify factors salient to the design and certification of primary flight displays that may contain terrain representations and flight guidance cues and to quantify their effects upon pilot performance (flight technical error, procedural performance, and terrain awareness). Not all of the listed issues will necessarily be addressed by empirical research, particularly where there are extant data pertaining to the question. Issues to be examined include the following: Manner of horizon depiction independently from the terrain to guarantee its availability to the pilot; optimizing format of terrain as a function of phase of flight; providing for deselection of terrain depiction; indications when extreme attitudes place terrain out of view; indications for failed or deselected terrain depiction; effects of variables associated with wire-frame presentations; point of regard (viewing vector); aiding recovery from unknown attitudes; use of pitch ladders; color coding schemes; optimal field of view by task; display aspect ratio; comparison with baseline standard instrumentation; substitution of other display enhancements for HITS-format guidance when terrain depiction present; separation or integration of terrain and flight-path guidance symbology. A summary of extant data will be prepared and empirical research will be used to obtain those data not available in the literature.1443

Background: Recent applications for certification of electronic flight displays have included aircraft attitude instrumentation/primary flight displays that depict perspective terrain as well as basic attitude information. In some cases there are also data for airspeed, altitude, and other flight-performance parameters. The manner in which these data are "integrated" can have a significant effect on pilot performance, particularly if the combining leads to clutter or the obscuration of key data because of inappropriate layering schemes. Data are needed to aid certification personnel in assessing which display formats, if any, will produce acceptable levels of safety in operations using these terrain-inclusive displays. The displays in question are any forms of display (head-down panel-mounted, head-up, head- or helmet-mounted) that are permanently installed in the aircraft and depict terrain or terrain with separate attitude indications as the primary means of assessing aircraft attitude.

The data required include but are not limited to graphical formatting of the terrain for presentation with attitude information (issues involving wire-frame, texture, color, transparency, priority of data), requirements for and formatting of attitude indices separate from the terrain depiction, and workload issues associated with major variations in display format.

There is an ongoing concern about the presentation of command guidance information on primary flight displays, including various forms of flight directors and highway-in-the-sky formats. Applicants for certification of new displays are now looking at using pathway formats for primary guidance, and data are needed by the certification community to determine how the level of safety attainable with these displays compares with that currently attainable with more conventional presentations, and if there are format issues that have critical impacts on pilot performance. Some of these data concerning display format effects are already available, but baseline data for performance with a flight-director display are needed that are directly comparable with those data already collected for pathway-format displays.

An additional concern when using such displays is to what degree the data provided are sufficient for maintaining attitude and altitude awareness. That is, to what extent can the terrain data alone be used as an attitude reference and as a means of maintaining separation from the terrain and obstacles on the terrain? The degree to which the displays provide usable information will directly impact the efficacy of use for recovery from unusual or unknown attitudes and the avoidance of controlled-flight-into-terrain accidents. Although it is expected that the terrain representation will serve as a redundant cue for both attitude and altitude information, reason exists to believe that the pictorial nature of the presentation may make it compelling and that it can and may exert an disproportionate influence over the pilot's interpretation of the overall situation.

<u>Output</u>: The performing activity will determine what factors are the major contributors to significant variations in pilot performance resulting from the use of terrain representations in primary flight displays, assess differences in pilot performance between "baseline" instrumentation and terrain-inclusive presentations for selected representative piloting tasks, and provide a summary of these findings in a form that certification personnel can use to determine the acceptability of displays, based upon human factors/human performance criteria, submitted for certification.

Specific questions to be addressed:

1) How should the horizon be depicted independently from the terrain to guarantee its availability to the pilot?

2) What format of terrain is 'best' as a function of phase of flight? (takeoff, climb, cruise, decent, approach)

3) Should the terrain depiction be selectable, i.e., is a provision for switching off the terrain an enhancement or detriment to safety?

4) If no terrain is visible in the display, what should the indication be?

5) Should the display be wire-frame grid?

6) What is the Point of regard?

7) Should the display have pitch ladder or comparable indication?
8) Color coding of terrain: What scheme should be used if color employed?
9) What is the field of view?
10) What is the aspect ratio?
11) Is a PFD with terrain depiction better than the standard instruments?
12) Do other display enhancements such as a velocity vector or other implementations preclude the need for a highway-in-the-sky depiction for flight-path guidance?
13) Should the synthetic terrain appear behind or be integrated with the PFD attitude and flight-path guidance symbology?

Regulatory Link: The sponsor will use the data to refine guidelines for the certification of PFDs containing terrain depictions and/or perspective graphical flight-path guidance indicators. The data will also be used to generate appropriate guidance documentation (certification check lists, advisory circulars, guidelines for potential applicants, other documents) where applicable.

Requirement ID: 797

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Priorities, organization, and sources of information accessed by pilots in various phases of flight.

Funded Requirement:
- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: Develop a systematic analysis of the information required by pilots in various phases of flight. To specify what information is needed, when it is needed, and how pilots conceive of the organization of the information.219

Background: Validate the Schvaneveldt et al. (2000) model that determines the effect of changes in the airspace system by providing baseline information about what information pilots need and when they need it.Schvaneveldt, R., Beringer, D.B., Lamonica, J., Tucker, R., and Nance, C: Priorities (2000). Organization, and sources of information accessed by pilots in various phases of flight. Civil Aviation Medical Institute (Report # DOT/FAA AM-00-26), Oklahoma City, OK.

Output: report

Regulatory Link:

Requirement ID: 632

Sponsor Organization: AFS POC: Anne Graham

Requirement Title: Reduction of Weather-Related and Maneuvering Flight GA Accidents

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04:
- FY05:

Requirement Statement: Weather related accidents and incidents still remains one of the major causes of general aviation accidents. This research program continues to address countermeasures and advances in training, technologies, and regulations to significantly reduce this GA issue.262

Background: Weather and maneuvering flight remain the two largest single factors associated with fatal GA accidents. Typically, each of these factors accounts for about one-quarter of the approximately 400 fatal GA accidents each year. The importance of weather as a causal factor in GA accidents is reflected in its place on the Administrator's Safer Skies Agenda for General Aviation. Also included in the Safer Skies Agenda is Aeronautical Decision Making which is a component in both weather and maneuvering flight accidents. Recently, a Joint Safety Analysis Team addressed the problem of weather-related accidents and produced an extensive analysis of the problems and potential solutions. The proposed solutions involve a mix of aircraft and air traffic systems, procedural changes, and human factors interventions and training. However, to successfully accomplish these solutions and to ensure that they truly have an impact on the safety of general aviation, a research program that address a broad range of human factors issues is required. Although the fact that pilots sometimes venture into meteorological conditions beyond their capacity is indisputable based upon the accident statistics, the reasons for their doing so are far from clear. Anecdotal attributions of causes such as "get-home-it is" do not provide sufficient basis for the formulation of an effective intervention program. In the same way, assuming that pilots dismiss the often-heard phrase "VFR not recommended" simply because it is often-heard, is not a sufficient explanation for pilots' apparent disregard of adverse weather information. To date, a similar depth of analysis has not been performed of maneuvering flight accidents, although they were addressed to a limited degree by the Joint Safety Analysis Team which investigated Controlled Flight Into Terrain (CFIT). The Flight Standards Service requires that a program of research, engineering, and development be established that will: a. Identify the human factors associated with maneuvering flight accidents and flight into instrument meteorological conditions by pilots unprepared for such conditions. b. Develop interventions that will address the human factors identified above so as to reduce the frequency of weather-related and maneuvering flight GA accidents. c. Develop and implement techniques to validate proposed interventions so as to ensure their acceptance, utilization, and effectiveness in the target population.

Output: The eventual outcomes of the research program include: enhanced understanding of the nature and characteristics of decision making in cross-country VFR flight; techniques for enhancing decision making techniques (e.g., checklists, cockpit reminders etc.); techniques for enhancing the training of cross-country VFR decision making (e.g., manuals, video tapes, CDROM interactive programs, etc.); articles for pilot magazines, technical reports, conference presentations and articles for scholarly publication in peer-reviewed journals.

Regulatory Link: a. AOA (FAA) Strategic Plan (1998-2003) – Mission Goal: Safety. By 2007, reduce U.S. aviation fatal accident rates by 80% from 1996 levels (pg. 13). Focus Area: Accident Prevention. General Aviation Initiative addresses CFIT, weather, runway incursions, loss of control, and decisionmaking. (pg. 14) b. FAA FY2000 Performance Plan -- Reduce the General Aviation Fatal Accident Rate (pg. 16). c. AVR Performance Plan -- Goal B-1, reduce fatal aviation accident rate attributed to human error

Requirement ID: 870

Sponsor Organization: AFS POC: Terry Stubblefield

Requirement Title: Training Requirements for Advanced Navigation Displays

Funded Requirement:
- FY02: No
- FY03: No
- FY04:
- FY05:

Requirement Statement: Installation of advanced navigation displays featuring automatic dependent surveillance – broadcast (ADS-B) technology, is scheduled for FY2003 in Prescott, AZ. The installations and the development of the ground infrastructure is a joint effort between the Safe Flight 21 Project Office and Embrey-Riddle Aeronautical University. The effort is being undertaken to address operational safety problems involving a significant number of near mid-air collisions. Approximately 75 aircraft based at Prescott Airport will be equipped with advanced avionics. This effort builds off of the Capstone Program currently being conducted in Bethel, Alaska. The implementation of these displays within a large training facility like Embrey-Riddle and the local Fixed Based Operators provides an excellent opportunity to determine the effectiveness and requirements for training for this class of avionics. Training effectiveness can be measured and the amount of time spent on various aspects of the display can be recorded. There is currently a need to establish training requirements for these advanced display systems. Their effective use in the cockpit and their impact on general aviation safety depends on proper training.1215

Background: In an effort to improve flight safety in Alaska, the Federal Aviation Administration (FAA) has been conducting an assessment of new cockpit avionics for general aviation (GA) aircraft. The assessment is being performed under the FAA's Alaska Capstone Program, which has focused its efforts in and around the town of Bethel, located in the southwest region of the state. The avionics system, developed by UPS Aviation Technologies, consists of a multi-function display unit, the Apollo MX-20, and an accompanying Global Positioning System (GPS) display, an Apollo GX-60. In addition, each aircraft is equipped with a Universal Access Transceiver (UAT), which is a remote-mounted (i.e., outside of the cockpit) radio that provides datalink communication between the aircraft and a ground station or from one aircraft to another like-equipped aircraft. Participants in the assessment are Part 135 airline operators and pilots in the Bethel area. Approximately 150 GA aircraft have been equipped with the advanced avionics equipment. The Capstone avionics provide pilots with a moving-map, weather, traffic and terrain displays. One question that still needs to be address is what are the appropriate training requirements for this kind of avionics. Capstone pilots received a variety of training programs; all of them in accordance with Part 135 operations. Training effectiveness has not been measured in a controlled environment. It is not known how variables like total flight hours, GPS display experience, and even computer gaming experience might affect the training time and effectiveness. There is a special concern within the AVN community concerning the training of pilots under Part 91 operations. Part 135 operations require a certain level of training and proficiency on aircraft avionics such as the subject avionics, whereas Part 91 does not have similar requirements.

Output: The proposed research is in response to a request from AFS-410 to look at the training requirements for this type of advanced cockpit display. The research will be conducted as a joint effort between researchers from FAA CAMI, ERAU (Prescott, AZ), and The Volpe Center. Test instruments will be developed for the collection of background information from pilots participating in the program. In addition, instruments will be developed for measuring the amount and type of training provided for various aspects of the displays and for assessing the effectiveness of the training on the displays. Results of the research will be collected and analyzed and a report will be generated that details the effectiveness of the training provided and gives recommendations for training requirements for these displays.

Regulatory Link: none

Appendix III

Human Factors General Aviation Fiscal Year Project Planning

FY03 Proposed Projects

FY04 Proposed Projects

FY05 Proposed Projects

Human Factors General Aviation

FY03 Proposed Projects (contract dollars)

Project Title	Performer	Sponsor	Req ID
Credit for Instrument Rating in a Flight Training Device	University of Illinois (Hank Taylor), Mike Wiggins (ERAU), Mike Crognale (U of Nevada Reno)	AFS-800, Mike Henry	767
Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device and an Airplane in Conducting Instrument Proficiency Checks	University of Illinois (Hank Taylor)	AFS-800, Mike Henry	
Human Error and General Aviation Accidents: A Comprehensive, Fine-grained Analysis Using HFACS	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	868
Primary Flight Displays, Terrain, Overlays/layers, Perspective Displays	Dennis Berringer, AAM-500	ACE, Jeff Holland	869
Developing and Validating Human Factors Certification Criteria for Cockpit Displays of Traffic Information Avionics	University of Illinois (Esa Rantanen)	AIR, Colleen Donovan	860

Human Factors General Aviation

FY04 Proposed Projects (contract dollars and some CAMI in-house)

Project Title	Performer	Sponsor	Req ID
Credit for Instrument Rating in a Flight Training Device	University of Illinois (Hank Taylor), Mike Wiggins (ERAU), Mike Crognale (U of Nevada Reno)	AFS-800, Mike Henry	767
Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device and an Airplane in Conducting Instrument Proficiency Checks	University of Illinois (Hank Taylor)	AFS-800, Mike Henry	
Human Error and General Aviation Accidents: A Comprehensive, Fine-grained Analysis Using HFACS	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	868
Primary Flight Displays, Terrain, Overlays/layers, Perspective Displays	Dennis Berringer, AAM-500	ACE, Jeff Holland	869

Human Factors General Aviation

FY05 Proposed Projects (contract dollars and some CAMI in-house)

Project Title	Performer	Sponsor	Req ID
Credit for Instrument Rating in a Flight Training Device	University of Illinois (Hank Taylor), Mike Wiggins (ERAU), Mike Crognale (U of Nevada Reno)	AFS-800, Mike Henry	767
Human Error and General Aviation Accidents: A Comprehensive, Fine-grained Analysis Using HFACS	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	868
Primary Flight Displays, Terrain, Overlays/layers, Perspective Displays	Dennis Berringer, AAM-500	ACE, Jeff Holland	869
New start	TBD	TBD	