

Office of the Chief Scientist for Human Factors

Aviation Maintenance Human Factors

Program Review
FY05



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Aviation Maintenance human factors research has the overall goal to identify and optimize the factors that affect human performance in maintenance and inspection. The focus initiates on the technician but extends to the entire engineering and technical organizational and all personnel involved in the endeavor. Research attention to personnel can include selection, qualification, training, motivation, health, professionalism, and the variety of human capabilities and limitations that affect efficient and safe maintenance task performance. The research considers many aspects of the work environment including both the physical and social aspects of the organization. The complexity of technical communication is an example of such research. The diversity of maintenance and inspection activity is unlimited. Thus the research attends to each and every action performed by individuals, teams, departments, and the collective organization. With a view of people, the environment in which they work, and the actions they perform a final focus is on the resources necessary for efficient and safe work. Research related to resources includes studies on the design of documentation and procedures, selection of tools, equipment, buildings, applications of advanced technologies for maintenance and inspection. The maintenance human factors research combines critical basic scientific understanding of human performance with applied studies conducted in cooperation with industry partners. The results are solid and proven science, psychology, and engineering delivered in plans, procedures, software, and even hardware that can be immediately implemented to affect efficiency and safety. To obtain a detailed description of current aviation maintenance human factors projects, projects completed, accomplishments, and products delivered, please point to <http://www.hf.faa.gov/maintenance.htm> Dr. Bill Johnson is the Chief Scientist of Aviation Maintenance Human Factors and Dr. William “Kip” Krebs is the research program manager.

The following report lists projects between October 1st, 2004 and September 30th, 2005. These projects address requirements identified by the Federal Aviation Administration Flight Standards office. 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 ATO-P R&D HF aviation maintenance program manager on the quality of the research program. Basically, this document is a means of holding each group (sponsor, investigator, ATO-P R&D HF program manager) accountable to ensure that the program is successful.

In FY05, the aviation maintenance research program distributed \$700,000 contract and grant dollars to multiple organizations. In addition, one project received supplemental support from the Civil Aerospace Medical Institute, Oklahoma City, OK. Of significant importance, the General Aviation Maintenance Inspector Training project was listed on the FAA’s Administrator’s Flight Plan. Additional information about the Flight Plan can be found at http://www.faa.gov/about/plans_reports/Performance.

William K. Krebs, Ph.D.
<http://www.hf.faa.gov/krebs>

**Project Justification:
Maintenance Requirements Mapped to Projects**

The table below lists each project with the corresponding research requirement. Please click on the research requirement link to understand the FAA sponsor research need for the project

Project Title	Requirement Statement	Sponsor	Research Requirement link
An International Survey of Maintenance Human Factors Programs in Maintenance Organization	Assess the status of maintenance human factors in countries regulated by FAA, Transport Canada, and the European Aviation Safety Agency.	AFS-300	link
Fatigue Effects in Fluorescent Penetrant Inspection	As a result of the National Transportation Safety Boards investigation into the July 6, 1996, uncontained engine failure in Pensacola, Florida, of Delta Air Lines flight 1288, a McDonnell Douglas MD-88, Safety Recommendation A-98-17 was issued to the FAA. This safety recommendation requests that the FAA, “conduct research to determine the optimum amount of time an inspector can perform nondestructive testing inspections (NDI) before human performance decrements can be expected.” A research project studying NDI as a whole is very expensive, time consuming and hard to quantify, however the two primary methods of NDI that lend themselves to such a study are Liquid Penetrant and Fluorescent Magnetic Particle Inspection.	AFS-300	link
General Aviation Inspection Training System (GAITS)	To demonstrate how advanced technology can be used for inspection training and reducing errors for the general aviation industry.	AFS-300	link
Human Factors in the Maintenance of Unmanned Aircraft	To investigate what human factors maintenance unmanned aircraft issues need be addressed so that the Federal Aviation Administration can begin to “develop policies, procedures, and approval processes to enable operation of unmanned aerial vehicles” (Federal Aviation Administration’s Flight Plan 2004-2008,	AFS-300	link

	objective two: reduce the number of fatal accidents in general aviation, strategy: establish standard procedures and guidelines for general aviation operators).		
Language Error in Aviation Maintenance: Findings and Recommendations	To determine whether the growing number of maintenance and inspection personnel who possess a wide range of non-native English reading, writing, and speaking abilities are more inclined to commit an error than personnel whose native language is English	AFS-300	link
Maintenance ASAP Programs: Barriers and Opportunities	<p>The overall goal of this research initiative is to identify factors that can maximize the likelihood of successful implementation of ASAP for aircraft maintenance programs, and to develop both guidelines and user tools for that purpose. Research tasks shall be as follows:</p> <ol style="list-style-type: none"> 1. A systematic survey and follow-up interviews of air carrier, repair station, labor association, and FAA participants in maintenance ASAPs will be accomplished. 2. Best practices will be documented. 3. Strategies for eliciting support from each of the various parties involved in ASAP MOU development and program implementation will be examined. 4. Appropriate methods for collection and analysis of maintenance errors reported under ASAP, categorization schemes for aggregating information on ASAP events and Event Review Committee (ERC) corrective action recommendations, data base design, information management, and user interface human factors considerations for archiving and querying ASAP information, and methods to display the results of ASAP program results to enhance the understanding of all ERC participants will be developed and documented. 5. Recommendations for Flight Standards Service consideration will be developed regarding the issue of appropriate acceptance and exclusion criteria for Maintenance ASAP reports. Within the latter effort consideration will be given to inadvertent errors, intentional disregard for safety, at-risk behaviors, negligence, and reckless behaviors in order to determine the relative usefulness of those terms in a maintenance ASAP context. It will include the development 	AFS-230	link

	<p>of recommended company guidelines for disciplinary action for ASAP events considered sole source by the ERC (because the only information available to the FAA is the ASAP report), but not considered sole-source by the company (because the company independently discovers the alleged violation, and informs the mechanic of it).</p> <p>6. Guidelines for how ASAP derived corrective action recommendations may most effectively be communicated and implemented at all levels of the maintenance system, including in particular the organization and design of maintenance documentation so as to reduce the probability of human error by mechanics, will be developed. Because of the multifaceted nature of these research tasks, more than one research provider may be required for their successful accomplishment.</p>		
Modeling the use of Computer and Broadband Technology in the Aircraft Line Maintenance Workplace	<p>The application of broadband technologies has significant impact on maintenance practices and on the positive potential to safety. Broadband applications run the gamut from digital documentation to electronic signature. The emerging technologies include, but are not limited to: training-on-demand, video-on demand, wireless access to technical documentation and much more. This research shall review the emerging technologies to the extent to which such technologies are impacting safety. This research shall also determine the extent to which human-centered design contributes to the successful application of these broadband technologies.</p>	AFS-300	link
Year 2: Development of a Web-Based Surveillance and Auditing Tool	<p>Develop existing PC /paper based auditing/surveillance tool to web-based application in performing auditing/surveillance/monitoring and validation of oversight of maintenance to ensure a consistent level of oversight is maintained. This system can proactively identify contributing factors of improper maintenance before aircraft is dispatched once work is complete. In addition, portions of this web-based surveillance/auditing tool can be used by aircraft manufacturers before delivery of aircraft to their customers.</p>	AFS-300	link

Aviation Maintenance Human Factors

FY05 Funded Projects

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An International Survey of Maintenance Human Factors Programs in Maintenance Organizations

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The purpose of this study is to assess what airline companies have done, are doing or are planning to do regarding the human factors maintenance elements of 14 CFR Part 145. International data will provide an opportunity to determine if voluntary versus regulatory approaches to the development of human factors programs for maintenance organizations has resulted in different practices. While covering a number of areas, questions are focused around training, error management, fatigue management, and additional human factors metrics. Additionally, respondents will be asked to describe their organization's support of their human factors program. A small survey of US maintenance organizations was conducted in 2002 as part of the Commercial Airplane Certification Process Study for Human Factors. This new proposed survey will provide an international comparison of the state of human factors in industry with the more limited national results found in 2002. This survey will help the FAA identify areas of concern and develop strategies, methods, and technologies to reduce airline accidents involving maintenance human factors.

INTRODUCTION

Commercial carriers have invested a great deal of financial and corporate resources in an attempt to address human factors both on the flight deck and within maintenance. It has been reported that U.S. airlines invest more than \$10 billion annually to keep their aircraft running smoothly (Boeing 2005). Wells (2001) reported that maintenance is a factor in nearly 50% of accidents. Maintenance-related errors have been associated with up to 15% of aircraft accidents worldwide (Murray, 1998). Human error has been documented as a causal factor within maintenance-related accidents (Boquet, Detwiler, Holcomb, Hackworth, Shappell, & Weigmann, 2005; Johnson & Watson, 2001).

Objective two of the FAA's 2005-2008 Strategic Plan (Flight Plan) Increased Safety Goal intends "to reduce the commercial airline fatal accident rate." One action being taken by the FAA's Aerospace Human Factors Research Division to meet this objective is an international survey of airlines focused on how they are currently implementing human factors initiatives into their maintenance operations. There are a variety of International approaches to the regulation of human factors programs for maintenance organizations. Transport Canada and the European Aviation Safety Agency have established specific, yet differing, rules regarding maintenance human factors. These rules pertain to such items as initial and continuation training and to requirements for formal error reporting systems. The FAA has not yet estab-

lished regulations but, instead, has created guidance documents and established voluntary reporting programs for maintenance organizations. The FAA has opted for a voluntary rather than a regulatory approach to maintenance human factors.

This research project centers on an assessment of the impact of voluntary versus regulatory approaches to maintenance human factors programs. What is the organizational impact, the impact to the aviation maintenance technician (AMT) (also called Licensed Engineer, in Europe or Aviation Maintenance Engineer in Canada)? What is the impact on maintenance-related incidents and accidents? Additionally, is there a significant difference in the implementation of maintenance human factors programs across the international spectrum?

The goal of this effort is to identify areas of concern so that the FAA may affect corrections in FAA policy, guidance material, and FAA-sponsored programs in order to improve the overall quality of airline maintenance.

METHODS

Employees at several international airline maintenance organizations will receive an electronic invitation to respond to the survey. With coordination from the European Aviation Safety Agency, several airlines, and FAA representatives, potential respondents will be identified. Publications including newsletters and notices will be sent to encourage employee participation. The respondents will be employed within the maintenance firms as engineers, quality assurance specialists, maintenance directors, and mechanics.

All participants will receive an e-mail invitation to complete the online survey. The e-mail will include an explanation of the survey as well as a link to the survey and username/password information. The respondent can then click the link and login to the survey. Once the participant completes the survey, the data will be stored in a database.

Airline Maintenance Survey

The survey has approximately 60 items that address human factors practices, human factors training, human error management and documentation, and issues related to quality assurance within airline maintenance. There are also several open-ended questions that ask respondents to comment on their company's human factors practices, error management, and human factors interventions aimed at reducing human error.

RESULTS

An initial draft of the online questionnaire has been developed, using input from FAA personnel as well as national and international industry representatives. With the assistance of Dr. Bill Johnson, we have compiled a fairly extensive address list of international representatives. An electronic version of the questionnaire was administered to approximately 30 representatives from Europe, Asia, South America, and the U.S. for review and comment. Feedback will be used to make final adjustments to the instrument prior to submission to OMB. The Federal Registry announcement was submitted and the mandatory period of review has passed. Dr. Hackworth will be attending the

JAA/EASA in October 2005 to discuss the survey's progress.

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Fatigue Effects in Fluorescent Penetrant Inspection

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Abstract

An experiment was performed to test the effects of fatigue factors on performance and stress in a high fidelity simulation of a fluorescent penetrant inspection of aircraft turbine engine blades. Five factors found in year 1 to be potentially related to inspection fatigue were tested in a mixed experimental design using 80 participants recruited from the local community. Many main effects and interactions were significant in performance analyses, although the vigilance decrement was not a strong effect in this task.

Introduction

This report follows the 2004 report on the potential for fatigue in repetitive inspection tasks in aviation. The motivation for the work remain unchanged: failures of both airframe inspection and engine inspection have highlighted the potential impact of human limitations on inspection system performance. Accidents that have occurred due to engine inspection failure include the Sioux City and Pensacola accidents. A common thread in all these incidents was that inspection failure occurred during inspection tasks of normal working duration, i.e. a working shift with typical breaks. A number of visual and Non-Destructive Inspection (NDI) techniques require the inspector to work continuously on repetitive tasks for extended periods. Examples are fluorescent penetrant inspection of engine rotor blades, eddy current inspection of large batches of wheel bolts, and magnetic particle inspection of landing gear components. Such tasks typically occur on all shifts and can involve inspecting at low periods of the human circadian rhythm. Inspectors may be subject to the effects of cumulative fatigue from overtime and shift work.

In all of these inspection tasks, the *a priori* similarity to classical vigilance tasks suggests that performance (defect detection) may decrease with time spent inspecting. However, much skepticism exists regarding the relevance of vigilance studies to the operational environment. In the case of aircraft inspection tasks, there is the added complication of the relevance of shift-work and circadian rhythm studies to these particular tasks. Thus, we have two issues:

1. Can we expect the findings from the vigilance literature to apply to aircraft inspection?
2. How well might the studies of circadian rhythms and cumulative fatigue from shift working apply to vigilance, and then to aircraft inspection?

Note that both of these issues concern the temporal effects of inspection work. Our earlier paper (Saran, Schultz and Drury, 2004) examined these issues by using an established

function analysis of inspection to show its characteristics, and then proposing a four-level classification of temporal effects to guide future applications. The analysis presented in that paper formed the basis for the design of the current experimental study of temporal factors in aircraft inspection. The first experiment, reported here, was designed as a factorial experiment to find the significant interactions among key variables, so that subsequent experiments could explore these in a more parametric manner. Only performance results are presented here as they are of the most immediate impact in aviation inspection and in the design of parametric experiments for the final project years.

Methodology

Participants: A total of eighty participants completed this study. Several participants were removed from the analysis for the following reasons: 1) inadequate computer skills, 2) not completing all three sessions, 3) not following inspection procedures as outlined in the training. Participants were selected based on calls from people in the local community who responded to a newspaper advertisement. All participants: 1) had previous industrial experience or were currently university students, 2) had sufficient computer skills to use a mouse and a keyboard, 3) had sufficient color vision, 4) were available for testing at sessions both at 9am and 3am, and 5) could complete one training session and 2 experimental sessions within about one weeks time. Participants were paid \$15 per hour for their participation as well as a \$20 bonus after completing the third session.

Materials: Two Dell Pentium 4 computers were used to run a simulation created in Visual Basic. Pictures of jet turbine blades with spots of fluorescent penetrant superimposed on them were presented to the participants. Sixty-three blades were photographed from 6 views so that the inspector could look at all sides of the blade (Figure 1). The simulation allowed participants to view each of the six

possible views of the blade by rotating 90 degrees in any direction. Visits to aviation FPI facilities were used to help develop the simulation, and to ensure that FPI inspectors found it valid. The simulation included recordings of hangar noise (80db) to recreate the ambient sounds realistic to this process.

In the simulation, targets were considered cracks that were hidden under spots of fluorescent penetrant. Participants were able to use the computer mouse to “swab” the spots of fluorescent penetrate. A defect was considered a spot of fluorescent penetrate that could not be removed by swabbing it with the swab tool. A magnification tool was included in the simulation that allowed inspectors to magnify areas of the blade at 2 times the regular size. This tool was used at the inspector’s discretion. To report a crack, inspectors clicked a mouse button that opened a dialog box to write a brief description of the crack, e.g. “front view at upper right corner”. The program recorded a Notepad text file which kept a time stamp of each inspector action including: blade numbers, start and stop points of swabbing, blade view changes, and reports. This information made it possible to classify any errors as: 1) if inspectors looked at a blade view where a crack was present, 2) if inspectors swabbed the area over a crack and failed to report it (or reported it accurately), and 3) if an inspector swabbed a crack but failed to report it.

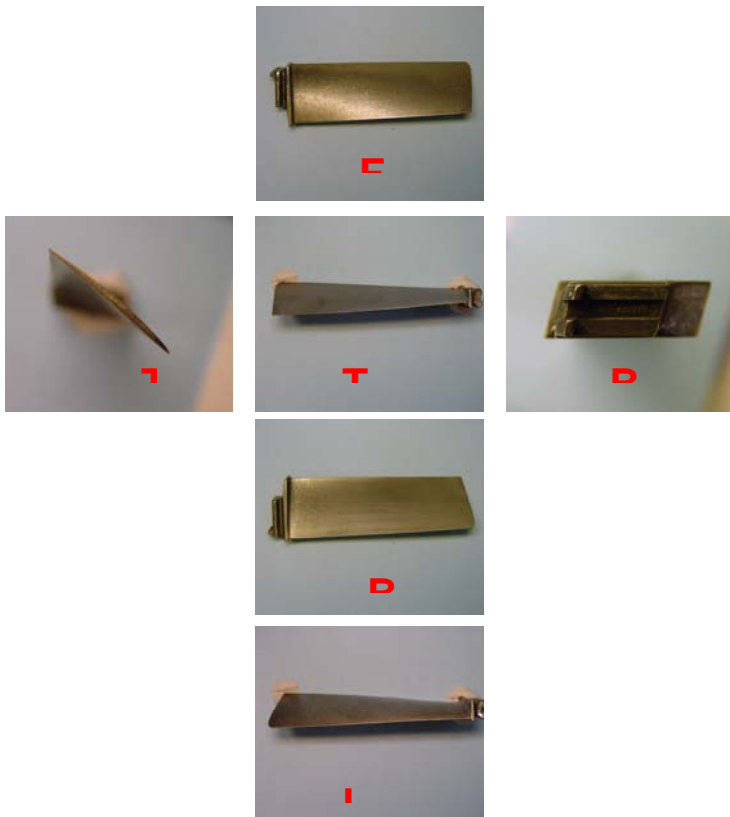


Figure 1: Six views of each blade in the simulation

Design and Procedure: Participants were randomly assigned to code numbers after passing the pre-screening process described above. Four between participants factors were tested: 1) illumination (light/dark), 2) time on task (1 hour or 2 hours), 3) breaks vs. no breaks (break condition consisted of a 3 minute break for every 20 minutes on task), and 4) defect rate (7% or 15%). In the analysis, defect rate was treated as a covariate (mean rate = 0.11) since the number of cracks seen by any participant varied in any 20-min interval depending upon their rate of working. Within-participant factors were of time of day (day/night) and 20-minute period within each session.

All participants completed a training session that included a series of paper and pencil measures of demographics and an informed consent form. Scales from sleep research were used at the beginning and end of the session: the SOFI and SSS sleep scales. Tests of visual acuity, color vision testing, an adaptation of the Folkhard scale, and the Group Embedded Figures Test (given with no time limit) were collected for possible use as covariates.

Training began with a self-paced PowerPoint presentation about the fluorescent penetrant and visual inspection processes. Comprehension questions were included to insure that participants read and understood the material. Next, participants were given a training exercise guided by the experimenters. A tutorial script was read aloud to explain how to use the tools in the simulator (i.e. swab tool, magnify tool, etc). Participants were allowed to practice with, and ask questions about, these tools. The tutorial emphasized that cracks are most likely to occur around the edges of the blades and that the majority of the time spent inspecting should be on that area of each blade. The tutorial included a nine blade practice set with feedback. The experimenters remained present to assure that every participant saw each of the three defects and reported them properly.

After completion of the tutorial, participants completed a computerized mental workload assessment (NASA-TLX) and then completed the SOFI/SSS tests again (creating documentation of pre/post levels of sleepiness). The participants were then instructed about how to use the Actigraph sleep watches and how to complete their written sleep logs. The second day of experimentation (either at 9 am or 3 am) consisted of the SOFI/SSS scales followed by the predetermined experimental condition (between subject factors). Prior to beginning the experiment, participants listened to a brief audio recording of the instruction and were given an optional 3 blade practice set. Upon completion of the simulation program participants completed the NASA TLX workload inventory as well as completing a second SOFI/SSS inventory. The third day of the experiment resembled the second day with the following exceptions. If the second day was conducted at 9am then the third was the

3am condition (and vice versa), and the order of defects was different to prevent some participants from seeing several obvious defects early in the experiment and others being presented with less obvious defects which are more likely to be missed.

Data Handling: The data was coded as a *hit, miss, false alarm, or a correct rejection*. Probability of Detection (PoD) was calculated as the total number of true positives (hits) divided by the number of true positives (hits) plus the total number of false negatives (misses). Likewise, Probability of False Alarm (PoFA) was calculated as total false positives (false alarms) divided by true negatives (correct rejections) plus false positives (false alarms). Speed data came from total blades inspected, mean time to accept a blade and mean time to reject a blade. Each measure was calculated for each 20 minute period to allow for comparisons between participants in the break condition versus those in the no break condition.

Results

Two General Linear Models (GLM) analyses of variance were performed because of the experimental design that included half the participants with a one-hour task and half with a two-hour task. The first ANOVA was of just the two-hour participants. The GLM ANOVA could not calculate all terms because of some missing cells, but the summary of only the significant effects is given in Table 1. The second used all conditions, but separated out the three time blocks: One hour participants in their only hour, two-hour participants in each of their first and second hours. In these analyses, actual defect rate and Run (first, second) were used as covariates, but only Run was significant for the three time blocks ANOVA. Table 2 shows significant results. Note that Run was only significant for speed measures, with a 21% improvement in throughput from the first to the second run.

Over both analyses there were fewer effects on accuracy measures than on time measures. The most consistent effect was of Time on Task, shown in Figure 2 for both speed and accuracy measures. For PoD there was an initial increase followed by level performance in Day conditions, but high initial performance followed by a slow drop and a final end surge at Night. For PoFA there was just a gradual decrease in false alarms over the whole two hours.

Both analyses showed an interaction between Light/Dark and Day/Night for Total Blades, with the data for the three time block analysis plotted here as Figure 3. Higher throughput was achieved when the internal lighting matched the external conditions. Another example of a significant interaction is the Breaks/No Breaks X Day/Night for two speed measures in one analysis and PoFA in the other. The Total Blades measure is plotted for

the two-hour data in Figure 4. Breaks give higher throughput in Day conditions, but No Breaks is faster at Night. The PoFA data show the same effect with less false alarms where there was better throughput.

Obviously not all interactions can be presented in five pages, and indeed the analysis to TLX and sleep variables will be needed to provide a full picture of the experiment, but there are interesting significant interactions on which to base further experiments.

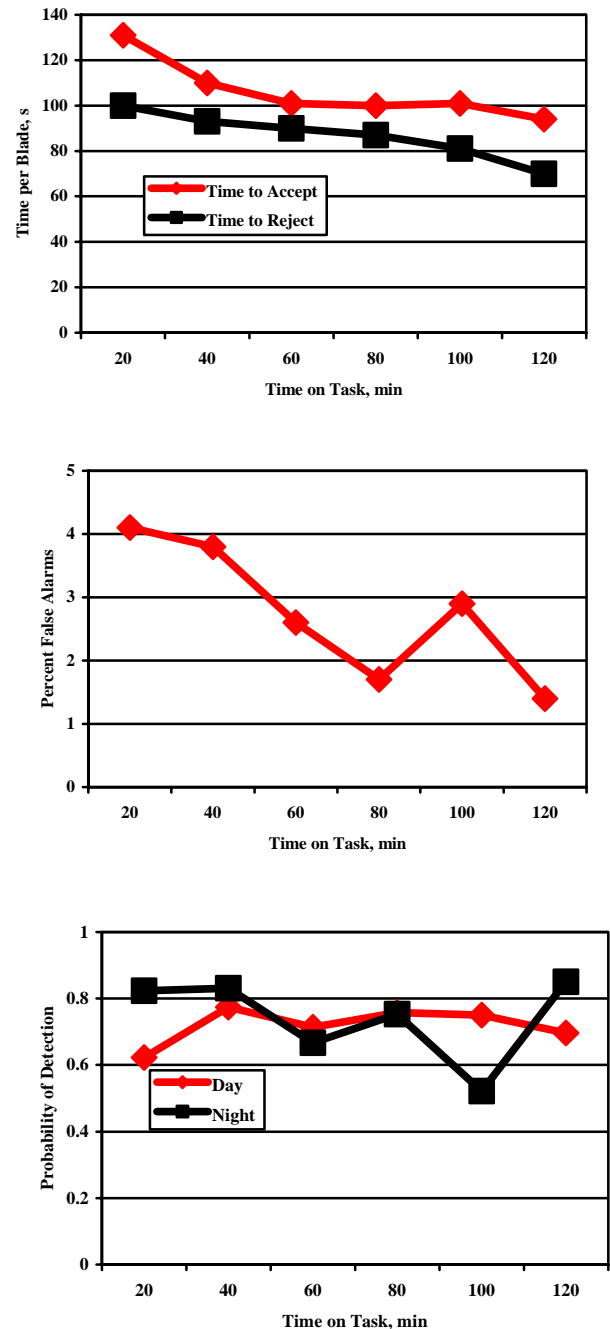


Figure 2: Time on Task effects for 2-hour participants

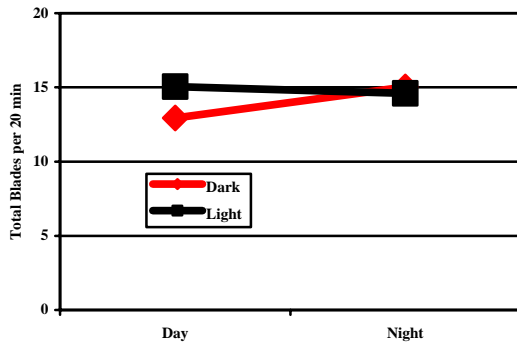


Figure 3: Day/Night X Dark/Light interaction

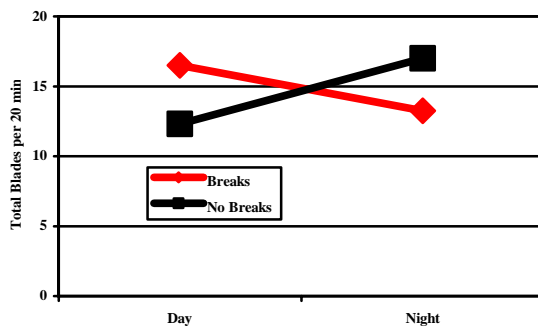


Figure 4: Day/Night X Breaks/No Breaks interaction

Discussion and Conclusions

The experiment reported here was a simulation of one type of repetitive inspection in aviation. It was checked with FPI inspectors who assured us it was at least face valid. The design chosen for this first experiment was a between-participants design with 5 industrially-experienced participants in each of the 16 ($=2^4$) cells of the design. With the addition of a single within-participants factor of Day/Night, this gave a 2^5 design so that many two-way interactions could be measured. The design ensured that there were no unwanted carry-over effects between conditions (except perhaps Day/Night which was given in a random order) and so was safe if less powerful than a within-participants design. The intention is to use the results of this experiment to design a more focused set of parametric experiments to measure more explicitly the effects of significant main effects and interactions across more levels of these variables. For example, now that we have established that Day/Night interacts with both Breaks/No Breaks and Light/Dark, we can include more Break durations and Light levels in future experiments provided we also perform the tests at Day and Night.

On a practical level, we concluded that there were the expected significant individual differences and that these can interact with some variables, e.g. Day/Night. Thus we can expect night working to affect inspectors differentially,

so that not all may be suitable for Night work. We also showed that across a long period of continuous inspection (up to two hours), performance measured by PoD may change differentially with Day/Night. The other dependant variables, PoFA and speed measures, all appear to improve with Time on Task. Any vigilance decrement may well be limited to Night conditions. In this combined search and decision task (Drury, 2001) with performance times measured in minutes rather than milliseconds per blade, vigilance decrement does not appear at the same magnitude as in typical laboratory vigilance tasks (e.g. Parasuraman and Davis, 1977). Horowitz, Cade, Wolfe and Czesler (2003) have already reported that the search function may not show the classic vigilance decrement phenomenon shown by primarily decision tasks.

Finally, there appeared to be interesting effects of working in light conditions vs. dark conditions, where the best condition for throughput was the one with the best match to the outside light levels, i.e. Day vs. Night. This may have practical implications for setting light levels in FPI inspection, which is always carried out at low levels of illumination so as to be able to view the fluorescence under UV lighting.

Acknowledgement

This work was financed by the Federal Aviation Administration, Grant No. 03-G-012; Contract monitor, William K. Krebs.

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Source	PoD	PoFA	Total Blades	Accept Time	Reject Time
Time (6 x 20 min intervals)		P = 0.019	P = 0.004	P < 0.001	P < 0.001
Subjects	P < 0.001		P < 0.001		
Light/Dark*Day/Night			P = 0.034		
Breaks/No Breaks*Day/Night			P = 0.001		P < 0.001
Day/Night*Time	P = 0.008				
Day/Night*Subjects		P < 0.001	P < 0.001	P < 0.001	P < 0.001
Breaks/No Breaks*Day/Night*Time				P = 0.048	

Table 1: Significant ANOVA results for the two-hour participants only

Source	PoD	PoFA	Total Blades	Accept Time	Reject Time
Run			P < 0.001	P = 0.003	P < 0.001
Light/Dark*Breaks/No Breaks				P = 0.036	P = 0.006
Light/Dark*Breaks/No Breaks*Time Block		P = 0.013			P = 0.025
Subjects	P < 0.001	P < 0.001	P < 0.001	P < 0.0	P < 0.001
Day/Night			P = 0.030		
Time			P = 0.001	P = 0.001	
Light/Dark*Day/Night			P < 0.001		
Breaks/No Breaks*Day/Night		P = 0.025			
Time Block*Day/Night		P = 0.001			
Time Block*Day/Night*Time	P = 0.014				

Table 2: Significant ANOVA results for the three one-hour time blocks

GENERAL AVIATION INSPECTION TRAINING SYSTEM (GAITS)

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This research demonstrates how advanced technology can be used for inspection training to reduce inspector errors in the General Aviation maintenance environment. It extends work from the past several years to a functional prototype computer-based training system, the General Aviation Inspection Training System (GAITS), consisting of the four modules of introduction, training, simulation, and design and analysis. The specific activities conducted in support of the development of GAITS included the following: (1) the development and evaluation of alternate interfaces, (2) the development of scripts and storyboards, with the scripts specifying the text, the computer-based graphics, the simulations, and the audio content to be used, and the storyboards depicting individual frames showing the specific content of the scripts for a single module, (3) the computer coding of the individual modules, and (4) the testing of the modules. This report provides a brief description of the development effort followed by an overall description of the tool.

INTRODUCTION

Aircraft inspection and maintenance is a complex system with many interrelated human and machine components. The linchpin of this system, however, is the human, who is fallible, despite the training mandated by the US federal government and the Federal Aviation Administration (FAA). In the General Aviation (GA) environment, the complexity of this system is further compounded by the variety of geographically dispersed entities, including repair and maintenance facilities situated at different locations, large international carriers, regional and commuter airlines, as well as the fixed-based operators associated with this domain. As a result of its inherently intricate nature, continuing emphasis must be placed on developing interventions to make the inspection and maintenance system more reliable and/or more error tolerant. Recognizing the importance of this to public safety, the FAA, under the auspices of the National Plan for Aviation Human Factors [1, 2], has pursued human factors research, primarily focusing

on the Aircraft Maintenance Technician (AMT).

Unfortunately, the GA segment, which constitutes a considerable portion of the nation's aviation system, is frequently not considered in this research. Since its reliability is crucial if we are to ensure the safety of the overall air transportation system, the lack of GA research is a significant concern. Furthermore, the GA inspection process, which is responsible for identifying and fixing aircraft defects, plays a key role in the maintenance system. As research has found, adhering to inspection procedures and protocols is relatively easy; however, the monitoring and tracking of the efficacy of these procedures is not. To address this issue, task analyses of aircraft inspection operations at geographically dispersed GA facilities operating under the Federal Aviation Regulation (FAR) Parts 91, 135, and 145 were conducted. The recommendations based on these analyses were then used to develop the General Aviation Inspection Training System (GAITS), a computer-based inspection training program focused on improving

inspector performance. The motivation for its development, as well as its precursors, grew out of previous and current approaches to training.

NEED FOR COMPUTER-BASED INSPECTION TRAINING

Existing training for inspectors in the aircraft maintenance environment tends to be primarily on-the-job. Nevertheless, this may not be the best method of instruction [1] because, for example, feedback may be infrequent, unmethodical, and/or delayed. Moreover, in certain instances feedback is economically prohibitive or not feasible due to the nature of the task. Even more significantly, although such training for improving visual inspection skills of aircraft inspectors has been shown to improve the performance of both novice and experienced inspectors [3, 4, and 5], it is frequently lacking at aircraft repair centers and aircraft maintenance facilities [6]. Current research, however, indicates that training using representative photographic images showing a wide range of conditions can effectively be used to teach visual inspection skills, in part because this approach provides immediate feedback on the trainee decisions [6]. The use of these realistic photographic images, as supported by trainee feedback, has been shown to be superior to OJT training alone [5, 7].

These findings, coupled with the many constraints and requirements imposed by the aircraft maintenance environment, suggest that one of the most viable approaches for delivering inspector training is through Computer-Based Training (CBT), and, in fact, this method does offer several advantages over traditional training protocols: It is more efficient, it facilitates standardization, and it supports distance learning. Specifically in the domain of visual inspection, the use of computers for off-line inspection training has shown

significant inspection performance improvement in a laboratory environment [8, 9, and 10]. Even though many training delivery systems, such as computer-aided instruction, computer-based, multi-media training, and intelligent tutoring systems, are currently being used, most of the applications of computer technology in training have been restricted to complex diagnostic tasks in the defense/aviation industry. Extending this computer-based training to inspection tasks resulted in the Automated System of Self Instruction for Specialized Training (ASSIST) [11], developed for commercial aviation in cooperation with Lockheed Martin Aircraft Center and Delta Air Lines. This research has now been extended to the GA sector through the development of the prototype training system, GAITS.

METHODOLOGY

The research for GAITS followed a structured methodology comprised of an analysis of visual inspection practices in GA, a task analysis of current GA inspection training procedures, the development and organization of inspection training materials, and the development of a prototype training system.

Analysis of visual inspection practices in GA

In the first step, the research team was formed, and a literature review was conducted. In addition, preliminary visits to GA facilities were made to outline the scope of the effort. The team visited sites with both light and heavy inspection and maintenance work governed by FAR Parts 91, 135, and 145. The GA partners, located at geographically dispersed maintenance sites, provided the research team with access to their facilities, personnel, and documentation, allowing the team to analyze their existing inspection protocols at

different times of the shift. In this process, the research team worked with the managers, line supervisor/shift foremen, and aircraft maintenance technicians and inspectors. Data was obtained through a variety of techniques, including observation, shadowing, structured and unstructured interviews, appropriate verbal protocol analysis tools, and the analysis of company-wide procedures, documentation, and manuals.

Task analysis

A detailed task analysis [12, 13] of the inspection process was then conducted to determine the knowledge, skills, and abilities necessary for its performance. From this analysis, the behavioral objectives of the training program were identified, forming the basis for the evaluation of the training program. The researchers conducted follow-up interviews as needed with the various personnel involved to ensure that all aspects of the inspection process were covered, discussing any remaining issues concerning the tasks.

Development and organization of material

Based on this research, the following six stages in the inspection process were defined: initiate, access, search, decision, respond and return, each having various inspection functions. Using an error taxonomic approach, the inspection tasks were analyzed, resulting in a list of possible errors and the correct outcomes. Following this analysis, a comprehensive error classification scheme was developed by expanding each step of the inspection process into sub-steps and then listing the possible failures for each using the Failure Modes and Effects Analysis (FMEA) approach. Next, a classification scheme for errors was developed based on Rouse and Rouse's Human Error Classification Scheme

[14], a framework classifying human errors based on causes as well as contributing factors and events. This scheme has been employed to record and analyze human errors in such contexts as detection and diagnostics, and trouble-shooting of aircraft mission flights. For all inspection functions, the possible errors were listed and mapped using this error taxonomy to identify the error genotypes. Based on this information, expert human factors knowledge was applied to the sub-tasks to identify specific interventions (e.g., providing job-aids), to minimize the negative effects due to specific error shaping- factors and to improve performance. Then, training needs were developed to produce the correct outcome.

Development of the prototype training system

Following the identification and organization of the inspection material, an initial prototype of the system was developed based on the activities described below.

Content: This activity outlined aircraft inspection training, organizing it using the feedback from the task analysis.

Method: This activity incorporated into GAITS the training methods that have been used effectively for inspection training [15]: pre-training, feedback, active training, progressive parts training, schema training and feedforward training.

Delivery system: This activity evaluated different potential solutions, identifying technical and

functional specifications for the training delivery system.

Development of the interface: This activity focused on developing and evaluating alternate screen designs. The interfaces, which had the "look and feel" of the final system, included such elements as screen layout, icons, and buttons. The prototypes, which focused on ease-of-use and simplicity in the presentation of information in addition to emphasizing human factors principles of interface design, were revised iteratively based on the input obtained from user testing.

Development of scripts and storyboards: With the content and the interface design established, this activity focused on developing the production script. The script itself specified the text, the computer-based graphics, the simulations, and the audio content to be used. The storyboards depicted individual frames showing the specific content of the scripts for a single module.

THE GAITS SYSTEM

The specific system specifications and system structure of GAITS are detailed below.

System specifications

GAITS was developed using Macromedia Authorware 6.5, Macromedia Flash MX and Microsoft Access. The development work was carried out on a Pentium(R) 4, 2.4 GHz platform. The training program uses text, graphics, animation, video and audio, with the input entered using a keyboard and a mouse.

System Structure

GAITS consists of four modules: 1) Introduction 2) Training 3) Simulator and 4) Design and Analysis. The software combines graphical user interface technologies with good usability features. Users interact with the software through a

user-friendly interface employing a multimedia presentational approach. This interface, which is interactive and self-paced, combines text, audio, images and video.

Introduction Module

The Introduction Module, which provides information to the trainee about various facets of the program, consists of six units.

Inspection: This unit gives an overview of the CBT tool, introducing the trainee to different aspects of the software.

Types of inspection: This unit provides information about the various kinds of inspection found in the GA environment in addition to discussing different levels of visual inspection.



Figure 1: The Introduction Module demonstrates inspection procedures, such as a systematic search strategy

FAR's: This unit addresses the FAR's as they relate to GA procedures and guidelines.

Tools: This unit discusses the common tools used in GA inspection.

Factors: This unit describes the factors affecting visual inspection in GA.

Procedures: This unit discusses the procedure for GA inspection (Figure 1).

Training Module

The training module (Figure 2), which focuses on the visual inspection process, is divided into six units, each of which looks at one aspect of the inspection process.

Initiate: This unit begins the inspection process, with the inspector following validated guidelines using appropriate documentation to plan the inspection task appropriately.

Access: This unit discusses locating and accessing the area to be inspected.



Figure 2: The Training Module incorporates videos to demonstrate good practices

Search: This unit introduces scanning the inspection area for indications of defects using a good search strategy.

Decision: This unit discusses identifying the type of indication found in an inspection area, categorizing it by comparing it to a standard, and deciding the future course of action.

Respond: This unit covers the writing and issuing of a Non-Routine Repair Card.

Return: This unit emphasizes the importance of checking and returning equipment to its appropriate location.

The different units comprising this module help the trainee understand the conditions leading to error occurrences. In addition, they prescribe correct inspection procedures, detailing steps to prevent errors. To check trainee knowledge and understanding of this material, each concludes with a quiz.

Simulator Module

The Training Module teaches the trainee the proper procedure for inspection. To check this knowledge and provide the trainee with hands-on experience, the simulator provides a utility which simulates an aircraft wing and potential inspection conditions. The simulator module (Figure 3) provides tools (a flash light and a magnifying glass) for use in the simulated inspection. The trainee visually searches for defects and upon identification completes a Non-Routine Report Card. The trainee's performance is tracked in real time by the Design and Analysis Module.



Figure 3: The Simulator Module allows trainees to practice inspection and receive feedback on performance

Design and Analysis Module

The Design and Analysis Module provides the instructor with utilities for creating the questions in the Training Module and for tracking the performance of the trainee based on their answers. In addition, it allows for setting up the wing simulation environment (Figure 4) and for developing schemas by manipulating various task complexity factors. This capability can be used to assign scenarios to specific trainees.

The inspection performance of the trainee using the simulator is also tracked by this module.



Figure 4: The Design and Analysis Module allows trainers to customize scenarios for use in the Simulator Module

CONCLUSION

GAITS, a tool designed to help improve the inspection and decision-making performance of aircraft inspectors in the GA sector, was developed using a detailed and scientifically sound methodology. It embodies the following inherent anticipated that its use will lead to reduced errors and improved inspection quality in the GA environment.

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characteristics that can mitigate the shortcomings of OJT:

Completeness: GAITS will serve as a single source for GA inspection training.

Adaptability: GAITS can be customized, and, hence, the program can be tailored to accommodate individual differences in inspection abilities.

Efficiency: GAITS allows for intensive training, providing an efficient tool for improving inspection skills.

Integration: The system is designed to be an integrated training tool combining a variety of training methods.

Certification: With its automated record keeping, GAITS can be used as part of the certification process.

Instruction: GAITS can be integrated into the curriculum of FAA-certified A&P schools for training, giving student AMT's exposure to inspection material which they otherwise would not have access to.

GAITS will be made available to geographically disperse GA locations for testing and evaluation. It is

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Human Factors in the Maintenance of Unmanned Aircraft

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Abstract

The accident rate for UAVs is higher than for conventional aircraft. A significant proportion of these accidents are associated with human error. If UAVs are to be permitted to operate in the National Airspace System, it will be necessary to understand the human factors associated with these vehicles. Unlike conventional aircraft maintenance, UAV operators must ensure the reliability of an entire system that comprises the vehicle, the ground station, and communication equipment. At present, there have been no published studies of the human factor issues relevant to UAV maintenance. Twenty-two structured interviews were conducted with personnel experienced in the operation of small- to medium-sized UAVs. Information was gathered on critical UAV maintenance tasks including tasks unique to UAV operations, and the facilities and personnel involved in maintenance. The issues identified were grouped into three categories: hardware; software/documentation; and personnel issues. Hardware issues included the frequent assembly and disassembly of systems, and a lack of information on component failure patterns that would enable maintenance personnel to plan maintenance effectively. Software/documentation issues included the need to maintain computer systems, and difficulties associated with absent or poor maintenance documentation. Personnel issues included the influence of the remote controlled aircraft culture and the skill requirements for maintenance personnel.

Introduction

The history of unmanned aviation can be traced back at least as far as World War I (Newcome, 2004). Recent technological advances, including the miniaturization of components and other developments in the fields of electronics, navigation and telemetry, are creating new possibilities for Unmanned Aerial Vehicles (UAVs). Potential civil and commercial applications include: communication relay linkages, surveillance, search-and-rescue, emergency first responses, forest fire fighting, transport of goods, and remote sensing for precision agriculture (Herwitz et al, 2004; Herwitz, Dolci, Berthold & Tiffany, 2005).

There have been different views about the precise definition of UAVs (Newcome, 2004). For the purpose of this study, the

definition provided by ASTM International was adopted. UAVs are here defined as “an airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation ... UAVs are designed to be recovered and reused...” (ASTM, 2005).

Several different classification systems have been proposed for UAVs (ASTM, 2005; Joint Airworthiness Authorities/Eurocontrol, 2004; CASA, 1998). UAVs range in size from micro vehicles measuring inches in size and ounces in weight to large aircraft weighing more than 30,000 pounds. In this study, the categorization system shown in Table 1 was used.



Figure 1. Two operators prepare a small-sized UAV for flight.

The weight categories encompass fixed-wing, rotorcraft and lighter-than-air vehicles. These vehicles have a range of propulsion systems including electric and gas powered engines. Cost, complexity and capability generally increase with weight. Our initial focus in this study was on the small- to medium-sized UAVs (weights ranging from 15 to 500 lbs.). The micro and mini, and larger UAVs will be examined in the next phase of this research.

Table 1. Size class groups for UAVs

ROA Class	Weight (lbs)	Range (miles)
Micro	Less than 1	1-2
Mini	1 - 15	A few
Small	15 - 100	100s
Medium	100 - 500	100s to 1,000s
Large	500 - 32,000	1,000s

Throughout the history of aviation, human error has presented a significant challenge to the operation of manned aircraft (Hobbs, 2004). Although UAVs do not carry an onboard human, operational experience is demonstrating that human error presents a hazard to the operation of UAVs (McCarley and Wickens, 2005). Given the fact that maintenance and ground support activities appear to be responsible for a growing proportion of airline accidents (Reason and Hobbs, 2003), this human factor element will

be a critically important part of UAV operations.

To enable the operation of UAVs in the National Airspace System (NAS), it is necessary to understand the human factors of unmanned aviation. The objective of this study was to identify human factors that will apply in the maintenance of UAV systems. Maintenance was defined as any activity performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle. Under this broad definition, maintenance includes assembly, fuelling, pre-flight inspections, repairs, and software updates. Maintenance activities may involve the vehicle as well as equipment such as the UAV ground control station.

The accident rate for UAVs is higher than that of manned aircraft (Tvaryanas, Thompson, & Constable, 2005). Williams (2004) studied US military data on UAV accidents. Maintenance factors were involved in 2-17% of the reported accidents, depending on the type of UAV. For most of the UAV systems examined by Williams, electromechanical failure was more common in accidents than operator error. In a study of US Army UAV accidents, Manning et al (2004) determined that 32% of accidents involved human error, whereas 45% involved materiel failure either alone or in combination with other factors. In contrast, Tvaryanas et al. and Williams found that a higher proportion of accidents involved human factors. These studies suggest that system reliability may be emerging as a greater threat to UAVs than it currently is to conventional aircraft. This trend may serve to increase the criticality of maintenance.

McCarley and Wickens (2005) reviewed the literature on human factors of unmanned aviation and identified a range of issues related to automation, control and interface issues, air traffic management, and qualification issues for UAV operators. At present, however, there have been no studies

specifically focused on the maintenance human factors of UAV systems.

Methods

Twenty-two structured interviews were conducted with UAV users from civil and military operations as part of a qualitative study. Interviewees were asked a series of questions designed to reveal human factor issues associated with UAV maintenance. The interview questions are listed in Appendix A. Site visits were conducted to selected UAV maintenance facilities. A distinction was made between manufacturers who fly and maintain their UAVs, and customers who purchased UAVs. Of the sample group, 36% were manufacturers and operators of their own UAVs. All of the civil operators were conducting line-of-sight operations.

Results

Issues that emerged from the structured interviews are arranged in three sections based on the SHEL model (Hawkins, 1993). Hardware issues are human factors that relate to the interaction of maintenance personnel with the physical structures of the UAV system. Software/documentation issues concern the interaction of maintenance personnel with computer systems and written documentation. The last section deals with personnel issues including the skill levels of maintenance staff.

Hardware

Packing and transport. Operators reported that transport and handling damage “ramp rash” are significant issues due to the need to move and assemble UAVs. The handling of UAVs is similar to sailplanes that are typically moved in trailers. One UAV manufacturer actually used the maximum size of a UPS box as a point of reference for designing their UAVs. A Sports Utility Vehicle or van may be used for the

smaller UAVs, but when wing spans start to exceed the dimensions of such a ground vehicle, then new packaging and human factors must be addressed.

Assembly. Small- and medium-sized UAVs are generally disassembled between flights for transport and storage. A particular concern is the frequent connection and disconnection of electrical systems, which can increase chances of damage and maintenance errors. One advantage of UAVs compared to conventional aircraft is that they are not generally stored outdoors where they would be exposed to threats from the elements.

UAV-specific elements. UAV systems may include unique components such as launch catapults, autonomous landing systems, sense-and-avoid instrumentation (ground-based or airborne) and flight termination systems (e.g. parachute release; engine kill).

Battery maintenance requirements. Batteries were noted as the cause of a high proportion of mishaps, both with the airborne and ground-based systems. Careful attention needs to be directed to battery charging/discharging cycles. In addition, some types of batteries (e.g., lithium polymer) can be dangerous if correct procedures are not followed.

Composite materials. UAVs tend to make extensive use of composite materials. Repair of these materials may require special expertise and equipment to deal with hazardous materials.

Distinguishing between payload and aircraft. In contrast to conventional aircraft, the payload on board a UAV is more likely to be integrated with the UAV structure and power supply. Maintainers may be expected to support the payload as well as the aircraft.

Salvage of UAV and associated hardware. UAVs often experience operational-related damage (e.g., hard landings; contact with water). Maintenance personnel will be required to make judgements about the reuse and salvage of components involved in such occurrences.

Repair work by UAV manufacturer. The small size of many components and the modular approach to many UAV designs enables operators to ship damaged components back to the manufacturer for repair. A trend was detected indicating that minor maintenance was performed by operators, but major repairs generally involved sending the UAV back to the manufacturer.

Absence of information on component failure modes and rates. The manufacturers of components used in small UAVs generally do not provide data on the failure modes of their components and the expected service life or failure rate of these components. This absence of information is particularly notable for components purchased from Radio Control (RC) hobby shops. In the absence of service life information, reliability-centered maintenance programs cannot be developed (Kinnison, 2004). For example, there is little information on the service life of servos designed for radio controlled aircraft, and now being used in UAVs (Randolph, 2003).

Recording of flight hours. UAVs do not generally have on-board meters that record airframe or engine flight hours. If this flight history information is not recorded by the ground station, the timing of hours flown must be recorded manually for maintenance purposes and inspection scheduling.

Lack of part numbers. Non-consumable UAV parts that can be removed and repaired (i.e., rotatable components) generally do not have part numbers. Tracking the maintenance history of

these components may become problematic, and may increase the risk of maintenance errors.

Unconventional propulsion systems. An increasing number of UAV designs propose the use of emerging technologies. Interviewees could not provide detailed information on the maintenance requirements of technologies such as fuel cells, solar power systems, and electric engines.

Fuel mixing. Unlike conventional manned aircraft, some UAVs require fuel to be mixed on-site. This task is typically performed by the UAV operator/maintainer rather than by dedicated refuelers. Human error during the handling of fuels may result in health and safety, and airworthiness hazards.

Software/documentation

Extensive use of computers. Virtually all UAV systems rely on laptops as the basis for flight control. Given the importance of computer components, several UAV owners require maintenance personnel to have an understanding of software and the capability to make software updates.

Autopilot software management. Maintenance personnel may need to update UAV autopilot system software, and then verify and clearly document the software versions being operated.

Availability of flight history data. UAV ground stations commonly record flight history such as engine performance. These data are useful for evaluating performance and identifying anomalous conditions. UAV maintenance personnel will require the ability to interpret such data.

Lack of maintenance documentation. Several operators reported that UAVs were delivered with operating manuals, but no maintenance

manual or maintenance checklists. As a result, the operators had to develop their own maintenance procedures and documentation. The need for well-prepared documentation is highlighted by the fact that several customers purchased UAVs without technical information such as wiring diagrams.

Poor standard of maintenance documentation. In cases where a UAV was delivered with maintenance documentation, maintenance personnel were sometimes dissatisfied with the quality of documentation. For example, UAV maintenance documents rarely, if ever, conform to the ATA chapter numbering system. In the course of the interviews, examples were given of poor procedures including poorly conceived Fault Isolation Manual (FIM) documents. One of the most common recommendations was the need to keep careful log books that document all tasks performed on the UAV.

Personnel issues

Complacency. Aware that there is no human on board the aircraft, there is a potential for maintenance personnel to become complacent, particularly with regard to deviations from procedures.

Model aircraft culture. The most commonly cited skill sought for UAV maintenance was experience with RC planes. Such personnel, however, do not necessarily reflect a mainstream aviation background. Some RC hobbyists may be accustomed to operating without formal procedures or checklists.

Lack of direct pilot reports. UAV maintenance personnel do not receive log book entries describing problems detected by an on-board pilot during flight. For manned aircraft flights, the pilot's log book entries are an important source of information for maintenance personnel (Munro, 2003). Although flight history may be recorded in the UAV ground control station and reports may be made by the

ground-based UAV operator, these reports will not contain any information on a pilot's direct sensory experience of the aircraft's flight performance.

Operator and maintainer may be same person.

A primary attraction of UAV technology is the ability to operate the vehicle with a small number of multi-skilled individuals. For small UAV operations, maintenance tasks tend to be performed by the operator.

Need for wide skill set. Small operators expect maintenance personnel to possess skills in a wide range of fields, including electrical and mechanical repairs, software, and computer use. Given the potential risk of electromagnetic interference (EMI), another fundamental requirement is an understanding of radio transmission, wireless communication, and antenna electronics.

Discussion

A key finding was that UAV maintenance requires attention not just to the aircraft, but to the entire system, including the ground control station, wireless communication links, sense-and-avoid instrumentation, and, in some cases, specialized launch and recovery equipment.

This study identified tasks that are unique to UAV maintenance, representing new challenges for maintenance personnel. These tasks include transport and assembly of the vehicle and associated systems, and pre-flight ground tests necessitated by the assembly of the aircraft at the flight location. The work of a UAV maintenance technician involves a broader range of tasks than those involved in the maintenance of conventional aircraft.

The diversity of UAV systems is typical of the early development stage of any new technology. The scope of maintenance activities ranges from repairing a small military UAV with duct tape to major work on complex

vehicles necessitating return to the manufacturer. The maintenance requirements for a 5 oz. micro air vehicle cannot be equated with those for a 32,000 lb. Global Hawk.

The interviews conducted thus far have been confined to manufacturers and operators of small- to medium-sized UAVs. The conclusions reached apply to these sectors of the industry.

The ability to ship components or even entire aircraft to the manufacturer for maintenance will have significant impact on the way maintenance is performed. It appears that major maintenance or major checks will be performed by the manufacturer, while the operator will attend to routine preventative maintenance and minor corrective maintenance. An increased trend towards modularity and “repair by replacement” may enable maintenance to be performed by personnel with a lower level of expertise than would be required if components were repaired in the field.

Human factors in conventional aircraft maintenance include time pressure, insufficient knowledge and skills, procedure design and coordination difficulties (Hobbs and Reason, 2003). The maintenance of UAVs involves not only these issues, but also additional challenges. The reliance on laptop computer for UAV operations means that the support and maintenance of a computer system and associated software is now an airworthiness task. As a result, human-computer interaction and computer system knowledge will be important human factors considerations for UAV maintenance personnel.

Several findings related to information management. Issues such as the lack of maintenance documentation, the poor quality of existing documents, a lack of formalized checklists and the absence of parts numbers are potential error-producing conditions.

Cultural issues also were identified as a potential area of concern. Many UAV maintenance personnel have a background in

RC aircraft, and they may bring expectations and norms that differ from those in conventional aviation.

The driving force behind the UAV industry is affordability and the need to minimize the number of personnel involved in UAV operations.

This driving force creates a pressure as well as an incentive to staff UAV operations with a small group of individuals. Although the trend towards modularity will reduce the need for complex maintenance in the field, the view was expressed that maintenance personnel will nevertheless require a wide range of skills. Key skills widely cited by the interviewees included knowledge of electrical and mechanical systems, radio communication, and an understanding of software upgrades and documentation.

During the interview process, it became apparent that there are two schools of thought regarding the maintenance of UAVs. One view is that the aircraft and control station must be maintained at the same standards as conventional aircraft. The other view is that small and medium-sized UAVs comparable in size to RC planes can be maintained to a different standard than conventional aircraft.

The next phase of this study will provide more attention to the extremes of the UAV industry as defined in Table 1 (i.e., micro, mini, and large UAVs). In future reports, specific attention will be given to the knowledge and skills required to perform UAV maintenance, the facilities required, and human factors training requirements.

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Appendix A: Interview structure.

1. Provide a general description of vehicle and operations.
2. Who performs maintenance?

3. What are the key maintenance tasks? Ground support tasks?

4. Are there maintenance tasks unique to unmanned aircraft? Are these tasks different to those in maintenance of RC aircraft?

5. Are there particular maintenance problems associated with your operation?

6. Special facilities needed?

7. What qualifications, skills and training are needed to perform maintenance? If you were advertising for a UAV maintenance person, what skills and experience would you be looking for?

Language Error in Aviation Maintenance: Findings and Recommendations

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Abstract

English is the language of aviation, including aviation maintenance. As more maintenance work is outsourced to non-English-speaking countries, language error may be a problem. A study of 941 maintenance personnel in Asia, Latin America, Europe and USA measured the reported incidences of seven scenarios and tested intervention effectiveness. Three of the scenarios had reported incidence of 4-5 per year, and the expected causal factors were reported. A test of interventions to work documentation showed that only translation into the native language produced performance improvements.

Introduction

This project is a direct response to the FAA's concerns that non-native English speakers, in repair stations in the USA and abroad, may be prone to an increased error rate that could potentially affect airworthiness. The documentation for repair provided by an English speaking airline is always in English, and this documentation must be used to govern all maintenance tasks, despite a potentially large proportion of mechanics who do not use English as a native language. This report follows earlier papers (Drury and Ma, 2003, 2004, 2005) and describes data collection trips to Asia using a methodology for quantifying the effectiveness of possible countermeasures to language errors.

As noted in our 2004 paper, this project developed seven scenarios of language error based on visits to sites in the USA and the UK; it also provided a model for these unique communication errors based on the communications literature and an analysis of several databases (e.g., NASA/ASRS).

The seven scenarios found were:

Scenario 1: "The Mechanic (Aircraft Maintenance Technician, AMT) or Inspector was not able to communicate verbally to the level required for adequate performance."

Scenario 2: "The Mechanic (AMT) or Inspector and the person to whom they were speaking did not realize that the other had limited English ability."

Scenario 3: "Native English speakers with different regional accents did not understand each others' communications."

Scenario 4: "The Mechanic (AMT) or Inspector did not understand a safety announcement over the Public Address (PA) system."

Scenario 5: "The Mechanic (AMT) or Inspector did not fully understand a safety placard."

Scenario 6: "The Mechanic (AMT) or Inspector did not fully understand documentation in English, for example a task card or a Manual."

Scenario 7: "The Mechanic (AMT) or Inspector did not fully understand a document translated from another language into their native language."

In our work, we have been visiting sites worldwide to measure the frequency of these scenarios, and evaluating the effectiveness of countermeasures. An intervention experiment has been designed and tested using a sample of 941 maintenance personnel from countries in Asia, Latin America, Europe and USA. In addition, data on reported frequency of these scenarios and factors associated with their occurrence was collected on the same sample.

Methodology

Three aspects of interest formed the basis for our data collection efforts, designed specifically to answer FAA questions about the nature and frequency of language errors and possible interventions to reduce these errors.

Demographic data were collected: age, gender, experience and reading level. The Accuracy Levels Test produced on the scale of reading grade level normed on US public schools.

For each of the seven scenarios the incidence questionnaire first asked whether each had ever been encountered. Respondents were asked whether the scenario occurred in the past week, month, year or longer. Also for each scenario, participants were asked to check the factors associated with increased likelihood of the error occurring (9 factors), with mitigating each error (10 factors) and with the discovery of each error (6 factors). The factors came from our previous analyses of databases of errors and focus groups used to derive the scenarios (Drury and Ma, 2003).

To test for how potential documentation errors can be reduced, we measured the effectiveness of document comprehension. In the study, a single task card was given to participants, with a 10-item questionnaire to test comprehension (e.g., Chervak, et al., 1996). The comprehension score was measured by the number of correct responses, with time taken to complete the questionnaire as an additional measure. Two task cards, Easy and Difficult, were used. There were five interventions:

1. The translation of a document into AECMA¹ Simplified English
2. The provision of a Glossary
3. The provision of a bilingual coach
4. The translation of a document and all related materials into a native language
5. Partial Translation of all except technical words into the native language plus combinations of Simplified English with the other interventions.

Results: Comparisons across Regions

Note that analysis of all of our data can be at the level of the individual MRO site, the country or the region: Asia, Latin America, Europe or USA. Individual countries and sites have been compared in the final report, but here we examine regional commonalities and differences.

Reading Levels

Within each region the reading grade levels were typically 4.5 to 5.5 for the samples tested. Higher levels were found where the countries or areas had a history of bilingualism in English: Puerto Rico in Latin America (10.0) and Hong Kong in Asia (6.6). In the USA and England for comparison, Reading Grade levels were very

high, about 14, as has been found in earlier studies of AMTs (e.g. Drury, Wenner and Kritkauski, 1999). Overall written English comprehension was at quite a high level throughout: about 5th grade in countries where English is not native or bilingual. The 5-6 grade levels of English reflect an often-stated aim of documentation to be written for a “6th Grade level”, although such a recommendation was never meant to apply specifically to aviation maintenance English.

Scenario Frequency and Factors Affected

The seven scenarios were found to be well-supported in all regions. There were differences in reporting these errors across the countries, but consistency across countries was high. A Friedman test of differences between scenario frequencies for the four regions showed a highly significant difference between scenarios ($S(6) = 18.9$, $p = 0.004$), i.e. substantial agreement across regions. Three scenarios gave high frequencies:

Scenario 1: “The Mechanic (Aircraft Maintenance Technician, AMT) or Inspector was not able to communicate verbally to the level required for adequate performance.”

Scenario 2: “The Mechanic (AMT) or Inspector and the person to whom they were speaking did not realize that the other had limited English ability.”

Scenario 6: “The Mechanic (AMT) or Inspector did not fully understand documentation in English, for example a Workcard or a Manual.”

The most frequently reported scenarios were the ones associated with direct communication surrounding the work itself. All three of these had reported return frequencies between 4 and 10 times per year, and reflected imperfect written communication (work documents) or imperfect verbal communication. The written communication difficulties occurred between the user and English documentation. The examples of scenarios collected from our focus groups confirmed this.

Factors seen as influencing scenario incidence also had a large measure of agreement across regions. For Error Likelihood factors a Friedman test similar to the one for scenario incidence was also highly significant ($S(8) = 21.3$, $p = 0.006$), showing high agreement on the relative importance of these factors. There was a consistent group of four highly rated factors:

¹ Aircraft European Contractors Manufacturers Association

- The mechanic (AMT) or inspector has inadequate written English ability.
- The mechanic (AMT) or inspector has inadequate verbal English ability.
- The task instructions are complex.
- Time pressure makes the mechanic (AMT) or inspector hurry.

The first two are connected to the individual performing the task. The third is a function of the documentation while the final one is part of the social environment of maintenance.

Prevention factors showed a similar pattern. Again, the Friedman test gave significant factor differences across regions ($S(9) = 22.5$, $p = 0.007$). The five most frequently cited factors that could prevent a language error were:

- The mechanic (AMT) or inspector is familiar with this particular job.
- The document follows good design practice.
- The document is translated into the native language of the mechanic (AMT) or inspector.
- The document uses terminology consistent with other documents.
- The mechanic (AMT) or inspector uses the aircraft as a communication device, for example to show the area to be inspected.

These again show individual factors, document factors on one procedural factor: using the aircraft as a communication device.

Error discovery factors were also consistent across regions ($S(5) = 18.3$, $p = 0.003$), with just two emerging as highly reported:

- The mechanic (AMT) or inspector asked for assistance or clarification.
- The mechanic (AMT) or inspector appeared perplexed.

Note that both rely on feedback from the message recipient to the message sender, as our communication model (Drury and Ma, 2003) would suggest. Note also that both occur very early in the process: detection of language errors is typically reported well before any maintenance/inspection errors have been committed, or the aircraft is released for service.

The typical picture arising across all of the measures is that language errors of many types are possible, although only a few are frequent, with a language error-prone activity having consistent characteristics:

- Complex task instructions
- Poorly designed document, in English
- Users with low ability in English and low familiarity with the task to be performed
- Time pressure to complete the task

When listed in this way, language errors appear to have all of the usual human factors ingredients for error, not just language error. All of these, apart from low ability in English, can be found in standard texts in human factors, such as Wickens and Hollands (2000) as well as those specifically directed at aviation maintenance, e.g. *Human Factors Guide for Aviation Maintenance* (Maddox, 1998). The implication is that if the “usual” error-shaping factors are present, then the “usual” interventions should be effective, e.g. training (Taylor, 1993), documentation design (Drury and Sarac, 1997), organization design (Taylor and Felten, 1993; Reason, 1997). We see more evidence for effective interventions as we add the results from the intervention effectiveness experiment and the focus groups.

Intervention Effectiveness

Direct measurement of intervention effectiveness produced significant results, largely consistent across interventions, regions and task cards, i.e. interactions were almost completely absent, making interpretation simpler. First, as expected, Reading Grade level and Age were highly significant covariates across all measures. Younger participants and those with better reading skills performed better, as has been seen in other studies of document comprehension (Drury, Wenner and Kritkauskay, 2000). Such results now extend to a non-native English speaking population. The significant Reading Grade Level correlations show that increasing mastery of English will have a significant impact on comprehension and is a vindication of the English language training programs invested in by many of the MROs we visited.

For the main factors in the intervention effectiveness experiment, the results were again consistent across regions. Intervention effectiveness, measured by comprehension performance, was largely unaffected by

anything except some form of task card translation, either full translation or translation of all except technical terms. Surprisingly, Simplified English had no consistent effect, in contrast to our earlier findings that Simplified English was most effective for non-native English speakers (Chervak and Drury, 2003). That finding was for non-native English speakers in the USA, so perhaps SE is less useful when applied in a setting where the native language is other than English. This negative finding appeared for both Chinese and Spanish speakers. Similarly, neither the interventions of a bilingual coach or a glossary produced any significant results, despite their widespread use as interventions at MRO sites. We suspect that at least part of that is due to the fact that almost none of the participants given these interventions used them during the comprehension test. In hangar floor observations AMTs *did* discuss their work with bilingual supervisors and often produced well-worn English / native language dictionaries. Also note that this experiment was entirely between participants, a safe but relatively low power design in the face of the large individual variability. The fact remains that the only consistent significant intervention was translation.

A direct visual comparison of the effects of translation in different countries and areas is shown in Figure 1 with arrows showing changes between baseline condition and translation.. No statistical comparison was attempted: our aim is not to measure whether one country is “better” or “worse” than another but to integrate the large mass of data across world regions. The USA and Hong Kong did not use translations.

Several points emerge from the baseline data on this graph. First, the USA had consistently the highest accuracy and lowest time: any other result would indeed have been surprising. Second, for the baseline condition, the “best” country or area in each region was the one where bilingualism was the norm: Hong Kong and Puerto Rico. Third, the one European country, Spain, had good performance compared to other Spanish speaking countries, as was expected from the OEM survey results (Drury and Ma, 2004).

When considering the data on translation, a new and interesting picture emerges. First, the accuracy of all countries and areas is now quite comparable, all between about 70% and 80% accurate. [Note that our comprehension test was quite difficult so that 100% would not be expected based on previous results from the USA.] Second, translation has brought up the accuracy

performance of all Spanish-speaking countries. At times this was accompanied by an increase in performance

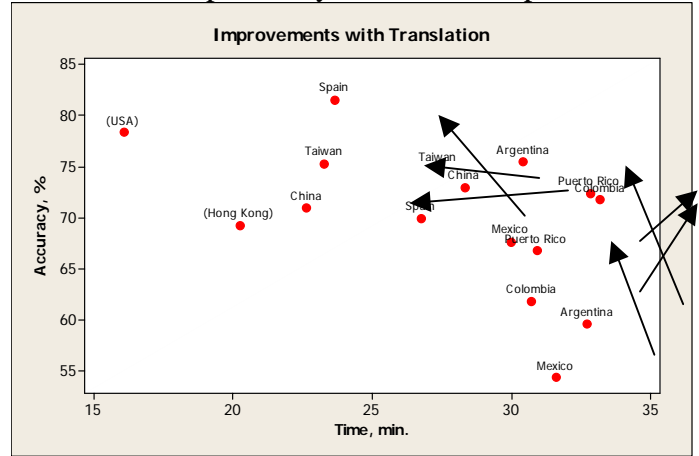


Figure 1. Changes in accuracy and time from baseline to translated conditions

speed, while at other times it was not. Third, there was a contrast between Asian countries where translation did not improve accuracy but reduced performance time, and the Spanish-speaking countries where accuracy did improve. In Asia, participants opted for constant (and high) accuracy, letting speed suffer. That is exactly the response the traveling public and regulators would like to see. In Latin America and Spain, accuracy was brought up to a high level by translation, even in Spain where the accuracy was high anyway. From the intervention effectiveness study, the conclusion is that translation works as an error control strategy, bringing accuracy performance to about the same level as in the USA. However, other considerations may be important in choosing translation as an intervention.

Conclusions

Testing of language error scenario incidence, intervention effectiveness and focus groups to learn industry best practices was performed on 941 participants on four continents. Language error was found to be a potential problem in contract maintenance performed in non-English-speaking countries, although detection and mitigation were generally effective.

Three scenarios, related to AMT abilities to understand written and verbal communication in English were the most frequent, being seen by participants about 4 to 10 times per year. Most language errors were detected early in the communications process. The

reading grade level of participants at USA MROs was about 14 as found in earlier studies. For MROs on other continents, the reading grade level was about 5, with higher levels where there was a history of bilingualism. On all continents, task card comprehension performance improved with reading grade level. In that test, accuracy performance was generally good, and was better in areas that were bilingual. None of the interventions except translation proved effective. Partial translation, leaving technical terms in English, proved as effective as full translation. The use of good practices in documentation design was seen as a contributing factor to language error mitigation.

A set of practical interventions emerged from the scenario frequency estimates, the comprehension test and the focus groups. Design of work documentation is the primary way to reduce written language errors. Good design practice helps reduce errors and translation into the native language, if performed carefully, was found to increase document comprehension. Individual ability of Aviation Maintenance Technicians (AMTs), inspectors, managers and engineers in written and verbal English communication was important, and can be improved by training and controlled practice. The organizational environment should recognize the deleterious effects of time pressure on errors, and also recognize the symptoms of imperfect communication when it occurs. The organization also needs to plan work assignments to allow AMTs to become more familiar with particular tasks, and provide planned English practice for all personnel. Time pressure on tasks needs to be managed if language errors are to be reduced.

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MAINTENANCE ASAP PROGRAMS: BARRIERS AND OPPORTUNITIES

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Aviation Safety Action Programs (ASAPs) in aviation maintenance organizations offer aviation maintenance technicians the mechanisms to report errors without a fear of retribution and contribute toward the development of a safer air transport system. Although the number of maintenance ASAP programs has more than doubled in the past two years, the key barriers of interpersonal trust and awareness continue to restrict the full potential of these programs. While some organizations continue to struggle with these barriers and are unable to implement an ASAP program, others are striving to increase the number of sole-source reports by increasing the awareness about ASAP programs among their stakeholders and also building industry-wide support groups to develop a stronger networking mechanism that would ultimately advance the entire industry's safety culture. As these efforts continue to progress, unique opportunities for collaboration and data mining are arising. This report presents an analysis of the two key barriers and presents a preview at how contemporary text analysis systems could be used to expand the overall value of the data collected by ASAP programs.

INTRODUCTION

Aviation Safety Action Programs (ASAPs) are specific error reporting programs designed to encourage mechanics, pilots, dispatchers, and flight attendants to report their errors through their respective ASAP programs. Each company needs to have its own ASAP agreement with the Federal Aviation Administration (FAA), and each agreement is specific to either the maintenance, flight, dispatch, or flight attendant group. While these programs are generally accepted as effective mechanisms for identifying and resolving systemic issues, different groups have their own unique challenges and therefore differ in the nature of their participation. For example, as of September 1, 2005, there were 45 flight ASAP programs, 21 maintenance and engineering ASAP programs, 20 dispatch ASAP programs, and 5 flight attendant ASAP programs (http://www.faa.gov/safety/programs_initiatives/aircraft_aviation/asap/participants/). Also, flight ASAP programs tend to have

about ten times as many reports as the maintenance programs do. Therefore, the effectiveness of the overall ASAP program should not be measured by the number of reports alone. Patankar and Driscoll (2005) define a successful maintenance ASAP program as,

“the one that has matured to such a level that there is a regular flow of ASAP reports, there are personnel dedicated to maintaining, analyzing, and implementing these reports, and there is a mechanism established to provide feedback regarding the overall effects or impacts of the ASAP program.”

Patankar and Driscoll (2005) also noted that maintenance ASAP programs tend to be “networked” while flight ASAP programs tend to be “linear.” Therefore, the investigation of maintenance ASAP reports is a lot more complex and time-consuming task than that of flight ASAP programs.

The overall goal of this research project is to identify the key barriers to successful maintenance ASAP programs and to

document the best practices from certain ongoing ASAP programs that may be of value to other fledgling programs.

In the first phase of this research, reported by Patankar and Driscoll (2005), a survey questionnaire was developed to identify the key success/failure factors. Over 5,000 maintenance personnel responded to the survey. Based on this survey, the factors that tend contribute toward a successful ASAP program in aviation maintenance organizations are as follows:

- There is a significantly higher level of trust between mechanics and their supervisors
- End-users perceive ASAP programs to be very valuable in improving the overall safety of the industry
- Good communication about the ASAP program and a standardized or a well-understood report handling process exists

Based on the same survey, factors that contribute toward the failure of an ASAP program in aviation maintenance organizations are as follows:

- There is a significantly lower level of trust between mechanics and their supervisors
- End-users don't seem to see a significant benefit in having an ASAP program—it is likely that they are satisfied with their internal error/hazard reporting program
- There is a severe lack of awareness about ASAP programs

In the second phase of this research, emphasis was placed on (a) seeking a qualitative or descriptive clarification regarding the barriers for maintenance ASAP programs and (b) testing the applicability of computerized text analysis systems to enhance the overall analytical capabilities.

LITERATURE REVIEW

This literature review focuses on two areas: (a) the value of interpersonal trust and awareness of ASAP program and (b) issues germane to the investigative challenges of qualitative reports and structured error classification schemes.

Interpersonal Trust and Awareness of ASAP Programs: The two broad challenges discovered through the survey research in the first phase of this project were lack of interpersonal trust and lack of awareness about maintenance ASAP programs.

Many research studies have identified interpersonal trust as a critical and essential factor in proactive error management programs (cf. Taylor & Christensen, 1998; Taylor & Thomas, 2003; Patankar & Taylor, 2004; Patankar, Taylor, & Goglia, 2002; Patankar & Taylor, In Press). While it is widely acknowledged that trust is essential, it is also perceived that “trust is hardest to establish when you need it the most” (Duck, 1998 p. 69). Therefore, it is important to understand the specific actions or inactions that might contribute toward a positive or a negative effect on the overall trust scale.

The Interpersonal Trust Scale: The interpersonal trust scale has emerged as one of the most significant measures during the course of multiple longitudinal studies that measured the effectiveness of Maintenance Resource Management (MRM) programs (cf. Taylor & Christensen, 1998; Taylor & Thomas, 2003; Patankar & Taylor, 2004; and Patankar & Taylor, In Press). Based on these studies, it is known that there is a wide variation in such trust among the various maintenance organizations—interpersonal trust tends to be higher in smaller organizations and military units and lower among larger organizations—the range of trust values seem to indicate that up to a third of the mechanics don't tend to trust that their supervisors will act in the interest of safety. Patankar and Driscoll (2005) not

only confirmed that finding across a national sample of over 5,000 maintenance personnel, but also discovered that the mechanic-management trust in companies with ASAP programs was significantly higher than those without ASAP programs.

The questionnaire items that constitute the trust scale—both in the MRM/TOQ (Taylor & Thomas, 2003) and in the Maintenance ASAP Questionnaire (Patankar & Driscoll, 2005) are as follows:

- My supervisor can be trusted
- My safety ideas would be acted on if reported to supervisor
- My supervisor protects confidential information
- I know proper channels to report safety issues

Lack of Awareness: A lack of awareness regarding the ASAP program is not just a public relations issue, but it is a matter of intentionally educating the stakeholders in the value, application, and overall significance of the program. The literature on intentional education of the stakeholders is limited; however, experience from MRM research indicates that a general awareness training program has been successful in informing the stakeholders of the relevance and value of the MRM program, in developing a common language that incorporates the key terminology and builds a shared understanding or mental model, and in involving the stakeholders in identifying key issues that need to be addressed for the program to take hold and mature to a higher level of acceptance and development (Taylor & Christensen, 1998; Patankar & Taylor, 2004).

Knowledge regarding maintenance ASAP programs seems to have spread mostly by people who were interested in developing such programs rather than a coordinated effort to educate the stakeholders. Since labor unions tend to represent technicians from multiple

organizations, they serve as a valuable conduit for transfer of best practices across organizational boundaries (Taylor & Christensen, 1998; Patankar & Taylor, 2004). Additionally, the FAA offers a training course on ASAP for its inspectors and has also published an Advisory Circular (AC-120-66B). Key people in the industry have used these resources to develop the ASAP programs for their respective companies; however, there is no evidence of a formal training program in any of the companies. Some companies have started to incorporate ASAP fundamentals in their existing MRM training program. While this is an effective means to raise the awareness, it is not widespread. One other company has used the “traveling road show” approach to have their Event Review Committee (ERC) go to various line and base maintenance stations to discuss the ASAP program face-to-face with the mechanics. They report that this approach has resulted in a significant increase in their sole-source reports (Patankar & Gomez, 2005).

Another mechanism that is starting to gain some momentum is the Maintenance and Engineering Subcommittee of the industry-wide ASAP/FOQA Aviation Rulemaking Committee. The maintenance subcommittee was formed in October 2004. Since then, the committee has started to gain increasing visibility and interest. Its membership is increasing and it is shaping an agenda that will not only raise the awareness of maintenance-specific ASAP issues, but also assist in building maintenance-specific error classification schemes that could be mapped with the overall industry’s Voluntary Aviation Safety Information-Sharing Process (VASIP).

Qualitative Reports Analysis: Challenges and Opportunities: Typical ASAP reports tend to be narrative text data. Such reports

are submitted to the program manager and then either the manager or the analyst codes the report using a structured coding scheme such as Boeing's Maintenance Error Decision Aid (MEDA) (Rankin & Allen, 1996) or an internal version that incorporates some additional fields that are important to that company. The prevalent analysis technique seems to be limited to the use of a structured classification system to code the incoming reports and to the presentation of its results in the form of bar charts or frequency tables (Patankar, 2005).

The flight ASAP community is developing VASIP, a data-sharing model that will allow multiple companies to share their ASAP reports. In order for such a system to work, the data classification schemes need to be compatible. Researchers from NASA and University of Texas researchers engaged in a project to develop a mapping system that would allow the partner companies to use their existing classification systems by translating the coding scheme to enable meaningful comparison across the companies (Chidester, Harper, & Patankar, 2005).

The maintenance community now has the unique opportunity to develop a common classification system that would not only map across the partner companies for maintenance ASAP reports, but also connect with the flight ASAP programs and enable cross-domain data mining (Chidester, Harper, & Patankar, 2005).

METHODOLOGY

In this research, emphasis was placed on (a) seeking a qualitative or descriptive clarification regarding the barriers and opportunities for maintenance ASAP programs and (b) testing the applicability of computerized text analysis systems to enhance the overall analytical capabilities.

Qualitative or Descriptive Clarification Regarding Barriers and Opportunities:

Prior phase of this research indicated that the two main barriers to implementing a successful ASAP program in aviation maintenance organizations were lack of interpersonal trust and lack of awareness.

An information sharing meeting was organized at Saint Louis University to inform airlines, repair stations, and FAA inspectors about ASAP programs and to solicit their feedback based on their experiences with either trying to get an ASAP program approved or in running the already approved program. This was an open discussion and its results are presented in the results sections of this report.

Computerized Text Analysis Systems:

One hundred ASAP reports were analyzed using a commercial off-the-shelf text-analysis tool called LexiQuest. This tool enables the analyst to submit narrative text reports and it analyzes these reports to identify related concepts. The analyst can then choose specific relationships for further investigation. This was an exploratory study to determine the potential applicability of such a system in the analysis of ASAP reports.

RESULTS

Discussion on Barriers to ASAP Programs:

A group of 30 individuals from airlines, repair stations, FAA Certificate Management Offices, labor unions, and FAA Headquarters participated in this discussion.

This group was asked to describe the specific barriers they faced in implementing ASAP programs. After the presentation of several specific examples and personal experiences, the following general results emerged:

- Corporate disciplinary policies that conflict with the intent and spirit of ASAP programs tend to stall ASAP agreements. If companies could adopt ASAP-friendly disciplinary policies, the number of ASAP agreements would increase. Labor unions are willing to negotiate a language that protects honest mistakes and penalizes intentional disregard to safety.
- Blame culture in the maintenance environment, coupled with lack of trust between the management, labor groups, and the local FAA inspectors, is a bigger barrier than the corporate disciplinary policy. This blame culture is exacerbated by variances in the awareness of both the intent as well as the value of an ASAP program in the three groups.

The following points were also expressed to further clarify:

- Company discipline, in general, is not an FAA issue. The standard language recommended in the ASAP MOU template is that information obtained exclusively from ASAP investigations will not be used by the company or the FAA.
- If the company obtains information from other sources and there is an associated ASAP report, then the company should extend similar disciplinary protection to the reporter—this is not in the ASAP policy. According to the policy, the company can use non-sole source information, obtained outside the ASAP process, for disciplinary action. This is where interpersonal trust, labor-management relationships, and past experience with confidential information play a significant role.
- When one ASAP ERC discussed their program with personnel from base and line maintenance, top management, and their human resources department, they

discovered that most people did not know much about the ASAP program. Now, they communicate with everyone regularly and the acceptance of the program is growing.

- The ASAP program is more important than the individual issue [of disciplining] and excessive or disciplinary action in the rarest of cases would threaten the program all together; it could collapse; it's all trust.
- As instances of actual changes made as a result of this program become more visible, the overall awareness and acceptance of this program will grow.

In summary, the trust and awareness issues are connected. Because some people are not fully aware of the intent, protocol, value, and effects of an ASAP program, there are some misconceptions about it in the industry. These misconceptions are compounded by the deeply routed blame culture which tends to focus on applying corporate disciplinary policies to punish the individual(s) who committed the error rather than addressing the systemic issues.

Computerized Text Analysis Systems: In order to test the capability of LexiQuest as a text-analysis system, 100 ASAP reports were used to explore some additional ways in which such data could be analyzed.

Generally, a text-analysis system detects unique concepts expressed in the narrative text—these concepts could be words or phrases. Then, the system groups these concepts based on their statistical relationship or proximity.

In this sample, the word “aircraft” appeared 65 times, the word “maintenance” appeared 28 times and the word “logbook” appeared 19 times. Such listing of how often a word appears in the dataset provides a perspective on which concepts may be mentioned more frequently than others.

Granted, just because a concept is mentioned more frequently does not mean that it is more important to explore. The fact that aircraft is mentioned 65 times is a case in point. So, we focused on the concept “logbook,” which was mentioned 19 times and had nine other concepts associated/linked with it.

Figure 1 is called “Concept Map.” It presents a network of concepts that are linked to each other. The farther we go from the core concept, the weaker the connection among those concepts. That means concepts in the first arc appear more frequently near “Logbook;” concepts in the second arc appear less frequently near “Logbook;” and the concepts in the third arc appear even less frequently near “Logbook.”

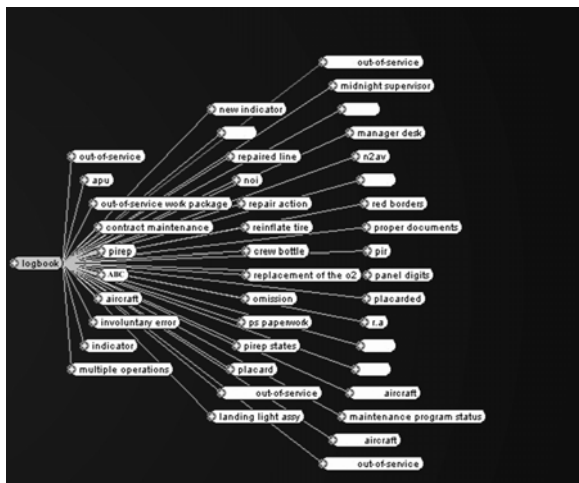


Figure 1: Concept map for the term “Logbook”

It is important to note that less frequently linked concepts or deeply buried concepts could be mined or “excavated” to identify “low-frequency---high-consequence” events. These are the events that occur less frequently or rarely, but could have a high-consequence. Typically, these events are lumped into the “other” category by structured classification systems. Also,

these links are buried so deep in the narratives that it is likely to completely miss the relevance of such links. For example, in

the case of logbook errors, typically, one would respond to such errors by simply adding a training course, especially when there is a deep, but valid link between “Logbook” and “Improper Logbook Training.” As we drilled deeper to identify additional concepts that may be linked with “Logbook,” we discovered that that “Improper Logbook Training” was linked with “Logbook,” “Contract Maintenance,” and “PIREP.”

In this sample, it seems that logbook errors are related to contract maintenance. So, prior to determining what type of training may be required, it would be important to understand what is needed and where it is needed.

In summary, there are two types of analysis systems: static and dynamic. The MEDA-type system is a static system and the text analysis system is a dynamic system. Both systems are complementary to each other and could enhance each other’s effectiveness. A static system could be used to keep track of the overall trends in maintenance errors and the effects of specific interventions; whereas, a dynamic system could be used to drill-down to specific low-frequency---high-consequence events that are difficult to detect otherwise.

Significance of the Results: Generally, this project is making a significant contribution toward facilitating the transfer of best practices across the various maintenance ASAP programs through information-sharing meetings. Such efforts of this project will result in a more cohesive feedback to the FAA from the maintenance community. For example, some key changes to the current AC 120-66B are being considered by the ASAP Maintenance Subcommittee.

Similarly, this research project is playing a key role in preparing the maintenance community to participate in the industry-wide VASIP program. Efforts are underway to take the knowledge of text analysis systems and build a consistent error classification scheme for the maintenance community that incorporates both structured as well as unstructured data analysis. These efforts will prepare the maintenance community to realize full benefits of the VASIP program.

CONCLUSIONS

First, interpersonal trust and awareness are related. Therefore, industry groups such as the Maintenance and Engineering subcommittee and appropriate labor organizations could make a significant contribution toward raising the awareness of maintenance-specific issues and enabling the transfer of best practices across organizational boundaries. As the awareness of the value and effects of an ASAP program increases, the trust in this program as well as among the people in charge of such a program is bound to increase.

Second, initial tests of the text analysis system indicate that such analysis could uncover deeply hidden systemic hazards that would not be detectable by the conventional error classification systems. A hybrid system that incorporates the advantages of both structured as well as unstructured techniques would be invaluable.

ACKNOWLEDGMENTS

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MODELING THE USE OF COMPUTER AND BROADBAND TECHNOLOGY IN THE AIRCRAFT LINE MAINTENANCE WORKPLACE

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ABSTRACT

Five models of the aircraft line maintenance process were created after shadowing line maintenance crew at a major air carrier maintenance facility over a period of several months. These models include: (1) the physical layout of the facility, including arrangement of artifacts and the distances between them; (2) the artifacts used by technicians along with a quantification of the steps required to use them; (3) the cultural relationships between participants in the maintenance process; (4) the flow of information between participants; and (5) a computer simulation of the sequence of steps required to service an inbound aircraft: including routine inspections, scheduled maintenance, deferred items, squawks reported by the flight crew, and squawks discovered during inspections. The five models are used to make specific recommendations about how computer and broadband can successfully impact safety in the line maintenance workplace.

Introduction

Casner and Puentes (2003) surveyed the marketplace of computer and broadband technologies as well as the use of these systems at aircraft maintenance facilities. Computer/broadband technologies were found at every maintenance facility surveyed. While some systems enjoyed regular use among maintenance technicians, other systems were regarded as having little practical use. Interviews were conducted with both managers who acquired computer/broadband systems as well as with maintenance technicians who would ultimately use (or not use) the systems. It was found that computer/broadband technology was viewed differently by these two groups. Managers' views of technology were often based on efficiency and costs concerns, while maintenance technicians' views were based on learnability and practical usability of the technology. In many cases, benefits were not realized in everyday practice because maintenance technicians did not feel that the technologies directly addressed their needs while working on the ramp, or suffered from design flaws that made the technology inconsistent with the way they do their jobs.

Casner, Encinas, and Puentes (2004) explored the issue of practical use of computer/broadband technology by creating a task analysis: a sequential, step-by-step description of the process that line maintenance technicians use when handling an aircraft in need of maintenance. An analysis of this sequential task analysis revealed that computer/broadband systems were used during most phases of the line maintenance process with one important exception. Other than providing technicians with electronic copies of existing documentation, the task analysis showed that no technology was available to support the problem of troubleshooting and solving maintenance problems. Technicians' responses to a questionnaire further indicated a mismatch between the capabilities offered by existing computer/broadband applications and the needs of the maintenance technician while performing their job. The task analysis and questionnaire responses also pointed to the need for an analysis that goes beyond the simple listing of steps in the existing work process. A key limi-

tation of that approach is that it overlooks many of the features of a work environment that influence the work process. At one maintenance facility we surveyed, technicians made reference to a technician, who no longer worked there, who had an unusual degree of familiarity with the MD-11 aircraft. Resolving a puzzling problem was often a simple matter of talking to that technician when he was on duty.

This study extends our previous modeling work beyond the simple detailing of work process steps. We use a technique prescribed in Beyer and Holtzblatt (1998) that attempts to make explicit more of the features of the work environment that influence the work process. Beyer and Holtzblatt (1998) argue the need for designers to create five types of analyses, called *work models*, for every workplace in which technology is to be introduced. These five models look at the work environment in different ways and attempt to capture the constraints under which workers do their business.

Flow Model: Details the division of labor in a work environment and shows how workers communicate or transfer the results of their work between each other to orchestrate a finished product.

Cultural Model: Makes explicit the constraints imposed by human relationships between all people involved in the maintenance process.

Artifact Model: Describes the tools that workers currently use to do their jobs.

Physical Model: Details the physical layout of the workplace: the arrangement of workers, the artifacts they use, and the distances between them.

Sequence Model: Outlines the individual steps in each task performed by each worker.

Collectively, Beyer and Holtzblatt describe these models as the "five faces of work" and stress how the five models

inform each other to define the work environment. For example, the flow model and the physical model can be used to discover inefficiencies in the layout of a workplace or the steps used to complete a task. For example, if two artifacts are used in sequence but are separated by a great distance, the workplace might be rearranged or the steps in the task reordered.

Five Models of the Line Maintenance Workplace

Five models were created to describe the operation at one major air carrier line maintenance facility.

Flow Model: Questionnaire responses from Casner, Encinas, and Puentes (2004) indicated that technicians place heavy emphasis on communication between technicians while troubleshooting. The flow model shown in Figure 1 suggests several immediate ways that technology might improve communication between maintenance technicians.

Technicians who work during the same shifts currently talk to each other by traveling around the ramp or by using personal cell phones. Traveling to other areas on the ramp uses time and draws technicians away from the job they are currently working. Cell phones typically only allow two technicians to talk at once unless special conferencing capabilities are purchased. Setting up a conference call typically requires more work than is practical for short information exchanges. One application of computer/broadband technology might be a device that allows technicians to easily talk in groups.

Technicians at work are currently unable to use expertise of technicians that are not currently working on shift. The flow model makes explicit how computer/broadband technology could be used to enrich the flow of information between technicians in two ways. First, technology could be used to expand entries that are left in "passdown logs": notes left by technicians who were unable to resolve a maintenance problem during their own shift. Second, questionnaire responses from Casner, Encinas, and Puentes (2004) indicated that technicians felt the need for some type of archival database of previous maintenance problems and solutions. Passdown logs only allow for the transfer of knowledge between technicians who work on the same aircraft, usually on consecutive shifts.

The flow model also raises the question of how well technicians' expertise is known to other technicians. It is an open question of how many times do technicians call an off-site maintenance control facility with a question that might quickly be answered by someone working on the ramp.

Cultural Model: The cultural model shown in Figure 2 diagrams some of the relationships between the people who interact during the maintenance process. At the facility we surveyed, the relationship between technicians and the lead technician was highly functional. The lead technician's job was to support other technicians. The lead technician had expertise and the time to share that expertise with others. The lead technician often did the preliminary work for technicians

so that they could start immediately on technical problems.

The relationship between technicians and flight crews was somewhat less functional. Flight crews wrote up maintenance issues in the aircraft logs and left them for technicians to read. Since this information was the starting point for technicians' problem-solving, technicians often wanted more information. Technicians reported that flight crews did not understand how valuable pilots' verbal inputs were in the troubleshooting process. Flight crews often came off of a tiring flight or were in a hurry to make another flight and seldom had enough time to talk to technicians to answer all their questions. This suggests the need to improve the flow of information between flight crew and technician. Barshi and Chute (2001) have suggested co-training for workers in different jobs who must work cooperatively (e.g., pilots and air traffic controllers). Casner et al (2005) provides ASRS reports that detail instances of breakdowns between flight crews and technicians.

Another interesting relationship identified by the cultural model is that between technicians and the central maintenance control facility. An important function of maintenance control is to support technicians in resolving maintenance problems. Getting help from maintenance control is often more time-consuming than seeking help from a colleague on-site. Since maintenance control has the goal of ensuring efficiency company-wide, technicians are often told to simply follow all prescribed maintenance procedures and use maintenance control as a secondary resource. A more efficient process that allows technicians to tap expertise of maintenance control might impact safety as well as efficiency. An archival database of stubborn maintenance problems might also address this problem.

Artifact Model: The artifact model in Figure 3 shows the computer hardware, software systems, software tasks routinely performed by maintenance technicians, and non-computer artifacts. There are two types of software tasks: (1) retrieving and printing needed information; and (2) making entries into the systems. We measured the average time to complete each software task and listed these times with the tasks in Figure 3. The times show that while some software tasks are performed quickly, others require lengthy interactions with the computer. A review of the steps required to complete each software task indicate that many tasks could be easily streamlined. The information needed to streamline a software system such as these is a quantification of the frequency at which the tasks are performed. With this information in hand, frequently-performed tasks could be quickly accessed from top-level menus, while less-frequently-performed tasks could be buried deeper in the system. Quantifying the frequency at which tasks are performed is precisely the goal of the sequence model. The safety impact of system interaction times might lie in how they affect technicians' decisions about whether or not to use the system to seek further information.

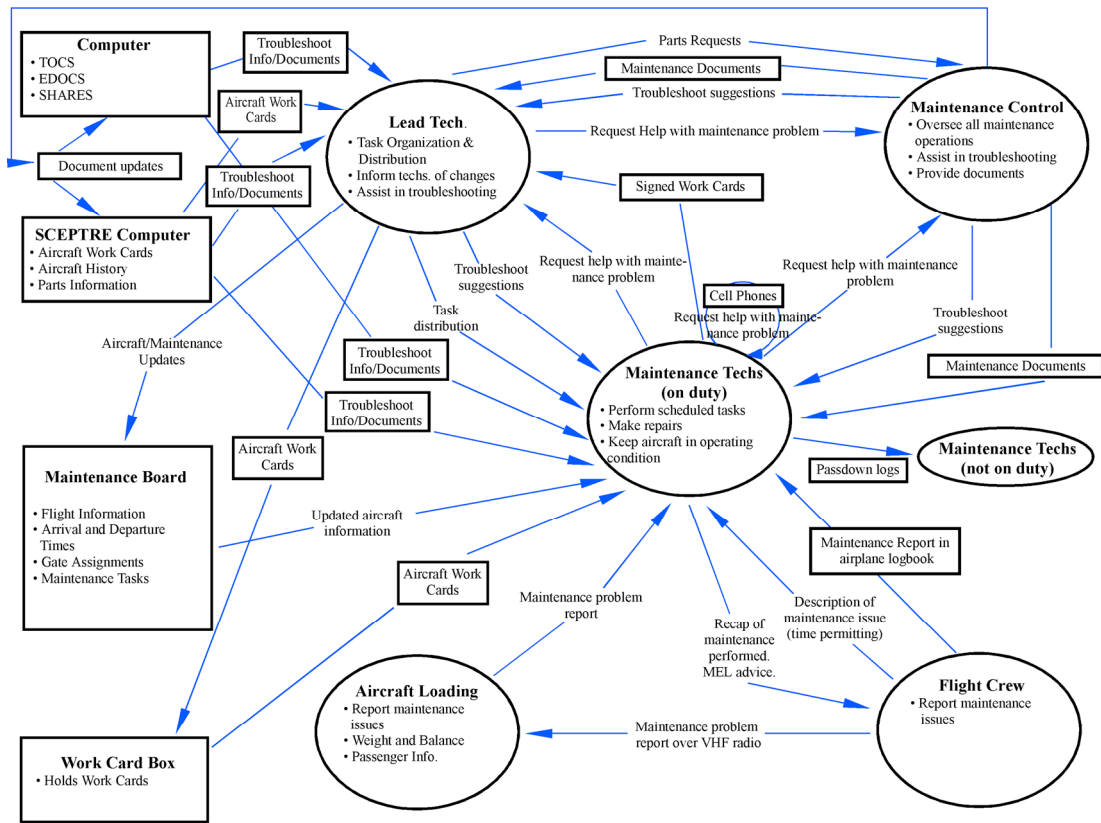


Figure 1: Flow model showing how information flows between entities.

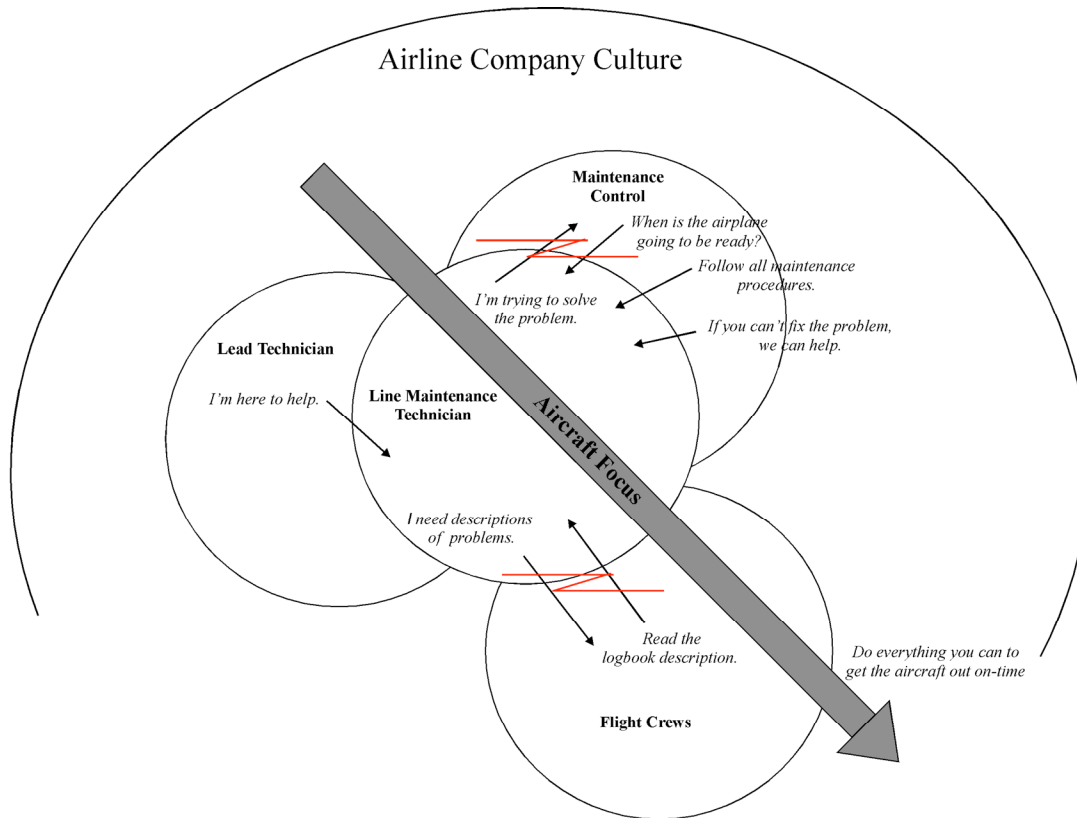


Figure 2: Cultural model detailing relationships between entities.

Technicians made extensive use of the printer, preferring to work with paper documents at the airplane.

Physical Model: The physical model in Figure 4 shows the geographical layout and the location of artifacts in the line maintenance workplace we studied. We used a simple measuring wheel to measure the distances between all important artifacts and locations at the maintenance facility. The layouts and measurements in the physical model are of little interest when considered alone. The arrangement of artifacts only becomes meaningful when we consider the sequence in which the artifacts is used.

Sequence Model: The sequence model is a more detailed rendering of the task analysis performed by Casner et al (2004). To make the sequence model more concrete and accurate, we developed our model as a runnable computer simulation. A sample run of the simulation is shown in Figure 5. The sequence model accepts a collection of aircraft with predefined maintenance issues and simulates, in a step-by-step fashion, the steps followed by maintenance technicians to resolve each maintenance issue. The sequence model uses the task performance times given by the artifact model (Figure 3) and the distances given by the physical model (Figure 4), and tallies the amount of time that technicians spend walking around the facility and the amount of time spent interacting with the computer systems in search of needed information. The sequence model performs all routine maintenance inspections, and attempts to resolve all maintenance problems reported by the crew, problems that have been deferred from previous flights, and all problems discovered during the routine inspection. The sample run shown in Figure 5 required one routine inspection and the handling of five maintenance issues: two problems reported by the flight crew (intermittent PTT switch and a broken seat), two deferred problems (inoperative CSD and a cracked landing gear door), and one problems discovered during the routine inspection (inoperative landing light). Performing all of the tasks required a technician to walk a total of 2,035 feet (0.39 miles) and spend a total of 13 minutes and 36 seconds interacting with the computers to retrieve information.

The sequence model suggests a number of ways in which computer/broadband technology could improve the work process. A first result generated by the model is the tiresome distances that technicians must walk during the course of working an airplane. In the simulation in Figure 5, technicians had to make several trips back to the maintenance office to access electronic documents. In some cases, these trips were required to gather significant amounts of information to perform a job (work cards, manual pages, etc.), and seem mostly justified. In other cases, trips had to be made to look up a single part number in an illustrated parts catalog so the technicians could then make a trip to the parts inventory to retrieve the part. It is clear that a device that allows technicians to remotely access this information, and print out pages from the ramp would be beneficial. Aside from the effici-

ency issue, the ASRS database contains many reports of documents and information being mishandled when time pressures are present and the effort required to retrieve information is significant [Casner et al, 2005]. Casner and Puentes (2003) found wireless laptops at one maintenance facility. However, technicians seldom used them complaining of intermittent wireless connections, limited battery life, and the lack of printers. This further suggests the need for modeling the specifics of the artifacts to be used: simply demonstrating the need for such an artifact is not enough.

A second result generated by the model is the amount of time that technicians spent interacting with the computer systems, validating the observations gleaned from the artifact model in Figure 3. Indeed, long interactions required for individual tasks result in tediousness when the systems are deployed in practical use.

A last issue made explicit by the sequence model is the inefficiency of fault isolation manual (FIM) approach to resolving maintenance problems. Using the FIM, technicians replace one part after another until the problem is resolved. Responses to questionnaire items in Casner, Encinas, and Puentes (2004) indicated that technicians felt that the FIM process often overlooks technicians' own expertise as a troubleshooting resource. Technicians described the parts-replacement strategy (i.e., "shotgunning") as sometimes wasteful. Prescribed procedures such as those found in the FIM have a safety consideration as well. If technicians rely constantly on prescribed procedures and do not exercise their own troubleshooting knowledge, that knowledge will surely atrophy.

Conclusions

A five-dimensional model was developed to further analysis opportunities for the use of computer and broadband technology in the aircraft maintenance workplace. By going beyond a simple breakdown of steps in the maintenance task, the model was used to make several safety and efficiency recommendations.

The flow model suggested the need for technology that improved the way technicians share expertise with one another: not only while working together on-shift, but also across shifts or even careers. The survey of technology in use by Casner and Puentes (2003) suggests that the capabilities afforded by computer and broadband technology to enrich the transfer of information between workers has yet to be realized.

The cultural model suggested the need to improve communication about maintenance problems between flight crews and maintenance technicians. This could be accomplished either by co-training pilots and technicians or by enriching the means by which flight crews record maintenance squawks.

The artifact model suggested the need to redesign the inter-

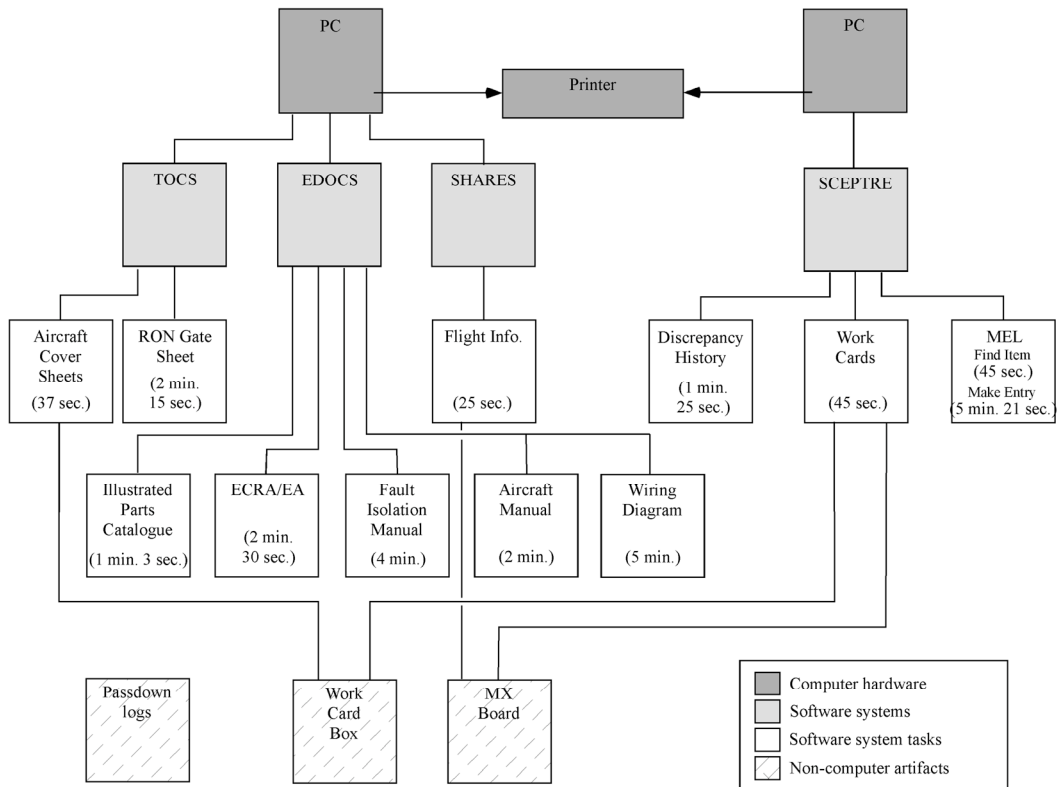


Figure 3: Artifact model showing computer and non-computer artifacts used by technicians. Task completion times are shown for all software functions.

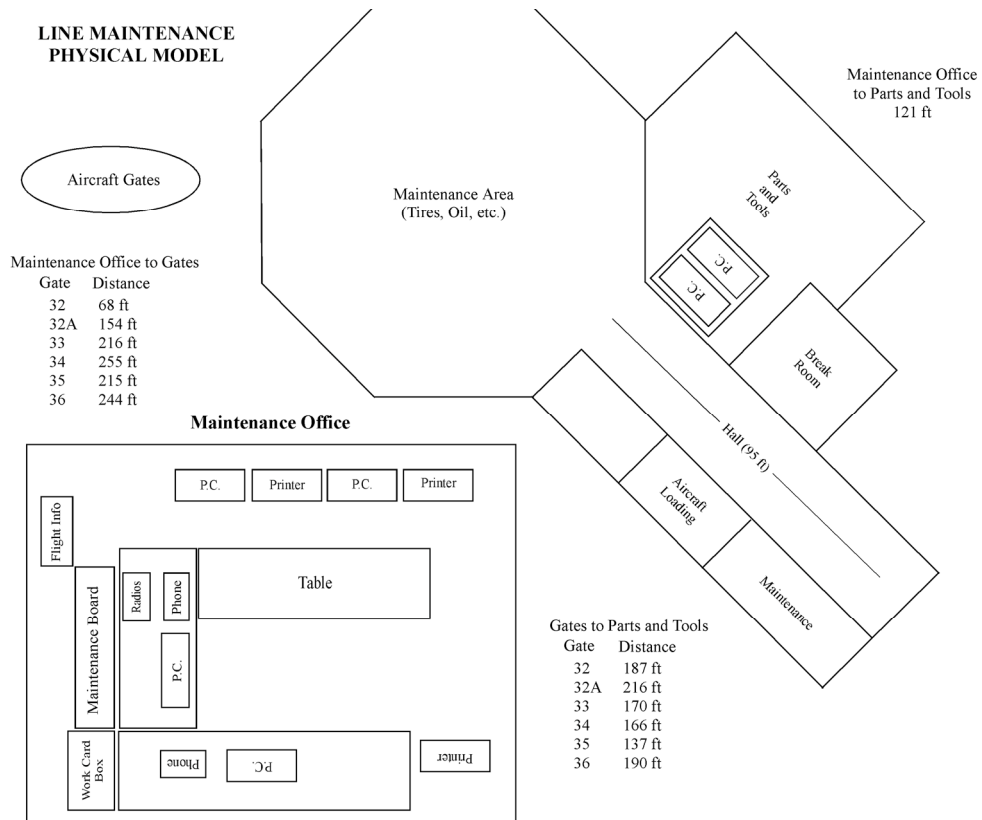


Figure 4: Physical model showing arrangement of artifacts at the line maintenance facility, including measured distances between them.

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sample run
***** BEGIN SIMULATION *****

GOAL: Get assigned airplanes
ACTION: Check passdown log
ACTION: Check maintenance board for assigned airplanes
ACTION: Access SHARES for to verify airplanes, gates, and times

GOAL: Get maintenance tasks
ACTION: Check maintenance board for maintenance tasks

GOAL: Get airplane cover sheets
ACTION: Check workcard box
RESULT: Coversheets not found in workcard box
ACTION: Access TOCS for cover sheet
ACTION: Print airplane coversheets

GOAL: Get routine inspections for airplane 226
ACTION: Check cover sheet for routine inspections
RESULT: Found inspections (S1)

GOAL: Get workcards for routine inspections: (S1)
ACTION: Check workcard box
RESULT: Found workcards in workcard box

GOAL: Check for in-range squawks reports from airplane 226
RESULT: Found the following in-range squawks for airplane 226: (Intermittent
PTT switch)

GOAL: Look up deferred items on airplane 226
ACTION: Check cover sheet for deferred items
RESULT: Found deferred items (CSD inop)
ACTION: Access SCEPTRE for discrepancy history on airplane 226

GOAL: Get DIPs for airplane 226
ACTION: Check cover sheet for DIPs
RESULT: Found DIPs (Landing gear door cracked)

GOAL: Get ECRAS to complete DIPs for airplane 226
ACTION: Check workcard box
RESULT: ECRAS not found in workcard box
ACTION: Access EDOCS for ECRAS
ACTION: Print ECRAS

GOAL: Gather troubleshooting resources before meeting airplane 226
ACTION: Access EDOCS for FIM
ACTION: Print FIM page
ACTION: Access EDOCS for illustrated parts catalog
ACTION: Get part number from IPC
ACTION: Travel to PARTS
RESULT: Parts found

GOAL: Perform routine inspections on airplane 226
RESULT: Problem discovered during inspection of airplane 226: Landing light
inop

GOAL: Defer Landing light inop
ACTION: Check MEL for Landing light inop
RESULT: Problem not deferrable ... attempting to fix

GOAL: Quick fix Landing light inop
ACTION: Calling office for parts lookup
RESULT: Technician available to lookup parts
ACTION: Travel to PARTS
RESULT: Parts found
ACTION: Travel to TOOLS
RESULT: Tools found
ACTION: Travel to gate 34
RESULT: Problem resolved

GOAL: Get squawks for airplane 226
ACTION: Check with flight crew for squawks
ACTION: Check aircraft logbooks for squawks
RESULT: Found the following squawks (Seat 3C reclining)

GOAL: Defer Seat 3C reclining
ACTION: Check MEL for Seat 3C reclining
RESULT: Problem not deferrable ... attempting to fix

GOAL: Quick fix Seat 3C reclining
ACTION: Calling office for parts lookup
RESULT: Technician not available to lookup parts
ACTION: Travel to OFFICE
ACTION: Access EDOCS for illustrated parts catalog
ACTION: Get part number from IPC
ACTION: Travel to PARTS
RESULT: Parts found
ACTION: Travel to gate 34
RESULT: Problem resolved

GOAL: Complete DIPs for airplane 226
ACTION: Perform DIP inspection

GOAL: Use the FIM to fix CSD inop
RESULT: Problem not resolved ... continuing troubleshooting
ACTION: Calling office for parts lookup
RESULT: Technician not available to lookup parts
ACTION: Travel to OFFICE
ACTION: Access EDOCS for illustrated parts catalog
ACTION: Get part number from IPC
ACTION: Travel to PARTS
RESULT: Parts Found
ACTION: Travel to gate 34
RESULT: Problem not resolved ... continuing troubleshooting
ACTION: Calling office for parts lookup
RESULT: Technician available to lookup parts
ACTION: Travel to PARTS
RESULT: Parts found
ACTION: Travel to gate 34
RESULT: Problem resolved

Total distance traveled(ft.): 2035

Total information search time(min.): 13.6

***** END SIMULATION *****

```

Figure 5: Sequence model showing a computer simulation of the handling of an inbound aircraft with multiple maintenance issues.

face to electronic documentation systems so that the most frequently performed or most important information-seeking tasks are the easiest and quickest to perform. The artifact model points out that the acceptance of any particular application might depend on interface design issues such as ease-of-access and reliability. The ability for technicians to access and print documentation while out on the ramp would benefit technicians.

The sequence model showed how technicians often spend excessive amounts of time traveling about the facility, and accessing information from electronic documentation systems. This finding echoes the need for remote access to these systems.

Casner and Puentes (2003) found that the delivery of computer and broadband technology to the marketplace has been largely driven by concerns of efficiency and operational costs. Perhaps the most important next step for the FAA and community is to incentivize the design, evaluation, and use of specific information-sharing tools that are designed to impact safety. At least one air carrier we surveyed had informal effort to devise a database system that archived difficult maintenance problems. Clearing the way for efforts like these to be developed and used in practice could be the next important step for technology in the aircraft maintenance workplace.

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**YEAR 2: DEVELOPMENT OF A WEB-BASED SURVEILLANCE AND AUDITING
TOOL (WEBSAT) TO ANALYZE AIRCRAFT MAINTENANCE OPERATIONS**
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The systematic evaluation of data collected on aviation maintenance processes can provide feedback on the performance of an airline and proactively support the decision-making process prior to the dispatch of the aircraft. In order to evaluate data, it is critical that the data being collected is standardized. This can be ensured by collecting data on variables, defined as *process measures*, which adequately measure the aircraft maintenance processes and eliminate existing inconsistencies. Once the data is captured by virtue of the process measures, analysis can be done to identify the problematic areas affecting the safety of an aircraft. This report briefly explains the methodology adopted during Phase I to identify and validate the process measures for the aviation maintenance processes. Phase II elaborates on the product design methodology used to prototype the technical audit module for WebSAT.

PURPOSE AND RATIONALE

It is evident from the literature that maintenance errors have a high impact on the safety of an aircraft. Various methodologies have been adopted in analyzing these errors so as to recommend human factors interventions that enhance the safety of an aircraft. Error classification schemes (Patankar, 2002) are very useful to identify weak points in a system, provided they are backed by comprehensive investigation procedures. In addition to these schemes, empirical models are needed to illustrate how the parts of the system work to influence outcomes. Recent example would be the Maintenance Error Decision Aid (MEDA) (Rankin et al., 2000). MEDA helps analysts identify the contributing factors that lead to an aviation accident. However, MEDA process is dependent on the erring technician's willingness to be interviewed about an error, anything that would decrease this willingness, such as a fear of being punished for the error, would have a detrimental effect on MEDA implementation.

Furthermore, such efforts tend to be reactive in nature, analyzing the accidents subsequent to their occurrence. Hence, there is a need for empirically validated models/tools that capture data on maintenance work and provide a means of assessing this data prior to dispatch of the aircraft. Also, it should be ensured that such models facilitate standardization. In order to contend with this issue, the current research proposes that standardization in data collection can be obtained by collecting data on variables which measure maintenance processes and eliminate existing inconsistencies. These variables are defined by the research team as *process measures*. Process measures incorporate the response and observation-based data collected from various aviation maintenance processes and facilitate the process of data analysis. The current research seeks to collect and present the error causes and occurrences using a web based surveillance and auditing tool (WebSAT) tool (Kapoor et al. 2004) which incorporates these process measures. WebSAT will capture and analyze data for the processes of surveillance, auditing and airworthiness directives control. This report elaborates on the results obtained from the first phase of the project, which is identification and validation of the process measures and also focuses on the preliminary results achieved in the second phase of the project, which is the development of WebSAT prototype.

The WebSAT system will be used by users from the four work functions of surveillance, technical audits, internal audits and airworthiness directives (AD) control as mentioned before. Within each work function there are two types of users – one at the operator level (e.g., auditors) who collects the data for various maintenance processes and the other being the managers of the different work functions of the quality assurance department of an airline who are more interested in the analysis of the data gathered. The upper management is also another potential user who uses the tool to administer the overall adequacy of all the processes.

With the introduction of process measures, the auditors or other personnel who are responsible for data collection will now be also responsible to categorizing the data obtained from a work card, or a checklist into respective process measure. Given the different scenarios that are to be presented to each user, based on their requirements, the design of the system plays a vital role in the accomplishment of the users' goals. Every design decision plays a role in the overall utility of the system in achieving the primary goal of ensuring aircraft safety. Since there are totally four modules to design, the WebSAT team has tried to familiarize itself with all the typical scenarios and decisions that a user makes in their daily work routine. This report further discusses about the implementation of design for the Technical Audit (TA) Module of WebSAT.

METHODOLOGY – PHASE I

Process Measures Identification and Validation

The team gained a comprehensive view of surveillance, auditing and airworthiness directives work functions during data gathering sessions. The data collection methodology employed has a direct effect on the quality and value of the information collected. The team adopted interviews focus groups, and observation sessions as these allowed them to take a first-hand look at the stakeholders' work environments and collect relevant procedural documents (Iyengar et al. 2004). Table 1 below shows two types of users who were interviewed during data gathering sessions. The first were employees in managerial positions, who would be involved with data analysis and would use findings, and other information from their respective work domain to keep a vigil on the performance of their work division. The second group

of users was quality assurance (QA) representatives or auditor personnel from the various work functions, who collect and enter maintenance data on a daily or a periodic basis to facilitate maintenance operation evaluation.

Table 1: Customer Selection Matrix for interview sessions

Market/Users	Managers	Auditors / QA Representative
Surveillance	2	4
Internal Audit	1	-
Technical Audit	1	1
AD	1	3

The team made notes on various observations that were made onsite and utilized this information in the brainstorming sessions to identify the problematic areas in the existing system. The team used questionnaires in a web survey subsequent to the interviews, focus groups and observation sessions to validate the identified process measures with FedEx, its aviation industry partner on the project, and other partnering airlines.

Survey Design for Validation of Process Measures: The users who participated in the online survey (See Figure 1 for a screenshot) consisted of the same user types that were selected for interview sessions. Six subjects, including the manager, for each work function and hence, a total of 24 subjects from FedEx were selected for the first survey to validate the appropriateness of the process measures. The second phase of the survey was conducted with partnering airlines. Twenty subjects from other partnering airlines were asked to take a survey to further validate the research team’s findings on the process measures.



Figure 1: Survey Screenshot–Questions’ screen

The survey was designed to last a maximum of 60 minutes for each of the four modules: surveillance, internal audits, technical audits, and airworthiness directives. The questions were of two kinds. There were forced-response, and open-ended questions. The team wanted detailed feedback from the subjects taking the survey and hence incorporated a ‘comments’ field for each question. Every web page of the survey consisted of a link to the process measures definitions document so that they could use it for reference while answering the survey questions. The survey was developed

using HTML, PERL scripting, and the usage of the cgi-bin on the Clemson engineering systems network. The survey responses were stored in text files (.txt) with the date and time stamp in the cgi-bin. The input from this survey was used to refine the identified process measures. The results from the second stage of this survey were fragmented. Very few respondents from other airlines participated in the survey. Consequently, the team proceeded with the data obtained from the FedEx personnel.

RESULTS AND DISCUSSION – PHASE I

Process Measures Identification and Validation

The process measures identified for different maintenance processes are given in Table 2 below. The definitions of these process measures are elaborated in the WebSAT Process Measures Definitions Document available with the team.

Table 2: List of Identified Process Measures (PM)

PM	Surveillance	Technical Audits	Internal Audits	AD
1	In-Process	Compliance/ Documentati- on	Administration	Information Verification
2	Verification	Inspection	Training	Loading and Tracking
3	Final Walk around	Facility Control	Records	
4	Documentation Surveillance	Training & Personnel	Safety	
5	Facility Surveillance	Procedures	Manuals	
6	Procedures Manual Surveillance	Data Control	Procedures	
7		Safety		

The results from the first survey show that these process measures adequately evaluate the respective work functions. In surveillance, four of the six responses (66.7%) indicated that these process measures were sufficient to evaluate the surveillance process. However, two responses suggested that metrics in the “additional findings” module – “information” and “aircraft walk around” should be incorporated as process measures rather than as other modules. For internal audits, two responses of the six (33.3%) indicated that the process measures for this category do not capture data from the FAA’s Air Transport Oversight System (ATOS) and hence do not entirely capture the data relevant to the internal audits department. The results obtained for the technical audits indicate that these process measures capture all the relevant data from the technical audit department and also communicate the purpose of each measure appropriately. The responses for airworthiness directives indicate that most of the processes that take place in the AD control group are verification processes and hence the identified process measures capture the data relevant to ADs.

The data collected from the surveillance work domain indicated that there are currently ambiguities in associating a process measure with a particular work card (data point). The QA representatives were required to memorize the definitions of 17 process measures and classify a work card based on the definition of the process measure.

Though the definitions of the existing process measures appear to be unambiguous to the managers they were often confusing to the QA representatives. The research team tried to eliminate the ambiguity by reducing the number of process measures to six and incorporating sub-categories in some of these process measures. The intent was to allow the representative to choose the process measure under which to classify a data point without having to memorize the definitions of the process measures. Two other modules “Additional Findings” and “Fuel Surveillance” that collect data on the surveillance activities were identified by the team to record the data for informational purposes. The team has not considered these two modules as process measures because the surveillance personnel, during the interview sessions indicated that this data is not used to rate vendor performance of maintenance tasks.

The technical audits group had developed several checklists to evaluate various types of vendors. The questions in these checklists were process specific and were grouped into categories based on the requirements they address. The research team formed process measures based on the checklist categories and on Coordinating Agency for Supplier Evaluation (C.A.S.E.) standards. The identified process measures evaluate the standards and procedures of suppliers, fuel vendors, and ramp operations at a system level and ensure compliance with Federal Aviation Regulations (FAR), and established company policies and procedures. All six survey respondents indicated that there are no ambiguities in the identified process measures. The team gathered various checklists used by the internal audits department and have identified that the existing process categorizes the data collected from these checklists based on six process measures. The team reached a consensus that the existing six process measures adequately capture the relevant data to measure the process in the internal audits department. The team did not take into consideration measures drawn from the ATOS system because of project scoping issues. The responses from the AD department indicate that the process measures capture all the relevant data pertinent to AD control process and hence adequately evaluate the process. The identified process measures would eventually enable a standardized data collection through WebSAT across the aviation industry. Furthermore, FAA could disseminate the research findings and implement these process measures across the aviation industry to facilitate standardization within and across airline facilities.

METHODOLOGY – PHASE II

Development of Technical Audits Module

The team then started to design WebSAT’s Technical Audits module. The user-centered design process is practiced through the application of a variety of methodologies within a structured design process. Such methodologies include contextual design (Beyer and Holtzblatt, 1998), task analysis (Gramopadhye and Thaker, 1998; Hackos and Redish, 1998), the development and use of personas (Cooper and Reimann, 2003) and scenarios (Rosson and Carroll, 2002), usability inspection methods (Nielsen, 1993), and usability testing

(Dumas and Redish, 1993; Rubin, 1994). These practices integrated into a design and development methodology as proposed by Ulrich and Eppinger, is structured in four stages:

1. Identifying Needs
2. Product Specifications
3. Concept Generation & Concept Selection
4. Iterative Prototype Testing (low fidelity prototypes)

The following sections will explain how the above mentioned phases were adopted for the development of the Technical Audit (TA) module of WebSAT prototype.

Stage I - Identifying Needs: The research team used interviews, focus groups, observation sessions and surveys as their modes of collecting data on the aviation maintenance processes at FedEx. Three members of the WebSAT research team prepared interview questions before hand. However, these questions were only to guide them through the interview process, and were helpful to tap the various aspects that need to be learnt about the systems at FedEx. The techniques of contextual inquiry proposed by Beyer and Holtzblatt (1998) were used as the interview progressed. If the interviewee shared any information which is not directly related to the question asked but very relevant to the product, the research team was quick enough to emphasize on those topics. Substantial documentation was sought by the team to understand the process better. Observation sessions helped the research team to understand a typical day of the technical auditor. Focus groups conducted with the manager of technical audits and another technical auditor helped the research team identify the various intricacies of the technical audit process. When one person in the team was focused on questioning the users, the other person was more focused on taking down detailed notes. The third person concentrated more in capturing behavioral gestures, concerns and emotions of the user while describing the current system. The team members also switched their roles and if one of them felt appropriate to interrupt the process to clarify certain issue, he / she did not hesitate to do so.

Information Gathered on Technical Audit Process

There are two types of technical audits: 1) Supplier Audits and 2) Fuel, Maintenance and Ramp (FMR) Audits. Further, in supplier audits alone there are several types of vendors involved. For each type of a vendor the auditors could use just one checklist or more than one. The checklists have questions that evaluate the procedures, regulatory policies, compliance standards of the vendors with the requirements of FedEx and FAA. The data collected from the checklists is in the form of Yes, No, Not Applicable, Not-Observed or some open ended comments. The findings obtained are shared with the vendor and the vendor is expected to address the corrective actions in a stipulated period of time. The data collected from the technical audit checklists for a particular vendor is reported to the TA manager by the auditors. This report also contains some of the concerns that the auditor and his comments which could be with respect to the vendor personnel or the facility or fleet type or some other aspect. The only two types of users involved in this work domain are the technical auditor and the TA manager. Having gathered substantial amount of data on the TA work domain, the team

moved towards identifying process measures for the work function. Process measures include all the data collected from the checklists. In order to identify the process measures, the team comprehended the various checklists that existed for TA. The team also studied Coordinated Agency for Supplier Evaluation (C.A.S.E) standards which has a detailed description of the various categories related to vendor evaluation. Using this documentation the team formulated the process measures based on the sections in the checklists.

Stage II - Product Specifications: With the gathered material on the work flows, the team had brain storming sessions where they discussed the transcribed material and encapsulated the information in the form of work flow diagrams. The team converted every customer statement into need statement. These need statements were grouped based on proximity and were then arranged in a hierarchy. Each group was given a name which is the primary need and all the need statements within that group were termed as secondary needs. Similarly every primary need comprised of several secondary needs in them. This list of hierarchy was sent to the client to get an importance rating for each need. The team members also gave a rating to the needs based on their intuition. The average of the rating obtained from the team members was compared with the rating obtained from the client and in many cases it was relatively the same except for very few cases. Based on the project scope and team consensus two needs were eliminated. Every need statement was then converted into a 'metric' which appropriately measures the performance of the product with respect to the need. An example of a customer statement, need statement and its metric is shown in Table 3. Having generated the metrics, the team started the phase of concept generation, while working on competitive benchmarking in tandem. Each member in the team generated one concept. Subsequent to the generation of the concept, the team followed the gallery technique using the whiteboard where the concept was enhanced with various ideas of the team members. The screen shots of the three concepts are shown in the figures below. Different scenarios were developed with respect to the two types of users. Then the team had brainstorming sessions on the pros and cons of each concept and consequently, attempted to enhance each concept to the best.

Table 3: Conversion of Customer Statement to Need Statement and to Metric

Customer Statement	I would like the tool to provide documentation of corrective actions for Non-Systematic audits.
Need Statement	The tool stores documentation on non-systematic audits.
Metric	Time taken to download the documentation on corrective actions for audits
Unit	Seconds

Stage III - Testing: In the next phase of testing, these concepts were pilot tested with two Human-Computer Interaction experts and one Management and Information Systems expert from Clemson University. The testing took place with low-fidelity prototypes, in that the prototypes showed all the features that the concept consists of, albeit, not functional. Prior to testing, they were informed about the

auditor's job role and responsibilities. Subsequently, they were presented with three scenarios and were asked to point out how they would go about performing the task.



Figure 2: Concept 1- Based on Google Search Engine but with multiple search criteria.

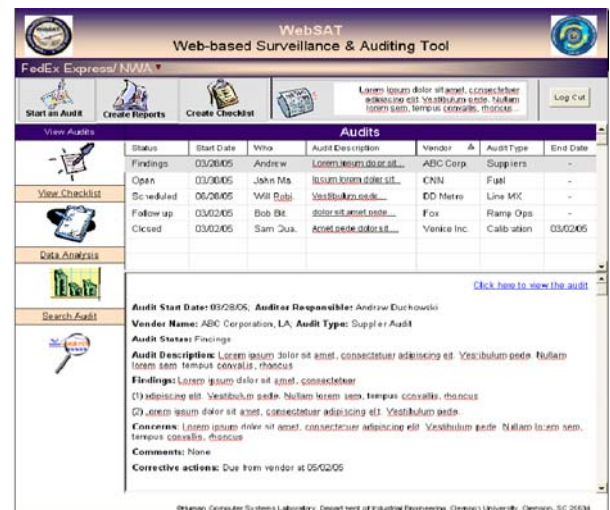


Figure 3: Concept 2 - Based on Microsoft Outlook



Figure 4: Concept 3 - Based on Tab Metaphor

They were also requested to think aloud while performing the task. The feedback obtained from this testing was only documented but was not implemented before the second phase of testing which involved testing with real users. Two audit managers were recruited for testing. They signed a consent form before participating in the study. The users were physically located in Memphis while the experimenters were at Clemson.

To enable smooth testing, the experimenters were sent a PowerPoint file which consisted of the storyboard of all the screen shots with instructions. The scenario was presented to them in one slide and in the next slide the screens appeared. The testing was done on a conference call and hence the team could ensure that the users were on the same page as the experimenters.

RESULTS AND DISCUSSION – PHASE II

Testing of Technical Audits Module

The results from initial testing phase with the faculty members showed that the organization structure of concept three was preferred to rest of the two concepts. The users also mentioned that the grid feature of concept two was very much liked by them and is quite intuitive. The results from final testing also showed that concept three was preferred the best. The grid feature of concept two was preferred by all the users who participated in the two phases of testing. One user mentioned that the dropdown for vendor list needed to be constrained based on other criteria such as vendor type as there could be 600 vendors in total resulting in a lengthy list. With the feedback obtained from testing the concepts were further refined and combined. The screen shot of the final concept is shown in Figure 5. Having selected this concept the team developed this concept using ASP.NET 2002 and SQL server. The organization scheme of this module will be extended to other modules as well.



Figure 5: Final Concept - Tab metaphor of concept 3 combined with data grid of concept 2.

RECENT ACCOMPLISHMENTS

The recent accomplishments of the WebSAT research team are listed below:

- Demonstrated the functionality of the Technical Audits Module to the FedEx group using various auditor scenarios.
- Conducted interview sessions with FedEx personnel to understand the data analysis requirements of WebSAT.
- Research in progress in the areas of
 1. Persona development to enhance the user experience with WebSAT interface -
 - a. Conducted a user profile survey to establish various user categories and generate personas for WebSAT development.
 2. Development of data reduction techniques to interpret qualitative responses in a standardized fashion.
 3. Generation of risk model to provide analysis of substantial maintenance data

Dissemination: Published and presented papers in the following journals and conferences respectively.

1. International Symposium of Aviation Psychology, Oklahoma City in April '05.
2. Industrial Engineering Research Conference, Atlanta, May '05
3. International Journal of Applied Aviation Studies, '05
4. Proceedings of Safety across High-Consequence Industries, St. Louis, September '05.

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