HUMAN FACTORS ADVANCES AT CONTINENTAL AIRLINES

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Abstract

In Phase IV of the human factors program, two distinct projects have been undertaken. The continuing involvement with Continental Airlines and SUNY at Buffalo on workcard design has now produced a portable computer-based system. This combines the successful improvements to the paper-based workcard (Phase III) with the advantages of a hypertext system allowing multi-level access to documentation for A-check and C-check tasks. Evaluation on the A-check task of landing gear inspection showed the computer-based workcard to be a significant advance over the original paper-based system. The second project was development of a program to audit human factors issues in aircraft inspection. This ergonomics audit program consisted of a sampling plan, an audit checklist, and a computer program to compare audit measurements against accepted human factors standards. Evaluation of the audit program showed that high reliability could be achieved by careful design of checklist items and that automated production of audit reports saved considerable time.

1.0 INTRODUCTION

This paper describes two complementary human factors improvements in the inspection area of Continental Airlines' maintenance program. Their common thread is in applying human factors techniques from other fields (e.g., manufacturing, computer-aided decision making) to the specific problems of aircraft inspection documented in this project's previous phases (Shepherd et al., 1991; FAA/AAM & GSC, 1992 and 1993).

The first project was a direct continuation of Phase III's demonstration of improved workcard design. Because the redesigned paper-based workcards received such good evaluations, an obvious next step was to incorporate the increased flexibility of document access available using a portable computer. A system was produced and demonstrated on five C-check tasks and three A-check tasks. The development and evaluation of this system is presented in Section 2.

The second project was performed in conjunction with another airline partner, a regional operator of scheduled helicopter services. It arose from the need to integrate the various human factors investigations sponsored by FAA/AAM into a tool for measuring potential mismatches between inspectors and the tasks, machines and environment with which they work. The outcome is an ergonomics audit program designed to measure the current level of ergonomics/human factors within a hangar and hence to focus attention on those aspects needing to be changed. This program was produced and evaluated at both airline partners, as detailed in Section 3.

2.0 DEVELOPMENT OF A COMPUTER-BASED WORKCARD SYSTEM

2.1 Issues of Computer-Based Workcard Design

The workcard is the primary document that controls an inspection task. It has, therefore, a great influence on inspection performance. During Phase I, many human-system mismatches were identified which could contribute to errors. Costs, due to undetectable faults or faulty detection, when weighted against the cost of providing quality documentation, make a strong case for developing optimum documentation and a methodology (coupled with a set of guidelines) for designing such documentation. This study develops such a methodology, based on the application of human factors knowledge to the analysis of aircraft inspection tasks. In Phase II, a paper workcard was designed to replace the current workcard. From this design, a set of guidelines was developed to improve workcard design. The methodology developed, being highly generic, can also be extended for the design of portable computer-based workcards.

Portable computer-based workcards can overcome some of the limitations of the paper-based workcards. Feedforward and feedback information can be presented in addition to the traditional directive information. Access to detailed information in attachments and maintenance manuals is easier. The display can act as an external working memory by keeping all the relevant information in front of the user at all times. Computer-based information also provides an additional flexibility for organizing information about the tasks. Multi-layered information usage can cater to the needs of both experts and novices. As an example of these benefits, Glushko (1989) described the advantages of using an "intelligent electronic manual" in organizing the information contained in maintenance manuals, which according to Higgins (1989) can be as much as 70 manuals for one plane.

Advances in the technology in portable computing systems are making the realization of these benefits more feasible. Hence, a combination of the increasing information needs of inspectors, and technological advances, ensures that the use of portable computer-based workcards to replace the more traditional hardcopy workcards is inevitable in the long term. While specialized computer hardware and software systems have been designed for automating complex diagnostic tasks in maintenance, such as the Air Force Integrated Maintenance Information System (IMIS) (Johnson, 1989), there is a need for a simpler, less expensive system using off-the-shelf components. Also, so far such computer-based systems have been traditionally aimed at diagnostic tasks, but here they are applied to more information-intensive procedural tasks which form a major portion of the aircraft inspection activity. Therefore, the objective of this study is to develop and test a prototype of a simple, inexpensive inspection workcard implementation on a lap-top computer. Specifically, the design had to be proven for both A-checks and C-checks.

While most of the issues concerning good design of information for workcards raised in Phase III applied directly to the design of a computer-based system, there were two new factors to take into account: hardware and software, particularly hypertext.

The choice of the hardware for implementing the computer-based workcard is one of the critical issues. The original paper-based system studied lacked a convenient hand-held integrated workcard holder although one was designed for the improved paper-based system. Current lap-top systems are inexpensive and getting smaller with new sets of features, while sacrificing little in computing power. Key breakthroughs in technology are feeding this process: storage devices are getting smaller, IC designs support fewer chips and thus power requirements are getting lower (Linderholm, et al., 1992). Also, designs are getting more rugged, which inspires confidence if a computer is intended for field usage. Using these systems is still inconvenient though, due to keyboard and pointer interfaces. Systems operated by keyboards and mice partially defeat goals of accessibility and connectivity (Meyrowitz, 1991). Pen-based computing allows links between information to be created by a mere pointing gesture, but this technology is still a year or so away from field use without special support.

Many of the advantages of using computer-based information rather than paper are due to the use of hypertext. Hypertext is a technology of nonsequential writing and reading: it is also a technique, a data-structure, and a user interface (Berk and Devlin, 1991). Hypertext systems split documents into components or <u>nodes</u> connected by machine-supported links or relationships. Conklin (1987) summarized the operational advantages of hypertext as:

1. Information structuring: Both hierarchical and non-hierarchical organizations can be imposed on unstructured information.
2. Global and local views: Browsers provide table of contents style views, supporting easier restructuring of large or complex documents; both global and local views can be mixed effectively.
3. Modularity of information: Since the same text segment can be referenced from several places, ideas can be expressed with less overlap and duplication.
4. Task stacking: The user is supported in having several paths of inquiry active and displayed on the screen at the same time, such that any given path can be unwound to the original task.

These features of hypertext solve many of the design issues identified within the taxonomy given in the Phase III report. For example, computer-based information provides a consistent typographic layout and a continuous layout with no page breaks. It also reduces redundancy and repetition and fosters generalizations across tasks. Computer-based systems are more supportive of graphics than paper-based systems. Hypertext easily allows for categorization and classification of tasks and information so that general information can be separated from specific information. Layering of information can be provided, which is conducive to expert as well as novice usage. Hypertext should make accessing and referring to information such as attachments and manuals considerably easier. In addition, the inspector can sign off tasks after their completion, write notes for non-routine maintenance within the computer-based system, and then easily return to the correct place in the task list to continue inspection.

Thus, it is hypothesized that hypertext can solve many of the design issues associated with paper-based workcards. The next step is to use the lessons learned from the design of paper- based workcards, knowledge of hypertext, and information on inspection tasks, to design specific examples of computer-based workcards.

2.2 Development of the Computer-Based System

A prototype of the computer-based workcard system was developed on an IBM Think Pad 700 PS/2 using Spinnaker PLUS. This is a hypertext program, an object-oriented programming language, which simplifies the creation of detailed information management applications by using links between stacks of information. Eight different inspection tasks were implemented into the system. The tasks of an A-check for a B727-200 were implemented, e.g. log books, nose landing gear, main landing gear, aircraft wings, aircraft empennage, and aircraft fuselage inspection. Left wing and right wing inspection for a C-check on a DC-9-30 were also implemented.

The design of the system adhered to the lessons learned from the development of the paper- based workcard as identified by the taxonomies given in the Phase III report. The design also followed guidelines given specifically for the design of computer interfaces (Brown, 1988; Smith and Mosier, 1986). The following specific guidelines were used to develop the computer-based systems:

Information Readability

1. Layout
    - Use a fixed set of proportions/grids
    - Use spatial layout as a primary cue for object grouping
    - Use a consistent layout across fields
    - Use fixed size/location for "functional category fields"
    - Left justify most important information
    - Use blank lines in place of graphic lines to reduce clutter
2. Typography
    - Use upper case only for short captions, labels, and headings
    - Use conventional punctuation and formalisms
3. Metaphors
    - Be very explicit in the use of metaphors
    - Use explicit screen transitions: e.g. iris open versus scroll
    - Use paper form metaphor for data input
    - Use soft button metaphor for all external links
4. Contrast
    - Use contrast sparingly and as a last option
    - Use contrast to attract attentional resources to select portions of text
    - Use maximum three levels of contrast coding

Information Content

1. Input information
    - Use familiar mnemonics for input

- Use congruent command pairs: e.g., R/Wrong & not R/Close
- Use "radio buttons" for all multiple choice information

2. System output information
    - Use the display as an external working memory of the user
    - Provide screen identity information
    - Display only the necessary information
    - Condense all unnecessary information into icons
    - A display density higher than 15% should be avoided
    - Use the inheritance metaphor to identify position in hyperspace
    - Use affirmative dialogue statements
    - Provide input acknowledgments and progress indicators
    - Use auditory feedback conservatively
    - System messages should be polite and instructive
    - Do not provide a system initiated help feature
3. Graphic information
    - Use graphics to reduce display density
    - Show all spatial, numeric, temporal information graphically
4. Iconic information
    - Use icons for all direct manipulation
    - Use icons to save display space and reduce clutter
    - Use icons for all external links
    - Use icons to permit cross cultural usage

Information Organization, Manipulation, and Access

1. Linking
    - Provide contextual internal links
    - Use internal links for all reference information
    - Use external links sparingly and only for non-contextual information
    - Provide a link backtrack option
    - Provide an UNDO option for navigation
    - Make linking explicit, do not leave anything to exploration or browsing
    - Use linking sparingly to avoid user confusion and disorientation
    - Label links where possible
2. General organizational philosophy
    - Organize for progressive disclosure and graceful evolution
    - Keep layered information optional
    - Do not use scrolling fields
    - Organize tasks in a fixed linear as well as optional nested structures

Other Pragmatic Issues

1. Physical handling and infield usability
    - Develop and implement standards for reverse video, contrast for varying lighting conditions
    - Follow a pencentric display design philosophy
    - Design for single handed operation
    - Minimize the use of key entries, use direct manipulation
2. Hardcopy
    - Provide feasible options for obtaining hardcopies in a fixed format

3. System response time
    - Keep the system response times for all actions within standards
4. User acceptability
    - Honor user preferences
    - Provide only those functions that a user will use

Features of the System

The design of the computer-based workcard follows these guidelines by the following features. The first screen of the workcard is the input manager in which the inspector enters data that normally would be found at the top of every page of the workcard such as the inspector, supervisor, and aircraft identification number. This information is then reproduced on all other documentation generated, such as the Accountability List and the Non-Routine Repair forms, thus relieving the inspector of repetitive form filling. The global view displays all of the tasks for the inspection and highlights the tasks completed, serving as an external display to augment working memory. While performing the tasks, the inspector has direct access to information for both input and output such as the general maintenance manual, the airplane's manufacturer maintenance manual, engineering change repair authorization, air worthiness directives, and attachments. This eliminates the need for the inspector to carry bulky attachments or leaving the inspection site to refer to a manual. For each task, the inspector has the option of signing off, reporting a non-routine repair, making a note on the writeup note feature, going to the home screen which shows the signoffs remaining for the task, going to the global screen, viewing an overview feature which displays the number of signoffs that were completed, or using a help feature. All of these features reduce memory and information processing requirements on the inspector. A continuously-updated accountability list may also be viewed at any time. This feature is a record of the inspector's activity using the workcard such as signoffs done, notes made, and tasks previewed. The outputs of the system are the accountability list and the non-routine repairs that the inspector wrote up.

Accessing these features is done by selecting icons or radio buttons which have pictures or labels designed for rapid learning. The links between these features are explicit and always have a backtrack option. Information for performing the tasks were categorized and layered to assist both experienced and inexperienced inspectors. General information was separated from specific task directive information. All spatial information was conveyed through graphics. Thus, these features serve to meet the design requirements and follow both the issues for developing workcards for aircraft inspection and guidelines for human computer interfaces.

2.3 System Evaluation

The computer-based workcard was compared against the current paper-based workcard and against the proposed paper-based workcard designed in Phase III of this project. The comparison was made using questions derived from the issues identified by the taxonomies above. The evaluation, and the specific questions, were designed to be similar to the evaluation of the C-check workcard performed in Phase III. Eight inspectors used all three designs of the A-check workcards in performing a nose landing gear inspection with fifteen signoffs. They were given an overall briefing as to the purpose of the study and general instructions, and answered a questionnaire on personal data. The questionnaire asked the subjects to rate their evaluation of the issues addressed by each question on a 9-point rating scale. Before the inspectors used the computer-based workcard, they were given a training session. A quiz on using the computer-based workcard assured that they understood how to use the workcard. After the inspectors completed the inspection using each form of workcard, they were asked to complete a questionnaire evaluating that workcard.

Two analyses of the evaluation response data are of interest:

1. Whether the feature of the computer-based workcard was judged as better or worse than a neutral rating.
2. How the computer-based workcard was evaluated in comparison with the existing paper-based workcard and the redesigned paper-based workcard.

For the first analysis the 39 questions asked about the computer-based workcard were divided into those where it was rated significantly better than neutral, not significantly different from neutral, and significantly worse than neutral, using the Sign Test with a significance level of $p < 0.05$. **Table 1** gives the results..

Table 1 Numbers of Items for Computer-Based Workcard Judged Against a Neutral Response

Outcome	Number	Percentage
Better than neutral	25	64%
Not different from neutral	13	33%
Worse than neutral	1	3%

The inspectors were highly enthusiastic about most aspects of the system. Many of the items judged better than neutral were overall evaluations (e.g., degree to which workcards like those should be used), but some were for very specific features (e.g., readability of buttons and icons), indicating that both the overall concept and detailed design were approved of by the users. Most of the neutral responses came from completeness and organization, or from features not used by the respondents on this task (automatic generation of Accountability List and Non-Routine Repair forms). Two of the questions which were not significantly different from neutral were not expected to be. Amount of information and amount of graphics information were not changed for the computer-based workcard, and were judged as not too much but not too little. The only feature significantly disliked by inspectors was one which gave time information, i.e., what percentage of the standard time had been spent. As has been found consistently in earlier phases of this project, inspectors strenuously resist implications of time pressure in their jobs. The time feature has now been removed from the system.

The computer-based workcard also compared favorably against the current and improved paper-based workcards. **Table 2** shows the numbers of responses where it was possible to make a direct comparison of the computer- and paper-based systems, using the Friedman Analysis of Variance with a significance level of $p < 0.05$.

Table 2 Numbers of Items for Computer-Based Workcard Judged Against the Two Paper-Based Systems

Outcome	Number	Percentage
Better than paper-based system	14	74%
Not different from paper-based system	5	26%
Worse than paper-based system	0	0%

On no issues did the inspectors rate the computer-based system worse than the paper-based system. Fourteen of the nineteen issues were judged significantly in favor of the computer- based system, including all of those issues which represented an overall evaluation of the system (e.g., overall ease of usability of workcard). Amount of information provided was judged almost the same in all three systems, which was expected as no information was added to, or subtracted from the original workcard in developing the two new systems.

Although the main comparison was between the original paper-based workcard and the computer-based system, the inclusion of an improved paper-based workcard was instructive. In all of the significant comparisons, the computer-based workcard was as good as or better than the improved paper-based workcard. However, for most questions, the major difference was seen between the original and improved paper-based systems, rather than between the improved paper-based and computer-based workcards. The conclusion is that many improvement can still be made without resorting to computer-based systems. It should be noted that the text and graphics which went into the computer-based hypertext system were the same ones used in the improved paper-based system. Thus any company would be well- advised to modify their paper-based system, as this completes most of the work needed to implement any future computer-based system.

Not shown in the results is the fact that all inspectors quickly became familiar with the computer-based system, none taking more than one hour to learn the system well enough to go through the steps of this single A-check task. More time would obviously be required for inspectors to become really adept at navigating the system and using all of its features, but the point to be made is that the time and test overhead associated with the introduction of this system is very low. This was a vindication of the design philosophy which utilized detailed task analysis and human factors interpretation of the inspectors' jobs, plus feedback from the inspectors themselves, to produce the final design.

Despite the good rating of ease of physical use, the computer-based system will clearly benefit from improved hardware. Weighing 6 lbs, and with a keyboard and pointing device, the current system cannot be used as easily as, for example, a future pen-based system. All features of the current hypercard system can be used directly on a pen-based system, with the added advantage of bit-mapped storage of signatures. All that is required is better screens for pen-based systems, and improved handwriting recognition for filling out Non- Routine Repair forms in a rapid manner. According to computer industry sources (e. g., *Byte*, October 1993) such systems should be fielded within a year.

3.0 ERGONOMICS AUDIT FOR AIRCRAFT INSPECTION

3.1 Audit Systems for Human Factors

Arising from this human factors analysis of the inspection job, a number of specific studies have been completed under the auspices of the Federal Aviation Administration, Office of Aviation Medicine (FAA/AAM). Projects with the airline industry have considered improved lighting (Reynolds, Gramopadhye and Drury, 1992), better documentation design (Patel, Prabhu and Drury, 1992), revised training for visual inspection (Gramopadhye, Drury and Sharit, 1993) and the impact of posture and restricted space (Eberhardt, Reynolds and Drury, 1993). The aim of these studies has been to allow airlines to use some of the benefits of ergonomics without necessarily having trained ergonomists. At this time there is a need to provide integrative tools to enable a maintenance organization to develop an overall strategy for applying human factors principles in a systematic manner. The audit program developed in this report is an essential step towards integration.

In order to know where to apply human factors, for example using the FAA/OAM developed Human Factors Guide (Parker, 1993), it is first necessary to know where there are mismatches between the human (inspector) and the system (equipment, tools, environment). The audit program provides a convenient, quantitative way to determine these mismatches. It starts from the common ergonomics basis of inspection as a task/operator/machine/environment system. The output from the audit can be used to focus design/redesign efforts where they will have the greatest impact on reducing the human/system mismatches which cause inspection and maintenance errors.

There have been previous ergonomics audit programs for manufacturing (Mir, 1982; Drury, 1988; Kittusway, et al, 1992), but the problems of the aircraft hangar are different from those of the factory floor. In inspection and maintenance, the workplace is rarely static; task, equipment and environment can change considerably throughout the course of a single inspection task.

The original two-phase audit program, detailed in Mir (1982), used outcome measures in Phase I to provide an overall context of the plant, followed by a workplace survey (Phase II) of the departments selected in Phase I. Information from first aid reports, medical records, OSHA reports of accidents and injuries, workers compensation payments, turnover rate, absenteeism frequency, lateness reports and productivity for the various departments were used to find the most representative departments for conducting the workplace survey.

The ergonomic audit developed here provides an overview of the ergonomics (human factors) of the inspection system. It will not point out the specific human errors that might result during the task, but rather indicate the **important** human factors issues that need to be addressed if the performance of the operator doing the task is to be improved. It provides a comparison of the current condition and the standards prescribed by current human factors good practice, incorporating national and international standards where appropriate. The report generated by the computer program gives guidelines to prioritize and systematize the application of human factor techniques, so as to develop improvements and achieve the set standards.

As with the previous audit programs for manufacturing (Mir, 1982), continuing observations of the task specify a series of measurements which need to be made. Some of these are measured with the help of instruments (e.g., light-meters, tape measures etc.), while some others are answers to checklist questions. The audit program has been designed to be modular so that the auditor can apply the particular measurements needed in each task.

3.2 Development of the Audit Program

There are three steps in the audit program designed here. First, a method must be developed to choose the correct tasks to audit. Second, a reliable audit checklist is required. Finally, a computer program is needed to compare the audit results against human factors standards.

3.2.1 Sampling of Tasks

The first decision which needs to be made is the basic unit to be audited. In a manufacturing environment the natural unit is the **workplace**, but in inspection (or maintenance) the task, represented by the workcard, is more appropriate as all job and quality control procedures already are based on this unit.

Of the various statistical sampling techniques available, the only two that can be effectively used to decide on which task to be audited are random sampling and stratified random sampling (systematic sampling). In random sampling, all tasks (workcards) are given an equal chance of being selected. This ensures that the sample selection is unbiased, but it may require larger sample sizes to provide appropriate coverage. However, an additional consideration is the fact that all inspection tasks may not be considered of equal importance. It may be more appropriate to concentrate the sampling on those tasks considered most critical. Stratification can be used to segregate items to be examined by sampling within pre- determined groups, or strata, of tasks. Some care must be exercised while establishing the strata. They should be determined so as to form a group having similar characteristics. As part of this program, a detailed technique, similar to those used in job evaluation, was developed to apply stratified sampling (Koli, et al., 1993). However, only the simpler random sampling is presented here.

Having decided which tasks to audit, the form and content of the audit system itself need to be determined. In form the audit was conceived as a two-part system. The first part is a checklist, presenting a set of ergonomic questions to the auditor. Having answered the questions, the second part, a computer program, is used to compare the answers against ergonomic standards and to prepare an audit report detailing the inspector/system mismatches.

As the aim is to determine which aspects (task, operator, machine, environment) may impact inspector-system mismatches, the content of the audit checklist can use any convenient taxonomy of factors affecting human performance. The generic task description developed in Phase I was used here, breaking any inspection job into the seven tasks of Initiate, Access, Search, Decision, Respond, Repair and Buyback. These can be grouped together into a pre- inspection phase (Initiate), an inspection phase (access, search, decision, respond) and a post- inspection phase (repair, buyback).

With this structure, it was now possible to define more clearly the features necessary in the overall audit system. An audit system:

- **is modular**, so as to include maximum coverage without unnecessary length. Insertion of new modules to modify the checklist and program for a particular industry is easy.
- **is self explanatory**, so as to minimize training time for auditors.
- **is based on standards from ergonomics/human factors.**
- **has standards built into the analysis program** rather than into the checklist questionnaire to reduce any tendency to "bend" data in borderline cases.
- **relies on measurements** and easily observable conditions to reduce judgment errors.
- **is usable in different aviation environments**, e.g. large fixed wing aircraft, general aviation aircraft, or rotary wing aircraft.

With these in mind the audit system was designed, and is described in the following section.

3.2.2. The Audit Checklist

From the taxonomy of factors, and the three phases of the audit, a checklist was produced. It is either a paper-based system or can be entered in the field to a portable computer, whichever is more convenient. Two versions of the paper-based system are available, a larger version with detailed instructions and pictorial examples, and a much shorter version to be used when the auditor is sufficiently practiced to be able to work without these aids.

A. Pre-Inspection Phase

In this phase the auditor collects information on ergonomic aspects which are not expected to change during the task sequence. These are represented by questions on:

- documentation, communication during shift changes etc.,
- visual and thermal characteristics of the environment and
- equipment design issues (NDT and access).

This information is gathered before the actual inspection to reduce the effort of the auditor (and any interference with the inspector) to a minimum once the task progresses.

B. Inspection Phase

During this phase the auditor evaluates the main issues, i.e., information, environment, equipment and physical activity, but the focus of attention is the task at hand, and the way in which this task is executed. The issues are:

- usage of documentation, communication between workers/supervisor
- task lighting, noise levels, operator perception of the thermal environment
- equipment availability and standards and
- access, posture, safety.

C. Post-Inspection Phase

This phase evaluates the maintenance activities, i.e. repair and buy-back. Although it uses the same guidelines of the inspection task and also follows the same structure and sequence, some additional modules to address issues specific to the maintenance activity have been included.

3.2.3 The Computer Program (ERGO) for Audit Analysis

The audit analysis program has a data input module and a data analysis module, which are further divided into several independent modules addressing specific issues of the pre- inspection, inspection and the post-inspection stage, e.g. documents, communication, visual characteristics, access, posture. The fundamental logic of both the programs is as follows:

1. opening the data file
2. accepting answers or values to the various questions in the checklist
3. updating the counter
4. writing the answers to a data file
5. accessing the data file
6. comparing values with correct value or answer
7. setting flags and proceeding to the next data set if the two answers are unequal
8. checking the position of all flags at the end of all data input
9. printing recommendations or prescribing guidelines for all the flags set.

A simple manual accompanies the program, showing how to:

- install the software onto a personal computer
- run the program
- create and view data files
- access data files for analysis
- create and view output files
- print data and output files and
- abort from within the program.

The manual has been written such that novice computer users can install and run the program.

3.3 Evaluation and Evolution

It is only possible to refine and develop a system such as the ergonomics audit program through continual input and testing in operational environments. Two airline partners were involved in the design, evaluation and development of this system. The first was a regional operation of passenger helicopters, and the second a major national airline. Requirements were initially perceived to be quite different in each environment, but a common audit system was eventually developed so as to be applicable wherever aircraft inspection is performed. The only differences between the different versions of the audit system are in the choice of aircraft types in the examples and illustrations. Versions exist for airline jets, regional turboprop airliners (or corporate aircraft), light aircraft (general aviation) and rotary wing aircraft. It is worth repeating that these different versions exist solely to make the auditors more comfortable by seeing familiar aircraft illustrated: the content of each checklist (and of the computer analysis program) is identical.

The Audit checklist evolved over three different versions.

Version 1.0 contained questions segregated into 18 modules spread over the Pre-Inspection, Inspection and Post-Inspection Phases. This version was evaluated at the sites of both airline partners, where the need for graphics was identified. Graphics were required for their greater comprehension capabilities, and were incorporated in Version 2.0. Thus, **Version 2.0** retained the same structure as the previous checklist; however, a few of the questions were appended with self-explanatory diagrams while others were rephrased to reduce ambiguity. This checklist was then tested for reliability at two different sites.

The ergonomic audit was administered simultaneously by two trained auditors on the following three tasks, spanning two aircraft types:

1. Audit 1 - Sikorsky S58T Phase III Main Rotor transmission inspection
2. Audit 2 - Wing Inspection on a DC-9
3. Audit 3 - Lavatory Inspection on a DC-9

The differences between the two auditors were analyzed using the Cochran Q test, which is a strong test to determine whether the same treatment generates different responses between subjects. The value of the test statistic X2 for each test is shown in Table 3, where all differences are significant at $p < 0.05$.

Table 3 Test for Significance of Differences Between Auditors

	Task Audited	**X^2**
1	Audit 1 S58T Phase III Main Rotor inspection	7.14
2	Audit 2 Wing inspection DC-9	5.00
3	Audit 3 Lavatory inspection DC-9	5.00

Table 3

The conclusion is that results did change between the two auditors. Specific questions whose responses were different between the auditors were not indicated by the significance test, and had to be determined by post-hoc investigations. As these differences were found, redesign of the audit program was required to provide a checklist which gave the same results for each auditor.

In order to better understand the disparities, the checklist questions were segregated into three categories dependent upon the type of question, and hence the possible errors in answering the question. Thus, any question on the checklist can either result in either a Reading Error, an Operator Perception Error, or an Auditor Judgment Error. Overall, 54% of the questions were of the reading off type questions, 24% were the operator perception type and 21% were the auditor judgement errors. **Figure 1** shows the percentage of each error type made on the three tests.

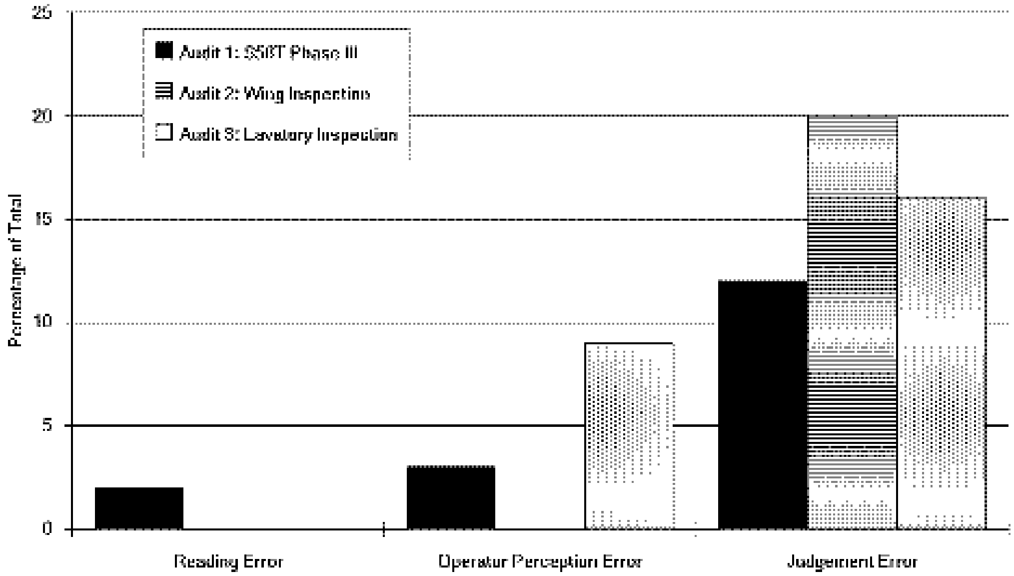

Figure 1 Percentage of Each Error Type on East Test

As can be seen from this figure, the maximum errors were due to **auditor judgement** followed by **operator perception errors**. **Reading off errors** contributed to only a very small percentage of the total errors.

Thus, in order to reduce the mismatch between auditors, auditor judgement errors have to be reduced to the minimum. This can be achieved by:

1. More explicit instructions assigned to auditor judgement questions
2. Reduce the number of "auditor judgement" type questions and increasing the number of "read off" type of questions.
3. Better training of auditors.

Version 3.0 of the audit checklist incorporated all of the above recommendations and was tested for reliability by administering simultaneously by two auditors on the task (Audit 4) of the Left Power Plant Inspection on a DC-9 (Table 4).

Table 4 X^2 Table to Test for Significance

Audit	Task Audited	X^2
4	Audit 4 - Left Power Plant Inspection/DC-9	2.1

Table 4

The differences between the two auditors was analyzed using the Cochran Q test, referenced earlier. The value of the test statistic X2 was now not even significant at $p < 0.10$, showing that results did not change between the two auditors. Thus, Version 3.0 of the audit was deemed to have proven reliability.

3.4 The Audit System in Practice

The audit evaluation emerges in the form of a memo to a supervisor from an auditor, using heading information generated within the program. This format can readily be changed, as the output file is a simple text file suitable for input into any word processor. Note also that the output does not just give information that there is a mismatch, but provides some guidance as to how corrections can be made, for example by giving recommended illumination levels or recommended air temperatures. The audit program is no substitute for a detailed ergonomic analysis, but it does provide a rapid tool for identification of error-likely situations. For more detailed recommendations, the FAA/AAM Human Factors Guide (in press) should be consulted.

Finally, it should be noted that the audit program takes about 30 minutes to administer. As this is less than the time typically required to type an audit report, the system is time-saving and cost-effective in addition to its primary role of providing wider access to human factors techniques in aircraft inspection.

The audit system has now been used by both airline partners, using the training version of the checklist and the computer documentation produced. It has been used in two rather different ways. At the rotary wing operation, several audits were performed and the results combined to provide guidance to management in the implementation of changes. From this compilation it was determined that the major ergonomic needs were documentation redesign, task lighting and access equipment redesign. Steps have now been taken to begin implementation of changes based upon those findings, and the audit program will be used after implementation to measure the effectiveness of the changes.

Our other airline partner has incorporated the audit program into its on-going Quality Assurance system. A single auditor has been trained in its use, and regularly uses it to produce audit reports on specific inspection activities.

4.0 OVERALL CONCLUSIONS

These two projects were separate but complementary. The first showed how a specific inspection subsystem (the workcard) can be enhanced using modern portable computer systems. Direct access to documentation reduced reliance on memory and waiting time to retrieve the information. Compared to the original paper-based workcard, the computer- based system was easier to understand, reduced the effort to locate information, increased organization and consistency of information, and increased overall usability of the workcards. The inspectors found the computer-based workcards interesting and would like to see them implemented at the workplace. Time to become familiar with the system was brief.

The second project showed how an overall assessment could be made of the quality of human factors design of inspection workplaces. This project also showed how sensible use of a computer system could enhance performance.

Perhaps the greatest point of similarity between the two projects was their impact on efficiency. Both were designed to reduce human/system mismatches, and thus impact inspection errors. But both systems impacted favorably upon the time required to perform the task. With computer-based workcards, unnecessary re-entry of information was eliminated, and all required documents were where the inspector needed them, thus removing the need to seek out other information sources. For the audit program, the ability to produce a typed audit report more rapidly than by hand has led to its adoption in the maintenance organization. Good human factors design eliminates human/machine mismatches and can result in time savings as well as error reduction.

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