DESIGN, IMPLEMENTATION AND EVALUATION OF A PERFORMANCE ENHANCEMENT SYSTEM FOR AVIATION SAFETY INSPECTORS

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1.0 Introduction

The **P**erformance **En**hancement **S**ystem (PENS) is an electronic job aid designed for Aviation Safety Inspectors (ASIs). The system was in design and development for nearly 9 months before the first substantive pilot evaluation began. At the date this paper is being written PENS is in evaluation in all nine FAA regions, from Fairbanks, Alaska, to San Juan, Puerto Rico.

This paper describes the PENS development and implementation process. It also considers the question - how much "human factors scientific discussion" is necessary when involving users in system design.

1.1 A Human Factors Approach to Design of PENS

Previous publications from the Aviation Medicine Human Factors in Aviation Maintenance research programs have defined human factors and have emphasized the focus on the human as the central part of a technical system (FAA/AAM & GSC, 1993; Johnson & Shepherd, 1993). The human is affected by such factors as personnel selection, training, job design, and environmental issues, as examples. The design of tools, procedures, and information can also have a significant impact on human performance. PENS falls under these topics.

The involvement of users in early stages of system specification and design is important. It ensures that the system in development, both hardware and software, is compatible with the needs, expectations, and capabilities of the potential user. Thorough front-end studies, including job/task analyses and cognitive task analyses, can help determine and/or validate user requirements. Rapid prototyping is another development technique that ensures successful product design (Sewell & Johnson, 1990). The "bottom line" of good design is that the final product enhances human performance and affects overall system efficiency and effectiveness (Johnson, 1993).

Terms like cognitive task analyses and rapid prototyping are from the lexicon of the scientist. The human factors scientist, however, should not burden users with such terms. Instead, the user must be guided to express reasonable system requirements by discussing the tasks of the job, the information requirements, the working environment, and other such job characteristics. The various system prototypes, in software or in hardware mockups, permit users to modify specifications as their perception of the product becomes mature.

Human Factors (HF) personnel must work diligently to not impose their process and language on their customers. The HF personnel must merely communicate that a systematic process shall be used to arrive at optimal design and that the user is at the central focus of the process. This approach was used for PENS design, development, and implementation (Layton and Johnson, 1993). The results have been positive.

User "buy-in" to the PENS concept has been a vital reason that the project is succeeding so well. At a recent FAA meeting on training and automation a senior FAA manager described the PENS project as "a revolutionary FAA approach whereby the project is first studying user requirements before selecting and installing hardware systems". While not necessarily revolutionary this approach is certainly aligned with a human-centered approach to system development. The remainder of this paper describes PENS (Section 2) and then discusses the evaluation design (Section 3) and preliminary observations. Finally, in Section 4, the future of PENS and other applications of mobile computing are discussed.

2.0 PENS - How does it work?

The Flight Standards Service within the Federal Aviation Administration (FAA) employs over 2,500 Aviation Safety Inspectors (ASIs). The ASIs serve as the inspection team for the FAA. Aviation Safety Inspectors perform a variety of tasks, including inspecting aircraft and equipment, reviewing manuals and records, certificating pilots, and evaluating training programs. The PENs project is developing job performance aids to support ASIs in their activities. The initial target of PENS is an ASI performing an airworthiness (safety) ramp inspection. (A ramp inspection consists of inspecting an aircraft, while it is at the gate, prior to a scheduled departure.) PENS is an electronic performance support system (Gery, 1991; Layton, 1993) that consists of two components: a "smart" data collection system and an on- line documentation system. PENS capitalizes on recent advances in pen computer technology.

2.1 Data Collection

As is typical with regulatory activities, there are several forms that must be completed while performing an ASI task. Currently, these paper forms require that some of the same information be recorded on each form. After completing the forms, the ASI either types the data into a local computer database or he/she submits the forms to a data entry clerk. There are several drawbacks to such an approach. First, redundant recording of data on multiple forms takes time that could be devoted to more productive activities. Second, the two-step process of recording data on paper and then entering the data into a computer is inefficient. Furthermore, one is either paying an inspector to perform a data entry task for which he/she is over-qualified, or one is paying for a staff of data entry clerks. Finally, a data-entry clerk may make transcription errors (due to misreading the inspector's handwriting) or errors due to incomplete knowledge and understanding of the inspector's activities. Such errors mean that the database is an unreliable source of information. ASIs complete an average of 400,000 copies of the Program Tracking and Reporting Subsystem (PTRS) form annually. In 1993 1000 PTRS entries into the national database had the date 1903, rather than 1993.

Pen computer technology can be easily applied to such tasks to minimize the number of steps required to collect data and assimilate it into the database. Pen computers use handwriting recognition software and a pen stylus for input, rather then a keyboard. The operator writes on the screen and the handwriting recognition software translates the written characters to typed characters. The pen stylus also acts as a pointing device, much like a mouse. When combined with graphical user interfaces, such as Microsoft Windows for Pen Computing or PenPoint, the pen stylus and handwriting recognition software hold the promise of making computers easier to use than traditional desktop computers. A comparison of typical desktop and pen computers is shown in Figure 1.

Figure 1 Comparison of Desktop and Pen Computers

PENS capitalizes on the relationships between inspection data and the constraints built into the PTRS form to prevent errors. For instance, some form fields cannot be used for certain activities; the forms are sensitive to the activity being performed so that restricted fields are not available for data entry. As shown in the PENS version of the PTRS form in Figure 2, if the inspector selects "Boeing" as the aircraft "Make", only Boeing models appear for selection in the "Model" field. Furthermore, PENS is tied into a database of aviation operator information so that only data options appropriate to that operator are available for entry. For example, if Mythical Airways owns only Boeing 757 and 767 aircraft, the inspector will have only those options to choose from when identifying the type of plane under inspection.

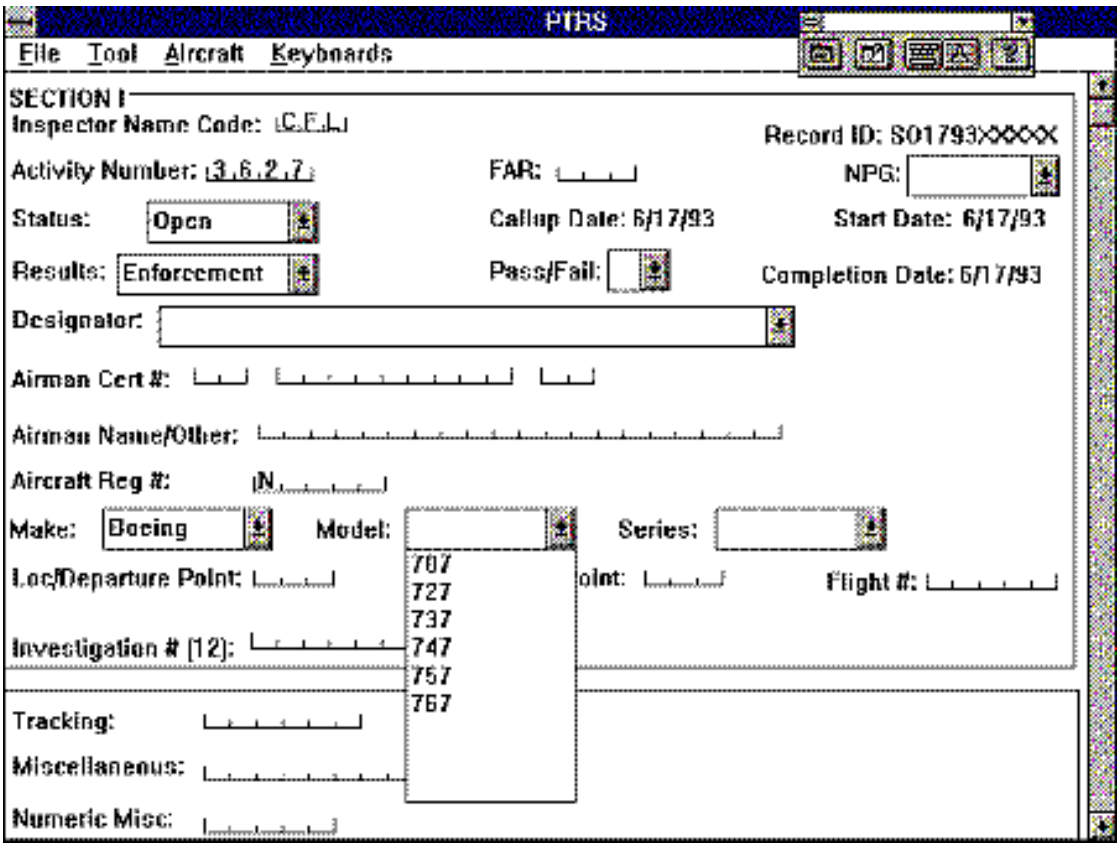

Figure 2 PTRS Form

Concerning the current data collection limitations identified above, forms can be linked together so that an entry in one form propagates to the other forms, thus eliminating redundant data entries. Furthermore, the data can be collected so that they are ready for direct uploading into the database. The inspector will return to the office at the end of the day, connect the pen computer to the office computer network, and start a utility that transfers all of her/his field-collected data to the local database. This method of collecting data obviates the need for data entry clerks and it eliminates data transcription errors.

2.2 On-line Documentation

The second major contribution of PENS is an on-line documentation system. Whereas ASIs currently must carry two briefcases full of books (including Federal Aviation Regulation, ASI Handbooks, and other regulatory documents), the necessary documents can be stored on the hard disk of the pen computer or on a CD-ROM (compact disc, read-only memory). Not only is the computer media more lightweight and compact, it also facilitates quick retrieval of specific information. For instance, an ASI can perform a Boolean search of the regulations for the word "corrosion" to answer a question on reporting aircraft defects. PENS then indicates all of the instances of the word corrosion, as shown in **Figure 3**. The ASI can then ask PENS to retrieve the relevant documents and display the pages that discuss the term. Figure 4 shows an example page with "corrosion" highlighted.

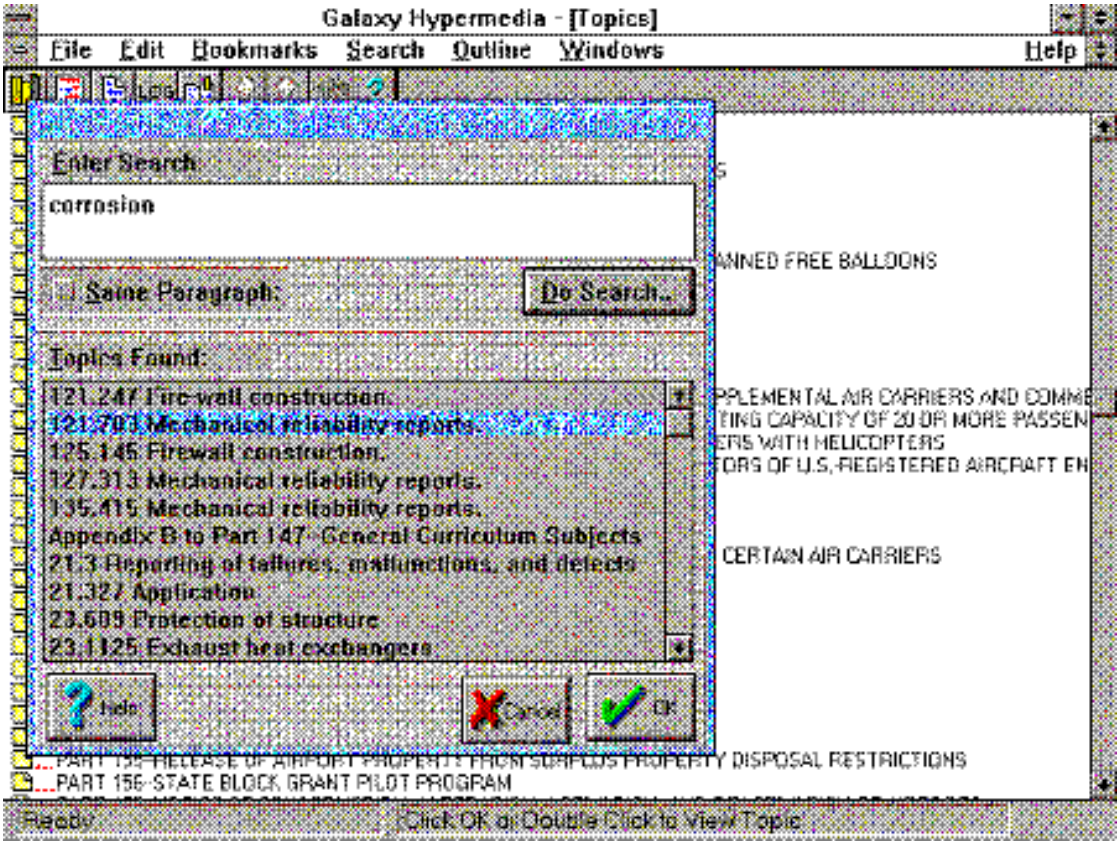

Figure 3 Search results for the word "corrosion" in the FARs

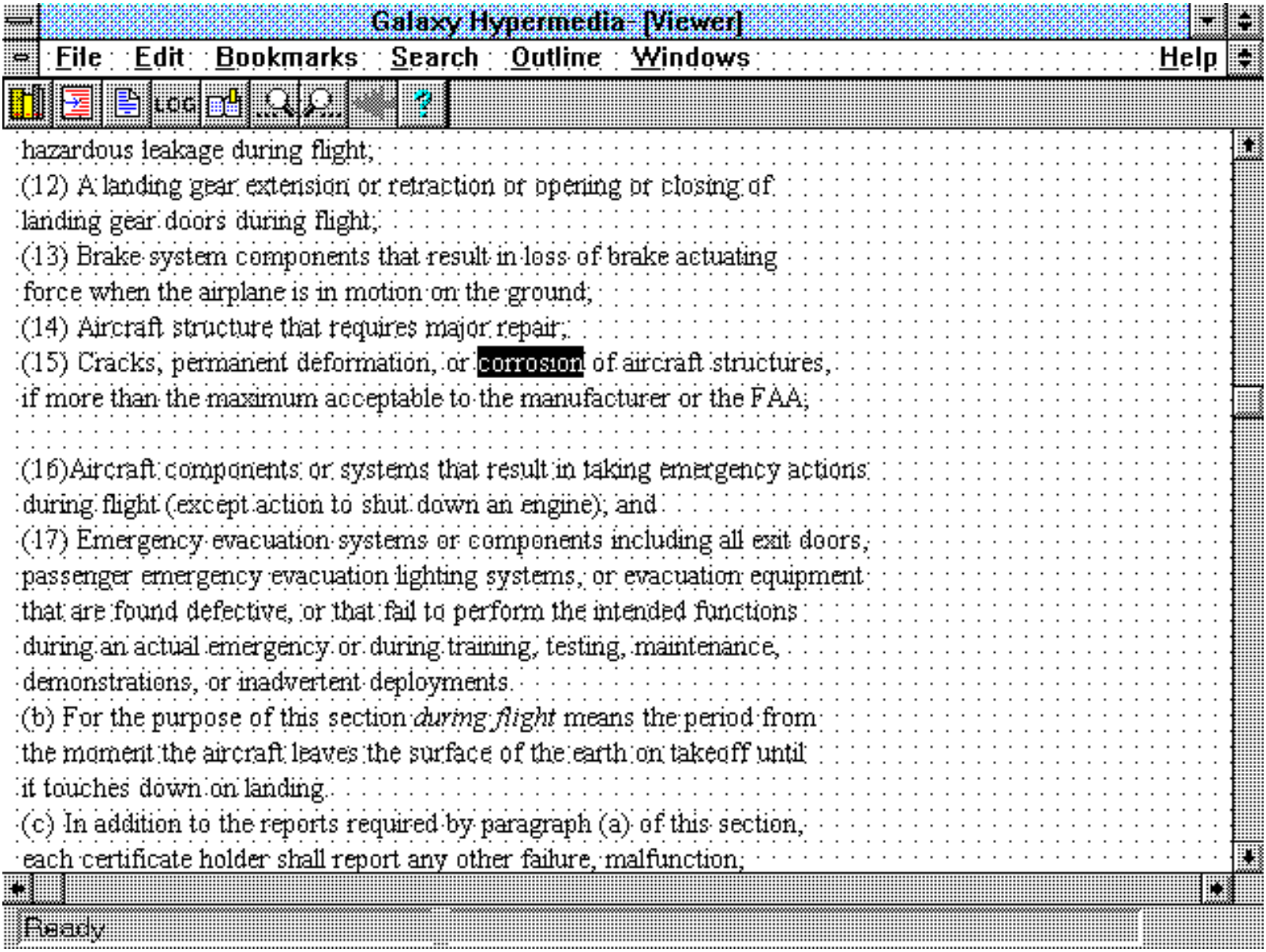

Figure 4 Text of FAR that discuses corrosion

The books are not only bulky and inefficient, they are also frequently out-of-date. One complaint made by inspectors is that they will tell an air carrier that it is not in compliance with the regulations, only to be shown a more recent edition of those regulations. That is, sometimes the air carriers get the most recent editions of the regulations before the inspectors get them. This problem can be dealt with by distributing updated documents through the FAA's computer network. For instance, a person in Washington, DC could edit a document and send the new version to the FAA's main frame computer in Plano, Texas. When the Flight Standards offices connect to the main frame to upload field-collected data, they can also download the new documents. Likewise, when the pen computers are connected to the office network to transfer data to the database, they can receive the new versions of documents. Thus, a new edition of a document could literally be electronically published one day and in the inspector's hands the next.

2.3 Increased Capabilities

A benefit of providing computer-based inspection tools is that it opens the door to other means of assisting inspectors. For example, data propagation need not be restricted to a set of forms. An on-line inspection checklist, shown in Figure 5, focuses the inspector's activities and her/his interaction with the computer; by completing the checklist, many parts of the forms are automatically completed. Furthermore, stock letters can be completed and printed based on information in the forms. Similarly, reports can be automatically generated based on inspection outcomes. A scheduling component will remind the inspector to follow up on inspections that identified problems.

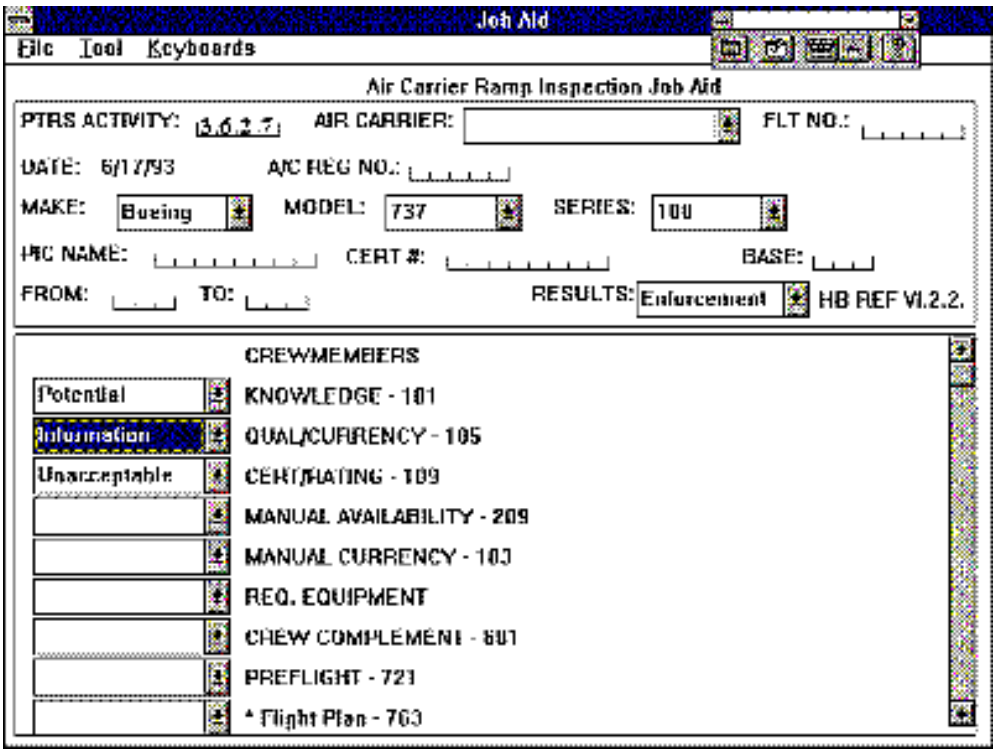

Figure 5 On-line inspection checklist

When documenting an inspection, ASIs currently must record their findings verbally. However, because many inspections are conducted by visually inspecting an aircraft, sketching is a more natural method for recording the results of such an inspection. Thus, if an inspector found a leaking seal on the wing of an aircraft, the inspector could annotate a line art drawing of that aircraft on the computer. This graphic is then stored along with the completed inspection form. **Figure 6** depicts one such annotated graphic.

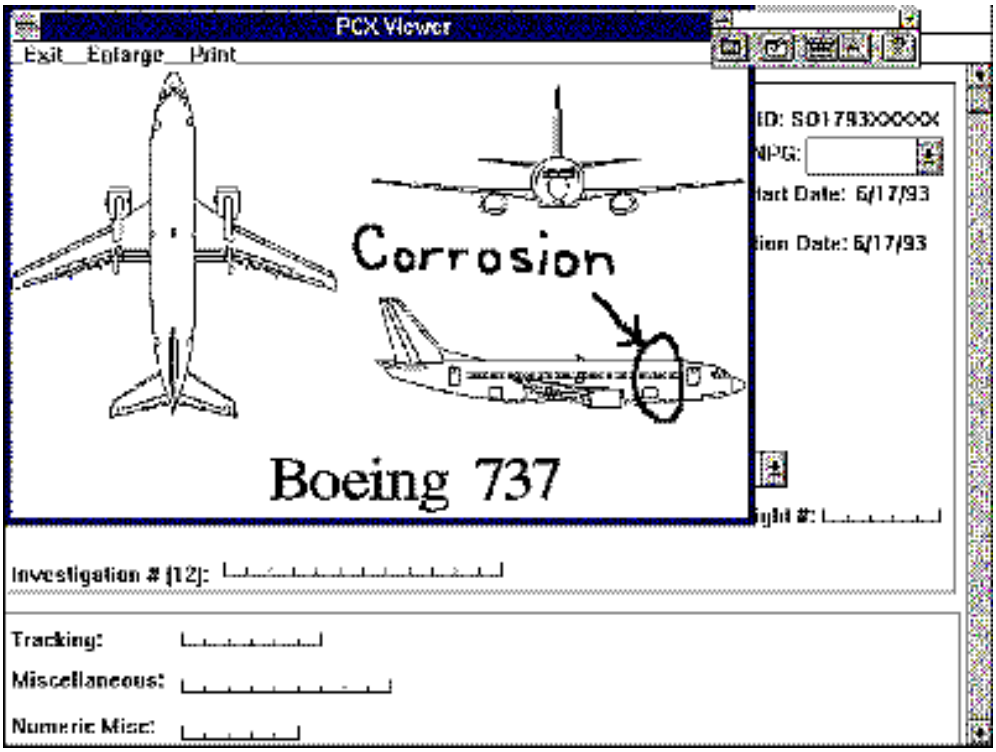

Figure 6 Annotated aircraft drawing

Finally, the data collection system is linked to the on-line documentation system so that the inspector has immediate access to all applicable regulations and handbook chapters. For instance, upon identifying the type of plane under inspection on the form, the inspector is notified of all of the Airworthiness Directives (specific regulatory documents) that apply to that aircraft. These documents are then called up on the on-line system for ready reference.

3.0 The Evaluation

There are a number of issues that can affect the success of introducing new technology into the ASI work environment. Many inspectors do not have experience using computers. Of those inspectors, some are willing to try the new tools based on promised increased productivity, while others are hesitant to embrace a new method for performing their tasks. Some inspectors are even concerned with how they will be perceived by the operators when they are carrying a pen computer.

During Winter 1993/Spring 1994 the PENs team is conducting a widespread field evaluation of both the prototype PENS software tools and various hardware platforms. A goal is to find out very early in the development process whether inspectors find pen computer technology an appropriate approach to alleviating some of their workload. In order for PENS to succeed, it is critical that the inspectors "buy in" to the project and take ownership of it. Inspector buy-in and ownership mean that the inspectors will know that their input is critical for development of the tools. In turn, they will be motivated to use the tools and improve them. Therefore, many aspects of the field evaluation are geared toward the goals of inspector buy- in and ownership. PENS is being fielded in all nine FAA regions, as shown in Figure 7, so that each region will participate. Inspector comments are actively solicited to ensure that the tools meet the inspectors' needs.

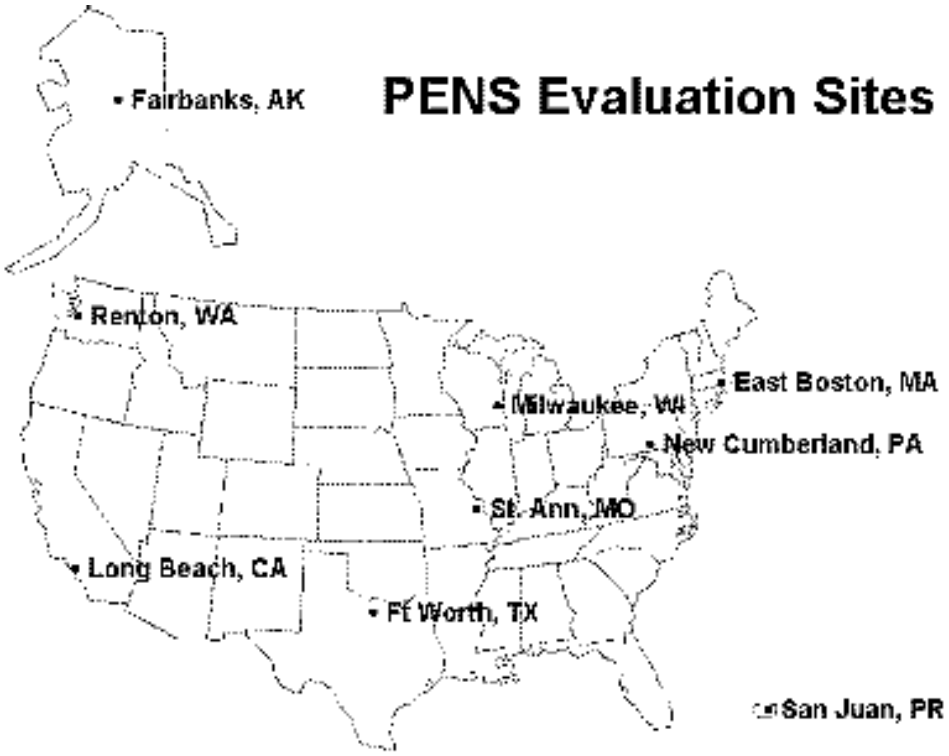

Figure 7 PENS Evaluation Sites

Four different computers are being fielded. Three of those computers are pen computers, while the fourth computer is a standard notebook. Each of the computers was selected based on a specific feature that distinguished it from the others so that we could allow the inspectors to assess the tradeoffs between the various designs. For example, the notebook computer was chosen so that we could answer the question of whether pen capability was really necessary. Other features included weight, attached vs. separate keyboard, and processor speed. A review of pen computers is reported elsewhere (FAA/AAM & GSC, 1993).

Four inspectors in each office are performing the evaluation. Each inspector uses a computer for a week and then rotates to a different computer. At the end of each week, the inspector evaluates the computer and at the end of four weeks, he/she evaluates all four computers and the PENS software. The rotation order is counterbalanced to eliminate order effects.

Rarely is a field evaluation of this magnitude performed. It represents a significant opportunity to obtain usability and preference data on computer platforms in a controlled study, while at the same time involving a large number of real domain practitioners in the evaluation and development of tools to support them. The report documenting the results of the study is of interest to not only computer manufacturers, but also to the human factors community at large.

4.0 The Future

The authors believe that mobile computing shall become as common as the desk top personal computer. Hardware is evolving rapidly to provide greater display resolution, faster processor speed, increased storage and memory, lighter weight, improved communication capability, longer battery life, and other features that ensure wide-range useability.

Software development is critical in order for mobile computing to rapidly reach its full potential. Software must evolve with the hardware. Software systems must provide an "information rich" environment for the mobile computing platform. Such an environment must be able, at a minimum, to offer the following: 1) large amounts of data translated to specific user needs; 2) training matched to the job at hand; 3) decision support tools, and; 4) a suite of software tools matched to users needs. Each of these capabilities is described below.

4.1 Data/Information

Mobile computing platforms must provide users with all information necessary for field decision making. For an aviation maintenance technician this information might include, for example, aircraft historical data, logbooks, maintenance manuals, illustrated parts catalogs, wiring diagrams, fault isolation manuals, and other airline-specific information. Inspectors might access additional information, including FAA Inspectors' Handbooks, Federal Aviation Regulations, and Airworthiness Directives. Such information must be easy to access and search. Critical related information must be connected ("linked") together so that users can easily navigate through a variety of information sources. New technology software for mobile computing must go beyond a digital microfiche system to intelligent information.

4.2 Training

Mobile computing must provide users with efficiencies resulting in lower costs. Reduction in classroom training has an immediate cost reduction impact. Economies are achieved through reduction in travel, time of the job, replacement personnel, training facility, and instructor salaries. Mobile computing platforms can be used to provide computer-based training on-the-job when it is needed. The term "just-in-time training" applies to the delivery of training only when it is needed. At such times workers are highly motivated to learn in order to complete a job requirement. Such training minimizes the impact of a worker forgetting critical knowledge and skill where there has been a long time lapse since formal training. Future mobile computing will be able to use powerful communications capabilities to remotely access multimedia training that is either provided by the user's employer or by a training contractor.

4.3 Decision Aides

Mobile computing software must be able to assist field decision making. Such software must capitalize on the extensive research and development with user modeling and expert systems. Software must be able to help the mobile computing user to select, access, and assimilate the massive information sources and analytic tools that can be immediately available. The software must be able to observe the user and then make inferences regarding best information sources. The computer shall become an active participant in the job tasks of the mobile computing user.

4.4 Suite of Tools

The mobile computing platform software environment must be versatile. It must provide a wide variety of tools. Successful Mobile Computers will not be designed for, or limited to, single tasks. Communications, word processing, data collection/retrieval, data analyses, and training development/delivery are but a few of the multi-purpose capabilities that shall be provided by mobile computing software environments.

4.5 Easy to Use

This paper began with a discussion of human factors and the design process necessary to ensure successful application of the FAA Performance Enhancement System. The same systems approach must be used to design any mobile computing software. The software must be compatible with users' expectations and capabilities. The powerful information technologies must be integrated so that the user can understand them. Finally the systems must undergo appropriate developmental and final evaluation to ensure effective and efficient field use.

5.0 References

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