CHAPTER FOUR
ERGONOMIC AUDIT FOR VISUAL INSPECTION OF AIRCRAFT

Sanjay Koli and Colin Drury
State University of New York at Buffalo
Department of Industrial Engineering
John Cuneo
National Helicopter
Jay Lofgren
Continental Airlines

4.0 Abstract

As more demonstrations of applying human factors interventions in aircraft inspection have been completed, the need has arisen to give airlines a tool to determine which interventions are most urgent in their own operations. An ergonomics audit was developed to provide a rapid evaluation of potential human/machine mismatches in any inspection task. The audit consists of a method of choosing tasks to be audited, an audit checklist, and a computer program evaluating checklist responses against national and international standards to produce an audit report. An evaluation of all three parts of the system showed that inspectors made consistent judgements for choice of tasks, that the audit checklist gave consistent reliability among auditors, and that the computer program produced valuable results for the airline partners cost-effectively.

4.1 INTRODUCTION

An aircraft's structure is designed to be used indefinitely, provided that any defects arising over time are identified and repaired correctly. Most structural components do not have a design life but rely on periodic inspection and repair for their integrity. The primary defects are cracks and corrosion, resulting from the intermittent flexing of structures when in the air, from pressure loads, and as a result of weathering or chemicals.

Inspection, like maintenance, is scheduled regularly for each aircraft. Each schedule is translated into a set of workcards. Equipment impeding access to the inspected area is removed. The aircraft is then cleaned, and the access hatches are opened. This is followed by the inspection process. Inspection can be described as a complex socio-technical system exerting both mental and physical stress on the inspectors and on other organizational players (Drury, 1985). At a more detailed level, the inspection task can be broken into a set of subtasks which follow a logical order (Table 4.1).

With these seven task steps, the complex problem of error control, design of equipment used, and environmental issues become more manageable as specific human factors knowledge is brought to bear on each issue in turn. Arising from human factors analyses of inspection tasks, a number of 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 benefit from ergonomics without their necessarily having trained ergonomists. There is now a need to provide integrative tools enabling a maintenance organization to develop an overall strategy for applying human factors principles systematically. The audit program developed in this report is an essential step towards such integration.

Table 4.1 Generic task description of inspection with examples from visual and NDT inspection (Drury and Lock, 1992)

TASK DESCRIPTION	VISUAL EXAMPLE	NDT EXAMPLE
1. Initiate	Get workcard. Read and understand area to be covered. Calibrate.	Get workcard and eddy current equipment.
2. Access	Locate area on aircraft. Get into correct position.	Locate area on aircraft. Position self and equipment.
3. Search	Move eyes across area systematically.	Move probe over each rivet head. Stop if any indication.
4. Decision-Making	Examine indication against remembered standards.	Reprobe while closely watching eddy current trace.
5. Respond	Mark defect. Write up repair sheet or if defect, return to search.	Mark defect. Write up repair sheet, or if no defect, return to search.
6. Repair	Drill out and replace rivet.	Drill out rivet. NDT on rivet hold. Drill out for oversize rivet.
7. Buy-Back Inspect	Visually inspect marked area.	Visually inspect marked area.

In order to know where to apply human factors, for example using the FAA/AAM-developed *Human Factors Handbook* (Parker, 1992), it is first necessary to identify the mismatches between the human (inspector) and the system (equipment, tools, environment). The audit program provides a convenient, quantitative way to identify these mismatches. It starts from the common ergonomics basis of inspection as a task/operator/machine/ environment system. The audit's output can be used to focus design/redesign efforts where they will have the greatest impact on reducing human/system mismatches which cause inspection and maintenance errors.

There have been previous ergonomics audit programs for manufacturing (Mir, 1982; Drury, 1988; Kittusway, Okogbaa, and Babu, 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 (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 identify the most representative departments for conducting the workplace survey.

Ergonomic Audit

The ergonomic audit developed here provides an overview of the inspection system's ergonomics (human factors). It will not point out specific human errors that might result during the task; rather, it indicates the **important** human factors issues that need to be addressed to improve the performance of the operator doing the task. It compares the current conditions with the standards prescribed by current human factors good practice, incorporating national and international standards where appropriate. The report the computer program generates gives guidelines to prioritize and systematize the application of human factors techniques, to improve and to achieve the standards.

As with the previous audit programs for manufacturing (Mir, 1982), continuing observations of the task specify a series of measurements that need to be made. Some are made with the help of instruments such as light-meters or tape measures; others are answers to checklist questions. The audit program is modular so that the auditor can apply the particular measurements needed for each task.

4.2 REQUIREMENTS FOR AN AUDIT SYSTEM

4.2.1 Deciding Which Tasks to Audit

Every auditor has to use a sampling process. Any sampling strategy has to address the following issues:

- how to sample
- how much to sample
- how to appraise sample results (Hill, Roth, and Arkin, 1962).

For the ergonomics audit, how to sample is more important than how much to sample. The mechanics of sampling may well decide the success or the failure of the test in providing the auditor with valid, reliable information. First, the auditor needs to identify the basic unit to be audited. In a manufacturing environment, the natural unit is the **workplace**. In inspection (or maintenance) however, the task represented by the workcard is more appropriate since all job and quality control procedures are already based on the task.

There are two possible sampling techniques: judgment sampling and statistical sampling (Willingham and Carmichael, 1979). Judgment sampling selects items subjectively, without statistical considerations for sample size, method of selection, or evaluation. Since selection criteria are based on the auditor's subjective judgment, one obviously cannot project the sample results to the entire population. Statistical sampling, in contrast, provides objective criteria for sample selection and is more appropriate for quantitative ergonomics audit. Of the various statistical sampling techniques available, only two can be effectively used to decide which task to audit: random sampling and stratified random sampling (systematic sampling).

In random sampling, all tasks (workcards) have given an equal chance of being selected. While ensuring that the sample selection is unbiased, random sampling may require larger sample sizes to provide appropriate coverage.

However, an important additional consideration is the fact that all inspection tasks may not be considered equally important. It may be more appropriate to concentrate on sampling 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. The methods discussed below provide one stratification strategy, although other strategies can be adopted for screening tasks.

Parallel to the development of audit systems, there have been job analysis systems aimed at evaluating the ergonomics and the technical design of working systems (Landau and Rohmert, 1989). The documentation and diagnosis of working system involves describing and quantifying the system's elements and their characteristics, e.g., stresses they exert, deduction of design needs, formation and verification of design properties, prevention of possible impairments by detecting unsupportable stresses, and purposeful reduction of stresses. Thus, job analysis and ergonomic auditing share many commonalities and have the same need to identify critical tasks.

The technique for selecting tasks (work-cards) in the ergonomics audit program used a points system (Lanham, 1955) similar to those used in job evaluation systems. Any sampling system must be:

- able to provide a thorough study of *all jobs to be evaluated*
- one which the *supervisor and the employees can understand* and are willing to accept
- *easy to execute*
- able to produce a *high degree of accuracy* (Lanham, 1955).

A points system fulfills these requirements. The system uses judgements of inspectors and/or management to determine which factors are important to error reduction.

The point system provides the rater with a scale or a "yardstick" to use in measuring the differences among jobs. In designing a point scale, the following steps must be completed:

- Select and define factors common to all the jobs to be evaluated
- Allocate the number of degrees to each factor (length of the rating scale)
- Weigh the factors, depending upon their relative importance
- Assign point values to each degree of each factor.

The task to be rated is measured, factor by factor, against the scale. The degree on the scale most nearly describing that factor's situation in that task is selected. The number of points which have been assigned to that degree on the scale is assigned to the job. When the proper degree has been selected for each job factor, the point values for the listed degrees are totaled. This sum represents the final point value of the job in question.

In addition to the final point value, each task can also be judged, based upon the value of the individual factors. For example, if one crucial factor of a generally low-rated task has been rated exceptionally high, that task, too, will be audited.

4.2.2 The Ergonomics Audit System

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

The audit's aim is to determine which aspects (task, operator, machine, environment) may impact inspector-system mismatches. The content of the audit checklist could use any convenient taxonomy of factors affecting human performance. Following Prabhu and Drury (1992) and Latorella and Drury (1992), the following taxonomy:

- **Information Requirements** - documents, communication
- **Equipment/Job Aids** - design issues, availability, standards
- **Environment** - visual, auditory, thermal
- **Physical Activity/Workspace** - access, posture, safety.

Although this taxonomy defines factors affecting human/system mismatches, it is not in the most convenient form for the auditor. To expedite auditing, it is preferable to turn to the generic task description found in Table 4.1 and to restructure the audit to follow the sequence of inspection tasks. These can be grouped into a pre-inspection phase (Initiate), an inspection phase (access, search, decision, respond), and a post-inspection phase (repair, buy-back).

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

- **is modular**, so as to include maximum coverage without unnecessary length. Inserting 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.

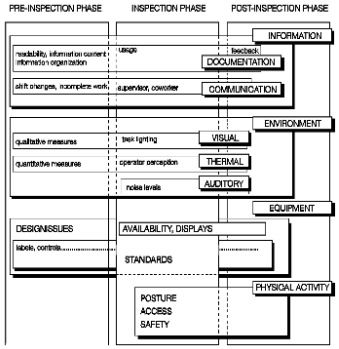
With these features in mind we designed the audit system described in the following section.

4.2.3 The Audit System Development

4.2.3.1 Audit Checklist

A checklist was produced from the taxonomy of factors and the three phases of the audit. The audit can be either a paper-based system or entered in the field on a portable computer, whichever is more convenient. There are two versions of the paper-based system available: a large version has detailed instructions and pictorial examples; a much shorter version is used when the auditor is sufficiently experienced to be able to work without these aids. Figure 4.1 shows the checklist's structure. The four factors from the ergonomic taxonomy and the three phases are overlaid on the detailed issues to be evaluated.

Figure 4.1 Structure of the Checklist, showing its relationship to the four groups of factors and three phase defined in Section 4.2.1



A. Pre-Inspection Phase

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

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

This information is gathered before the actual inspection to keep the auditor's effort (and any interference with the inspector) to a minimum as the task progresses.

B. Inspection Phase

During this phase, the auditor evaluates the main issues, i.e. information, environment, equipment and physical activity. However, the auditor's focus is the task at hand and the way this task is completed. The issues are the following:

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

C. Post-Inspection Phase

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

4.2.3.2 The Computer Program (ERGO) for Audit Analysis

Turbo Pascal 6.0 was chosen as the language for developing the audit program. It is a structured, high-level language with multiple overlapping windows, mouse support, a multifile editor, and an enhanced debugging facility.

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

- opening the data file
- accepting answers or values to the checklist questions
- updating the counter
- writing the answers to a data file

- accessing the data file
- comparing values with the correct value or answer
- setting flags and proceeding to the next data set if the two answers are unequal
- checking the position of all flags at the end of all data input
- 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
- abort from in within the program.

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

4.3 EVALUATION AND EVOLUTION

It is only possible to refine and develop a system such as this ergonomics audit program through continual testing in operational environments. Two airline partners were involved in designing, evaluating and developing this system. The first was a regional operation of passenger helicopters; the second, a major national airline. The requirements were initially perceived to be quite different for each environment, but a common audit system was eventually developed that is applicable wherever aircraft inspection is performed. The only difference among the different versions of the audit system is 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 the different versions exist solely to make the auditors more comfortable by letting them see familiar aircraft illustrated: the content of each checklist (and of the computer analysis program) is identical.

4.3.1 Sampling Plan Evaluation - The Point System

Before actually proceeding with the audit, it is imperative for the auditor to identify the task/tasks to be audited. The criticality of a task does not necessarily indicate the magnitude of its human factors mismatches. Those remain to be assessed by the audit checklist and the program itself. The Point Rating scheme identifies tasks where the probability of error occurrence is high and samples the likely problem areas.

4.3.1.1 Step 1. Selecting Factors

The basis of the sampling system developed was the experience and expertise of the employees who rate these tasks. We want to know whether the component of the screening method reflects the domain being tested and whether the components taken as a whole cover it in a representative fashion.

We employed a method of **"Multiple Judges"** to enhance their confidence in judgments of content validity. Eleven inspectors and three auditors were each asked to

- study the definition of the aircraft inspection domain
- generate a pool of possible factors influencing an inspection task
- refine that pool.

As a result of a survey study, the factors listed below were identified:

- **Mental demands:** the amount of information needed from documents, reference manuals, and communication with the supervisor and co-worker
- **Physical demands**: the amount of force/pressure to be exerted for task execution
- **Visual demands:** illumination levels required for the complete inspection
- **Access demands:** the space restrictions for carrying out the task
- **Postural demands:** the awkward postures adopted to access and inspect)
- **Temporal demands:** time stress during the inspection
- **Safety:** how safe the inspector feels during the inspection.

4.3.1.2 Step 2. Ranking the Factors

After having identified the seven factors, the inspectors were asked to rank order these factors in terms of their "degree of importance and criticality" with respect to the task. Ten inspectors with three years or more experience on C-check inspections were asked to rank these factors. The average ranking for the seven factors is as given below:

Most Important Safety

Mental demands

Visual demands

Access demands

Physical demands

Temporal demands

Least Important Postural demands.

A correlation analysis was conducted of these ten inspectors' rankings. The correlations of the individual subject readings with the average were relatively high, the lowest being 0.67. A non-parametric measure of overall correlation, **The Kendall Coefficient of Concordance (W),** measures the degree of association among inspectors had the value W = 0.674. This result was highly significant ($p < 0.001$), showing considerable agreement among inspectors.

4.3.1.3 Step 3: Weighting the Factors

It is possible to use the ranking values obtained above to determine weightings for the seven factors, using the Rank Order method (Guilford, 1954). In Table 4.2, the average ranks are shown in the first column. The second column gives the normalized ranks, assuming an underlying normal distribution of ranking responses by inspectors. Weights are then derived in the third column by dividing all the normalized ranks by the largest one (6.5). Thus, according to the inspectors' judgements, the least important factor (posture) should only receive just over half of the weight (0.51) of the most important factor (safety).

Table 4.2 Development of factor weightings from average rank values

FACTORS	MEAN RANK	NORMALIZED RANK	WEIGHTING
Safety	6.5	6.5	1.00
Mental	6.3	6.4	0.98
Visual	4.1	5.1	0.78
Access	4.0	4.9	0.75
Physical	2.8	4.6	0.71
Temporal	2.0	3.8	0.58
Posture	2.0	3.7	0.51

4.3.1.4 Step 4: Listing the Inspector Tasks

A comprehensive list of all the inspection tasks in a C-check were obtained from the airline partners operating fixed-wing and rotary-wing aircraft. For the fixed-wing aircraft, the airframe was segregated into six zones, depending upon the area under inspection:

- Fuselage
- Empennage
- Wings
- Wheel well and landing gear/cargo compartment
- Power plant
- Door and windows

A similar exercise was conducted for the rotary-wing aircraft's inspection tasks, where the natural classification was into phase inspections (Phase I through Phase V).

4.3.1.5 Step 5. Rating Tasks

For a particular zone selected, e.g., power plant, experienced inspectors were asked to rate a list of five tasks with respect to the seven factors indicated. For each task, the inspectors were asked to rate the factors on a scale from 1 to 5 as follows:

|_____|_____|_____|_____|

1 2 3 4 5

very easy very demanding

From these ratings and from the weights assigned earlier, sampling plans could be developed to concentrate auditing effort onto the most critical tasks.

4.3.2 Results of Sampling Plan

Three inspectors with ten or more years of experience with C-checks were chosen to rate the seven factors for each task listed under Power Plant Inspection and Wing Inspection. For each task, each factor rating is multiplied by its respective weight, and the values were summed over the seven factors to give one final score. The scores were then compared to each other to estimate the degree of criticality of each task. The final ranking of the tasks is presented in Table 4.3.

For the rotary-wing airline partner, three inspectors with six or more years experience with Phase inspections were chosen for a similar rating. The final ranking of the tasks is presented in Table 4.4.

From the data presented in Tables 4.3 and 4.4, it is apparent that differences among tasks are not large. Thus, while some tasks were found to have more critical ergonomic needs than others, none could be safely neglected.

Table 4.3 Final criticality ratings of power plant and wing inspection tasks

RANK	POWER PLANT TASKS	WING INSPECTION TASKS
1	Power plant inspection (15.04)	Tee Cap inspection (14.1)
2	Thruster-reverser drive link inspection (13.74)	Wing inspection (13.59)
3	Pylon inspection (13.17)	Aft spar wing control inspection (12.89)
4	Engine accessory inspection (12.16)	Flap hinge bracket penetrant inspection (10.97)
5	Power plant check (11.43)	Flap hinge bracket inspection (10.66)

Table 4.4 Final criticality ratings of inspection tasks on Sikorsky S58T and Bell 206L type aircraft

RANK	SIKORSKY S58T	BELL 206L
1	Phase I (18.87)	Phase III (20.23)
2	Phase V (14.46)	Phase IV (15.49)
3	Phase IV (13.94)	Phase II (15.42)
4	Phase III (13.71)	Phase I (13.16)
5	Phase II (13.47)	

The final result of these manipulations can again be tested for its reliability. If the inspectors are indeed judging consistently, then there should be a high degree of agreement among the final rankings of the tasks. Thus, the same inspectors were asked to rank the criticality of the tasks within each of the four sets ("fixed wing power plant" to "Bell 2062"), and these rankings were compared using the coefficient of concordance. All four values were significant at $p < 0.01$, with values as follows:

Fixed Wing, Power Plant 0.913

Fixed Wing, Wing Inspection 0.813

Rotary Wing, Sikorsky S58T 0.910

Rotary Wing, Bell 2062 0.900

These results in fact do show a high and significant level of agreement.

4.3.3 Audit Checklist

The Audit checklist evolved over three different versions. **Version 1.0** contained questions in 18 modules spread over the Pre-Inspection, Inspection, and Post-Inspection Phases. This version was evaluated at the sites of both airline partners. The need for graphics was identified because of their greater comprehension capabilities. Graphics were incorporated in Version 2.0. Version 2.0 retained the same structure as the previous checklist. A few 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.

4.3.3.1 Reliability of the Ergonomic Audit (Version 2.0)

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

- Audit 1 - Sikorsky S58T Phase III Main Rotor transmission inspection
- Audit 2 - Wing Inspection on a DC-9
- 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 4.5; all differences are significant at $p < 0.05$.

Table 4.5 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 DC-9 Wing inspection	5.00
3	Audit 3 DC-9 Lavatory inspection	5.00

Thus, results were different between the two auditors. Since the significant test did not indicate which questions had different responses between the auditors, these had to be determined by post-hoc investigations. As these differences were found, the audit program was redesigned to provide a checklist giving identical results for each auditor.

There are two ways to compare differences between the auditors: by module and by question type. First, the mismatches between the two auditors were determined for each of the 18 modules; these results are shown in Figure 4.2. The modules on Posture and Task Lighting showed the greatest number mismatches, but examination of these modules did not reveal a trend in the type or the number of mismatches.

In order to better understand these disparities, checklist questions were divided into three categories, dependent upon the type of question and, hence, upon possible errors in answering the question. Thus, any question on the checklist either result in either a Reading-Off Error, an Operator Perception Error, or an Auditor Judgment Error. Overall, 54% of the questions were reading-off type questions; 24% operator perception type; and 21% auditor judgement type. Figure 4.3 shows the percentage of each error type inspectors made on each of the three tests.

As seen in Figure 4.3, most errors were due to **auditor judgement,** followed by **operator perception**. **Reading-off errors** contributed a very small percentage to 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 the following strategy:

- Have more explicit instructions assigned to auditor judgement type questions
- Reduce the number of "auditor judgement" type questions and increase the number of "read-off" type questions.
- Provide better training for auditors.

Figure 4.2 Frequency of mismatches for the three audits by modules

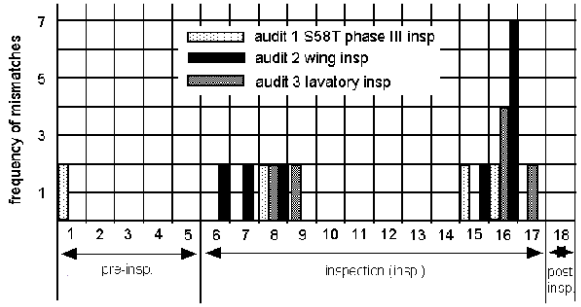
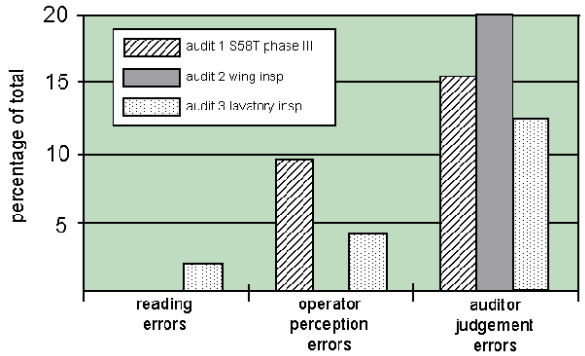


Figure 4.3 Percentage of each error type on each test



Version 3.0 of the audit checklist incorporated all of the above recommendations and was tested for reliability by having two auditors administer audits simultaneously on the task (Audit 4) of the Left Power Plant Inspection on a DC-9. The differences between the two auditors were 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 (Table 4.6). Thus, Version 3.0 of the audit was deemed to have proven reliable.

Table 4.6 X^2 Table to test for significance

AUDIT	TASK AUDITED	X^2
4	Audit 4 - Left Power Plant Inspection/DC-9	2.1

4.4 THE AUDIT SYSTEM IN PRACTICE

Both airline partners have used the training version of the checklist and the computer documentation produced, although each partner has used the audit system in a rather different way. The rotary-wing operation performed several audits, and the results were combined to guide management in implementing 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 implementing changes, based upon the findings. 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 program. A single auditor has been trained, and regularly uses the system to produce audit reports on specific inspection activities. An example of output from the program is Chapter 4 Appendix, obtained after an audit of a fixed-wing aircraft late in 1993. Names, dates, and numbers have been changed to preserve anonymity.

The audit evaluation takes the form of an auditor's memo to a supervisor, 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. Also, the output does not simply identify a mismatch. It 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 identifying error-likely situations. For more detailed recommendations, the FAA/AAM Human Factors Guide should be consulted.

Finally, 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 providing wider access to human factors techniques in aircraft inspection.

4.5 REFERENCES

Drury, C. G. (1985). Stress and quality control inspection. In Cooper, C. L. and Smith, M. J. (Eds.), Job Stress and Blue Collar Work, 7, Chichester, UK: John Wiley and Sons, Inc.

Drury, C. G. (1988). Inspection performance and quality assurance: Job Analysis Handbook, Chapter 65, New York: J. Wiley.

Drury, C. G. and Lock, M. W. B. (1992). Ergonomics in Civil aircraft inspection. In Contemporary Ergonomics, London: Taylor & Francis, 116-123.

Eberhardt, S., Reynolds, J., and Drury, C. G. (1993). Effect of working postures in confined areas. FAA/AAM 8th Meeting on Human Factors Issues in Aircraft Maintenance & Inspection (in press).

Gramopadhye, A., Drury, C. G., and J. Sharit (1993). Training for decision making in aircraft inspection. Proceedings of the 37th Annual Human Factors and Ergonomics Society Meeting, Seattle, WA, 1267-1271.

Guilford, J. P. (1954). The method of rank order. Psychometric Methods, 8, New York: McGraw-Hill, 178-196.

Hill, H. P., Roth, J. L., and Arkin, H. (1962). Why statistical sampling? Sampling in Auditing -A Simplified Guide and Statistical Tables, 1, New York: The Ronald Press Company, 1-10.

Kittuswamy, N., Okogbaa, O. G., and Babu, A. J. G. (1992). A preliminary audit for ergonomics design in manufacturing environments. Industrial Engineering, July 1992, 47-53.

Koli, S., Drury, C. G., Cuneo, J., and Lofgren, J. (in press). Ergonomic audit for visual inspection of aircraft, Human Factors in Aviation Maintenance - Phase 4 Progress Report.

Lanham, E. (1955). Selection of the rating plan. Job Evaluation, 4, New York: McGraw-Hill Book Company, 39-52.

Latorella, K. A. and Drury, C. G. (1992). A framework for human reliability in aircraft inspection. In Meeting Proceedings of the Seventh Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection, Atlanta, GA, 71-82.

Mir, A. H. (1982). Development of ergonomic audit system and training scheme, M.S. Thesis, State University of New York at Buffalo.

Parker, J. (in press). Human Factors Guide, Bio-Technology, Inc.

Patel, S., Prabhu, P., and Drury, C. G. (1992). Design of work control cards. In Meeting Proceedings of the Seventh Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection, Atlanta, GA, 163-172.

Prabhu, P. and Drury, C. G. (1992). A framework for the design of the aircraft inspection information environment. In Meeting Proceedings of the Seventh Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection, Atlanta, GA, 83-92.

Reynolds, J. and Drury, C. G. (1993). An evaluation of the visual environment in aircraft inspection. Proceedings of the 37th Annual Human Factors and Ergonomics Society Meeting, Seattle, WA, 34-38.

Reynolds, J. L., Gramopadhye, A., and Drury, C. G. (1992). Design of the aircraft inspection/maintenance visual environment. In Meeting Proceedings of the Seventh Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection, Atlanta, GA, 151-162.

Rohmert, W. and Landau, K. (1989). Introduction to job analysis. A New Technique for Job Analysis, Part 1, London: Taylor & Francis Ltd., 7-22.

Willingham, J. J. and Carmichael, P. R. (1979). Sampling for audit evidence, *Auditing Concepts and Methods, 6,* New York, McGraw-Hill, 166-195.

CHAPTER FOUR APPENDIX - Example Output from Ergonomic Audit

TO **:Ms Supervisor**

FROM **:A.N. Auditor**

Task Description **:APU Compartment Inspection.**
Date **:August 4, 1993**
Time **:3:00 am**

Station **:LHR**
Hangar Bay **:**
Aircraft No. **:A300**
M/E No. **:87-1831-1-0001**
Q/A No. **:24A76**

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/DOCUMENTATION

A. Information readability

1. Typographic layout of the current workcard is inconsistent with other work cards. Maintain interdocument consistency in terms of:
a: Spatial organization b: Font type, Font size
c: Typographic cues (e.g., boldfacing, italics, etc.)

2. Make use of typographic cues. For spatial layout use Primary type cues like:
a: Vertical spacing b: Lateral positioning c: Paragraphing
d: Heading positioning

Within the spatial layout use secondary type cues like:
a: Bold-facing b: Italics c: Capital cueing d: Underlining, etc

3. Dot matrix printers with a 5X7 matrix of dot characters is minimally acceptable for reading purposes. If used, check for character specifications:
Minimum Character Height = 3.1mm to 4.2mm
Maximum Character Height = 4.5mm
Width/Height ratio = 3:4 - 4:5
IMPORTANT: Do not use lower case letters, since features can get easily confused.

4. Graphics/attachments illegible. Likely causes:
a: Photocopy deterioration b: Microfiche copy deterioration
c: Blueprint copy deterioration

5. Standards are not prescribed. State "TIME" and "QUALITY" standards to ensure consistent print quality.

B. Information Content

Text

6. Feedforward information not provided to the inspector. Present information on
a: previous faults detected b: locations of prior faults c: likely fault prone
areas for the specific task and current aircraft under inspection.

Graphics

7. Present information on body station positions in a graphical format. All spatial information should be presented in a diagrammatic form.

C. Information Organization

8. Incorrect sequencing of tasks in the workcard. Tasks need to be sequenced in the natural order in which the task would be carried out by MOST inspectors.

9. Avoid carryover of tasks across pages at ILLOGICAL points. Tasks should begin and end on the same page. For longer tasks, break into several subtasks with multiple sign-offs. Each subtask, should then begin and end on the same page.

10. Excessive number of tasks per action statement. More than 3 actions/step increases the probability of action slips.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/COMMUNICATION

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/VISUAL CHARACTERISTICS

1. Mercury Vapor lamps: "Poor" color rendition properties. Color rendition is the ability to distinguish true colors correctly. This is especially useful in detecting corrosion faults. For best results consider incandescent bulbs.

2. No "shades/shields" on illumination sources. This may cause "direct" or "disability" glare.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/ACCESS

ACCESS - STEP LADDERS

1. The height of the step ladder is 36.00 inches. The maximum height should be 27 inches.

ACCESS - TALL STEP LADDERS

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/DOCUMENTATION-PHYSICAL HANDLING & ENVIRONMENT FACILITY

1. The inspector does not sign off workcard after each subtask. This may lead to errors of omission.

2. Writing tools do not facilitate writing in all positions. Consider providing a workcard holder.

3. The inspector does not fill out discrepancy sheets/Non-Routine Repair sheets as soon as fault is detected. This may lead to errors of omission.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/COMMUNICATION

1. The inspector felt that verbal instructions from the supervisor were not explicit.

2. No performance feedback was given to the inspector conducting the task. Consider intermittent supervision by the supervisors to indicate when inspector was not performing up to standards.

3. The inspector was not encouraged to identify error likely situations in "Existing Designs".

4. The inspector was not encouraged to identify error likely situations in "Existing Procedures".

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/TASK LIGHTING

1. The average task illumination is 72.50 foot candle (fc) and the variance is 2718.75. The recommended task illumination should be 100.00 fc. The variance is exceptionally high.

2. Hand lamps deliver a maximum of 85 fc. of light. This illumination level is inadequate for "Detailed Inspection". Hand lamps also lack aiming control. Consider usage of Standing Lamps (Halogen 500 watts - 1200 fc.) or Portable lamps (Florescent 27 watts - 164 fc.).

3. Consider head lamp for hands free illumination; except in explosive environments. e.g., Fuel tank inspection.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/THERMAL CHARACTERISTICS

1. The current DBT is 31.00 degrees centigrade. The recommended temperature is between 20-26 degrees centigrade.

2. The current task has been identified as having MODERATE physical workload. The current air velocity is LOW (less than 1.5 m/s), and the WBGT is 29.00 cent. The recommended WBGT values for MODERATE w/load and LOW air velocity is 30 de.g., or less.

3. The current task has been identified as having MODERATE physical workload. The DBT is 29.00 cent. and the clo value for clothing is 0.58 clo. The recommended DBT values for MODERATE w/load and clo values between 0.5-0.75 are 18-22 degrees centigrade. Consider change in clothing.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/OPERATOR PERCEPTION OF THERMAL ENV.

1. The operator found the current workplace temperature to be slightly warm.

2. Operator wanted the workplace temperature to be cooler than the current temp.

3. The operator found the summer temperature at the workplace to be warm.

4. Operator wanted the summer temperature at the workplace to be cooler than the current temperature.

5. The operator found the winter temperature at the workplace to be cool.

6. Operator wanted the winter temperature at the workplace to be warmer than the current temperature.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/AUDITORY CHARACTERISTICS

1. The variance is high.

2. This task involves verbal communication. The average noise level is 65.00 dbA. The distance of communication is 20.00 feet. The noise level for communication at a distance of 10-20 feet should not exceed 50 dbA.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/ACCESS EQUIPMENT USAGE

1. Neither the correct access equipment nor the substitute access equipment was available.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/ACCESS - ACTIVITY

1. The operator felt that access was difficult.

2. Access equipment was repositioned too frequently. This consumes a lot of operator effort. Consider using multiple access equipments.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN INSPECTION/POSTURE

The following extreme postures were observed during the current inspection task:
Urgent intervention is requested.

1. Arms in air, back bent and loading on one leg.

2. Arms in air, back twisted and loading on one leg.

3. Back bent and twisted and loading on one leg.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN PRE-INSPECTION/SAFETY

1. No safety attachments provided when operator performs inspection at heights. Consider using safety screens on stair landings, rails, cages etc.

HUMAN FACTORS MISMATCHES/RECOMMENDATIONS IN POST-INSPECTION/FEEDBACK

1. Consider inclusion of standard information like ATA codes, station #, sup.#, employee #, etc. in the workcard. This considerably reduces the cognitive load on the inspector.