Chapter Eight
Training for Visual Inspection of Aircraft Structures

8.0 INTRODUCTION: THE STATE OF VISUAL INSPECTION TRAINING

Although much has been written about training for aircraft maintenance in the past several years (e.g., Shepherd and Parker, 1990), very little applies directly to the acquisition and enhancement of visual inspection skills. Typically papers concern either the overall structure of training program (Skinner, 1990; Desormiere, 1990) or the technology of training delivery systems (Payne, 1990; Kurland and Huggins, 1990; Goldsby, 1991; Rice, 1990). Visual inspection has skill, rule and knowledge-based components and, as such, is less amenable to rule-based diagnostic procedures. Such procedures have received widespread study in avionics (Johnson, 1990; Johnson, et al., 1992) and nuclear power (Kello, 1990) and can represent the technological leading-edge of training delivery. However, for visual inspection, visits by the State University of New York (SUNY) team to many airlines have revealed a relatively uniform approach. Training content is seen as either knowledge or skills, with knowledge imported in the classroom and skills through on-the-job training (OJT). Despite the overall effectiveness of inspection, our site visits have revealed a strong desire to find enhanced ways to implement visual inspection training.

Examples of high quality inspection training can be seen in many airlines, but in all there is the same classroom/ OJT split of delivery methods.

- On-the-job training (OJT) is the preferred way of imparting training to new inspectors. Most of the classroom training targets pre-flight checks, non-destructive test (NDT) or orientation. One airline (Lutzinger, 1989) has such a program where 5% (approximately 15-17) of their inspectors are trained daily. They also have a program called C-3 under which, when a supervisor discovers an aircraft discrepancy missed during an earlier inspection, he codes this item C-3. These C-3 items are used to point out to inspectors what kinds of discrepancies are being missed during aircraft checks.
- An aircraft manufacturer has developed a "task analytic training system" model to address training needs for NDT (Walter, 1990). However, elements of this model are generalizable to visual inspection. This method consists of performing a job task analysis to identify training needs and job instruction training to impart knowledge. This methodology also emphasizes a team approach to developing the training modules. A design team, an approval team, and a team facilitator comprise the personnel creating a module. An iterative procedure involving the work force is utilized. An annual audit assesses the status of each training module.
- Another airline combines orientation training with on-the-job training (OJT). There is a new inspector orientation training called Q.C. transition orientation which lasts for 16 hours over two days. The inspector is then put on a 40 hour OJT at the end of which he/she is Required Inspection Item (R.I. I.) certified. The airline has instituted an inspection research request program. Under this, inspectors who detect a problem with inspection procedures, workcards, documentation, etc. can submit a request to the quality control analyst for a review. Inspectors also have available information on inspection alerts that are generated by engineering. When a new aircraft arrives, Q.C. denotes one of its foremen as a training instructor. The training instructor visits the manufacturer and gets information to set up a training program for inspectors. Quality control then initiates training for the whole department to familiarize them with the new aircraft.

There are, however, drawbacks to the classroom/OJT approach. These have been identified by proposers of simulation as a delivery intervention (e.g., Johnson, 1990; Lesgold, 1990; Kello, 1990) who show that classroom/OJT is not an optimum way to train.

Shepherd and Parker (1990) recognize both the content and the delivery system as crucial to training. Content has been defined for maintenance in terms of knowledge, skills and abilities (KSA) since the Allen report in 1972. Currently, the KSA's for maintenance are being redefined for Part 147 schools, but again there is little on visual inspection. A recent compilation of training research and practice (Patrick, 1992) can be used to define the current status of training and the issues involved. These lead to experimental evaluations of particular training interventions for visual inspection, which in turn provide the basis for enhanced training programs.

8.1 CURRENT METHODS IN TRAINING: AN OVERVIEW OF RESEARCH

Training design deals with the issue of translating training content into a training program. Patrick (1992) identifies training content, training methods and trainee characteristics as the three main components of a well-designed training program. With the advent of computer-based training (CBT) and multi-media approaches, we should add training delivery systems as another component.

8.2 TRAINING CONTENT

Training content pertains to identifying the knowledge and skills needed to perform the set of tasks that define a job. For example, Wirstaad (1988) identifies knowledge categories (e.g., layout knowledge), knowledge objects (documents, etc.) and depth of knowledge as a way of identifying job training requirements.

A systematic analysis of the task is necessary to identify the training content. Patrick (1992) classifies analysis techniques into (a) task-oriented analysis and (b) psychological techniques. Task-oriented techniques use task-oriented data to derive the needs, objective and content of the training program. Examples are Task Analytic Training (e.g., Walter, 1990), hierarchical task analysis, HTA (Drury, et al., 1990), critical incidents technique (Flanagan, 1954) and task inventory (e.g., USAF Task Taxonomy, Christal, 1974). Psychological approaches typically use taxonomies that categorize aspects of the task in terms of human motor/perceptual/cognitive processes. This can help the analyst understand the psychological elements that need to be addressed (e.g., decision making skills, reasoning, etc.) by specific training methods.

8.3 TRAINING METHODS

Training methods deal with techniques that can help transfer the training contents to the trainee in an effective manner. Some of the common/popular methods (Patrick, 1992; Drury and Gramopadhye, 1990) are discussed below.

8.3.1 Pre-Training

Pre-training provides the trainee with information concerning objectives and scope of the training program. Pretests can be used to measure (a) level at which trainees are entering the training program, and (b) cognitive or perceptual abilities that can be later used to gauge training performance/progress. Advanced organizers or overviews, which are designed to provide the trainee with the basics needed to start the training program, have been found to be useful. The elaboration theory of instruction (Reigeluth and Stein, 1983) proposes that training should be imparted in a top-down manner where a general level is taught first before proceeding to specifics. Overviews can fulfill this objective by giving the trainee an introduction to the training program and facilitating assimilation of new training material.

8.3.2 Knowledge of Results

Knowledge of the results is probably the most common and effective method of training. Drury and Kleiner (1990) suggest that training programs start with rapid, frequent feedback which is gradually decreased until "working" level is attained. Additional feedback beyond the end of training will help to keep the inspector calibrated (Drury and Gramopadhye, 1992). Gramopadhye (1992) classifies feedback as performance and process feedback. Performance feedback for inspection typically consists of information on search times, search errors and decision errors. Process feedback, on the other hand, informs the trainee about the search process, i.e., areas not covered, inter-fixation distance, number of fixations. Research (explained in the next sections) supports the beneficial effects of process feedback on inspection performance. Another type of feedback called "cognitive feedback" has emerged from the area of social judgement theory. Cognitive feedback is the information to the trainee of some measure of the output of his or her cognitive processes. It is suggested that cognitive feedback allows the trainee to perceive the error in their judgement as well as why the judgement was in error (Hammond and Summers, 1972; Doherty and Balzer, 1988).

8.3.3 Guidance or Feedforward

Guidance or feedforward provides the trainee with information prior to action, concerning how to carry out part or all of the task. For example, an experienced inspector can tell the novice how he looks for evidences of corrosion in the cargo compartment. Guidance could be physical (for acquisition of motor skills), demonstrations, verbal advice (e.g., prompting), and cueing (telling when and what signal occurs in perceptual detection tasks). Feedforward can also be by informing the inspector what to expect in a certain area that he is going to inspect next. Feedforward should provide the trainee with clear and unambiguous information which can be translated into performance.

8.3.4 Part-Task Training

Part-task training constitutes partitioning or simplifying the whole task into parts and then teaching these parts to the trainee. Part-task methods are classified by the manner in which parts are practiced. Isolated parts training consists of learning each part separately for either a fixed number of trials or to some criterion, and then doing the whole task together. Progressive part training teaches components of the job to criterion, and then successively larger sequences of the components (Drury and Gramopadhye, 1990). Repetitive part training involves practicing one part, then parts one and two, then parts one, two and three and so on (Patrick, 1992). In general, part task training has been found to be beneficial for complex tasks. Drury (1990) reported good results in industrial inspection tasks when using progressive part training methods.

8.3.5 Whole-Task Training

Whole-task training involves the trainee on the task as a whole instead of breaking it into parts. Naylor and Briggs (1963) have postulated that for tasks of relatively high organization, as task complexity is increased, whole-task training should become relatively more efficient than part-task training methods. This is an intuitively appealing principle because as parts of the task become more interdependent the trainee might have a harder time integrating performance on the whole task if trained on part task. Whole-task training also becomes necessary when it is not possible to identify task parts having natural segmentation with relation to the task as well as the skills needed from the trainee.

8.3.6 Adaptive Training

Adaptive training tries to accommodate the characteristics of the trainees. This method comes from a recognition that individual differences exist in the skills, knowledge, abilities and aptitudes that trainees possess. Bartram (1988) has reported a study involving operators at a post office, in which adaptive training methods were used to train the operators to sort mail at an average time per item of 1.8 seconds or less and error rate of less than 1%. Adaptive training involves measurement of the trainee's performance and making changes in the program/ method as a function of the trainee's performance.

8.3.7 Active Training

When the trainee has to actively discover information or cues, and make a physical response, learning is enhanced (Czaja and Drury, 1981). A good passive training scheme, where the information is merely presented to the trainee, is often inferior to an equivalent active scheme, where a response is required at each step.

8.4 TRAINING DELIVERY SYSTEMS

Training can be delivered to the trainee through a variety of media. With the increasing use of computers and the advances in multi-media technologies, the choices in delivery systems are varied and the task of selecting one is non-trivial. We can classify training delivery systems under the following broad categories.

8.4.1 On-the-Job Training (OJT)

On-the-job training is a much maligned word in the area of training and much of the literature is full of examples of its inadequacies. While this is true, there is a case to be made for structured OJT supplemented by adequate classroom instructions. This is especially true in cases where realistic simulators cannot be developed or are too expensive.

8.4.2 Traditional or Conventional Training

In this system we have the traditional method of instructors tutoring to trainees using slides, blackboard, and paper and pencil methods. Further embellishments include using video and TV media and even 3-D projections (Rice, 1990) to explain instructions or provide concept training. Training aids can include prototypes or models of objects used in the actual task. All the principles of training design can be used to varied extent in this system. In a review of training systems in the U.S. military, Orlansky and String (1979) found trainee achievement using conventional training and computer-based training about equivalent. However, with the advent of better and more powerful computer systems with higher quality graphics and computer-based training (CBT) methods that utilize more training design principles, the balance might be tilting in favor of CBT systems.

8.4.3 Computer-Based Training (CBT) Systems

Training systems of this type are also called computer-aided instruction systems (CAI). Patrick (1992) identifies four main roles for computers in training: (a) provision of training, (b) development of training, (c) management of training, and (d) research in training. CBT systems typically are used to fulfill the first and third roles, in which the computer is used to present training material to the student and schedule him/her through various training exercises, record progress, administer tests and provide progress summaries to the instructor. Boeing has produced a series of maintenance training CBT lessons on the 767 airplane (Lukins, 1990). They are also investigating the area of instructor-led CBT used in a classroom environment.

8.4.4 Intelligent Tutoring Systems (ITS)

Computer-based tutoring systems attempt to create interactive learning environments in which the learner/trainee can carry out simulated tasks. Typically, an ITS contains (1) an explicit model of the domain, (2) an expert program that solves problems in this domain, (3) a model of the student that explains what the student understands, and (4) a tutoring model that provides instructions (Clancey and Soloway, 1990).

SOPHIE-III (Brown, Burton and deKleer, 1982) is an intelligent simulation training system that supports interactive training by estimating and responding to student needs. SHERLOCK (Lesgold, Lajoie, Bunzo and Eggan, 1992; Lesgold, 1990) is a practice environment for learning troubleshooting a complex device on the F-15 manual avionics test station. It analyzes inferred student models with respect to expert models and emphasizes refinement of mental models. The Integrated Information Management System (IIMS) developed by the U.S. Air Force has imbedded training systems that include such features as multi-level representations for expert, novice and trainee, preview of little used tasks, and troubleshooting simulations (Johnson, 1990). The Environmental Control System (ECS) Tutor is an intelligent simulation that provides appropriate feedback and advice to the student based on observed interaction (Norton, 1992).

8.5 EXPERIMENTAL EVALUATION OF TRAINING INTERVENTIONS

Combining the literature on training for visual inspection with the demonstrated need for new techniques of inspector training, it is apparent that there are major issues in need of testing. Both visual search and decision-making aspects of the task require assistance if we are to achieve and maintain high levels of inspector effectiveness within a visually-complex, but often repetitive, visual inspection task. These issues can be classified as:

- Visual Search Issues

1. Can training improve defect conspicuity? Specifically, can the visual lobe size be increased, and if so, does this increase generalize across different defects?

2. How effective is feedback in changing search strategy? Specifically, should feedback be about the inspector's performance, or about the inspector's strategy?

3. How effective is cueing or feedforward in changing search strategy? Specifically, do inspectors perform better with generalized information or specific recommendations?

- Decision-Making Issues

1. Perception of multiple defect attributes: is an active training scheme better than the equivalent passive scheme?

2. Integration of multiple defect attributes: is an active training scheme better than the equivalent passive scheme.

Note that these issues are ones suggested by the literature on industrial inspection, but untested in the airframe inspection context. Note also that issues have been chosen which do not imply the need for particular delivery systems, even though the evaluation of each issue was carried out on a computer-based simulation.

Each of the issues above defines a training intervention which was evaluated using a consistent methodology. Each test was aimed at determining whether a particular intervention had an impact on improved performance. Because these needed controlled conditions, often with many repetitions of similar faults, actual airframes and inspectors were not logically possible. For example, the hundreds of cracks and dents required for the visual lobe training would never be available to an inspector. Thus, a visual inspection simulator was developed, using a SUN workstation computer to reproduce the essential aspects of the visual inspection task.

In this task the inspector searches for multiple defect types and classifies them into different severity categories. The seven possible fault types are missing rivet, damaged rivet, pooched/dished rivet, loose rivet, rivet cracks, dents and corrosion.

The entire inspection task is a series of search areas where each search area is that portion of the task which is shown on one screen. A part of the aircraft fuselage (one search area) is presented to the subject, whose task is to locate the fault in the search area and indicate its discovery by clicking the left mouse button on the fault. The layout of the multi-window simulated inspection task is as shown in Figure 8.1. The function of each window is as follows:

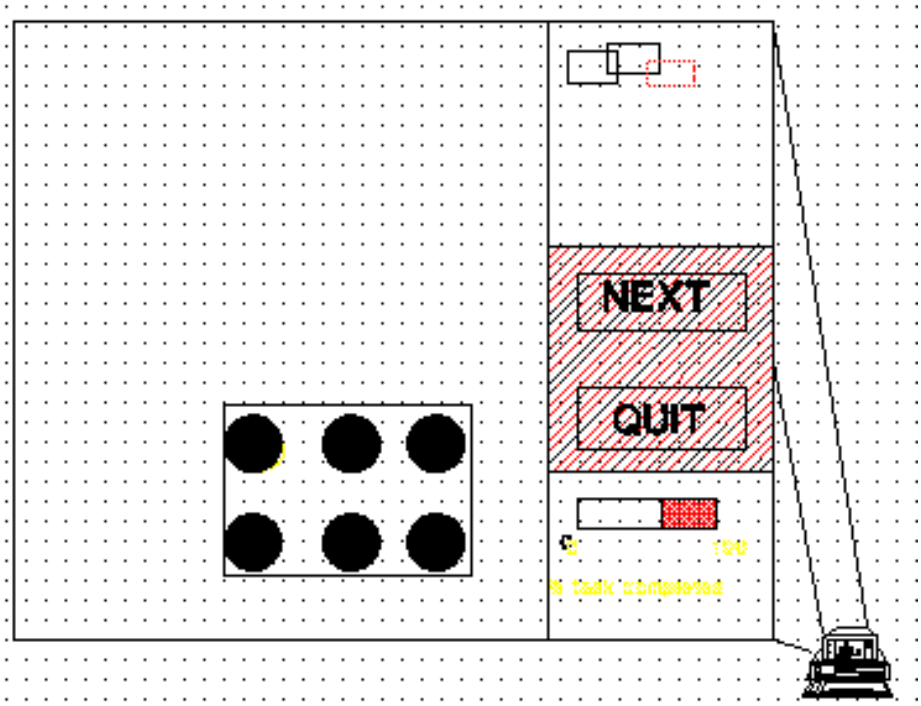

Figure 8.1 Screen of Visual Simulation

1. Inspection Window. The area currently being inspected is shown in the left (large) window. To simulate the use of local lighting, such as a flashlight beam, only a smaller window within this area is fully illuminated. Within this smaller window, or "viewer", faults can be seen and responded to by clicking them using the left mouse button. The entire area of the inspection window can be viewed by successive movements of the viewer.
2. Search Monitor Window. This is a monitoring device which helps the inspector keep track of the window movement in the inspection window. The viewer in the inspection window is represented by a tile in the search area window. As the viewer is moved, so does the tile, which has a different color from its illuminated background area. The darkest shade of the tile is the point of previous fixation so that the sequence is given by the shade of the color--lighter shades indicate earlier fixations in sequence while darker shades indicate later fixations.
3. Macro View Window. This window represents the entire task to be inspected, and provides information to the inspector about his current position with reference to the entire task.

The visual inspection simulation generates an output data file of subject performance consisting of both individual statistics for each search area, and summary statistics averaged over all search areas. Both performance and process measures are collected. The performance measures include: the number of faults located, the time to detect each fault, the stopping time, the number of hits, misses, and false alarms, and the average time spent in each search area's nine zones. The process measures collected include: the percentage of search area covered by the viewer, the number of viewer fixations used to search the area, the interfixation distance, the percentage overlap of the viewer fixations, and the pattern of viewer movements. A set-up program allows fault types to be assigned to different rivets, and information such as feedforward and feedback to be added. Obviously, not all features of the simulation were used in all experiments.

In all of the experiments, engineering student subjects were used, as these represent well the technically-fluent, but inexperienced, labor pool from which the aviation mechanics (who will eventually become inspectors) are drawn.

The five intervention issues were tested in five experiments. All five measured performance by many measures, using statistical tests to determine whether each intervention had the predicted impact on each measure. It is not the intention of this report to provide exhaustive experimental details, but rather to demonstrate the main results, interpret these results in terms of training of airframe inspectors, and outline any still-unresolved issues in terms of future evaluation needs. Full details are available elsewhere (Gramopadhye, 1992), and will eventually be published as a sequence of individual technical papers. This sequence has already begun with the visual lobe training evaluation (Latorella, et al., 1992; Drury and Gramopadhye, 1992).

8.6 VISUAL SEARCH TRAINING EVALUATIONS

In a visual search task, the inspector's eyes move across the inspected area, fixating subareas with the eye stationary and jumping rapidly between fixations. The area within which a target can be detected during a fixation is the visual lobe. The size of this visual lobe is important as it determines how thoroughly an area will be searched in a given time period, and hence directly determines the probability of defect detection. Search strategy is the sequence of fixations used by the inspector and determines the total coverage of the area. An effective and efficient strategy is one which covers the whole area with the minimum overlap between fixations and the minimal back-tracking. The first issue concerns the visual lobe size, while the second and third issues evaluate strategy.

8.6.1 Can Training Improve Defect Conspicuity?

The objectives of this experiment were to determine the relationship between visual lobe and search performance, relate changes in lobe size to search performance, and to evaluate the effectiveness of lobe training. In particular, the experiment measured whether crossover effects exist in visual lobe training. It used two types of rivet faults (cracks and loose rivets) and two types of area faults (corrosion and dents) to determine whether visual lobe training on one fault would generalize to other faults of the same or different classes.

The experiment consisted of a familiarization training followed by four visual search tasks, each consisting of 20 examples of one fault type. Following these tasks, each of the four groups of six subjects undertook different training schemes based on a visual lobe task which presented a fault for 0.3 seconds at one of six positions around a central fixation point. The four groups received the following training:

Rivet Group: Five trials of 120 visual lobe screens containing loose rivets.

Area Group: As Group 1 except using dents.

Neutral Group: As Group 1 except using a fault (cross) which was irrelevant to the search task.

Control Group: An equivalent time on a word processing task on the same computer.

Following training, the four visual search tasks were repeated for all groups.

To determine whether the visual lobe increased in size during the training, an ANalysis Of VAriance (ANOVA) was conducted for the lobe size for the three groups (1, 2 and 3) receiving lobe training. Over the five training trials significant effects of group ($F(2,15) = 11.05$, $p < 0.0011$) and training trial ($F(4,60) = 13.46$, $p < 0.001$) were found. To test whether the visual lobe training transferred to the visual search task, ANOVAs were performed on the mean search times for each fault type. For all four fault types, the patterns of the ANOVA results were similar. There were no group main effects ($p > 0.15$ in all cases), significant trial effects ($p > 0.05$ in all cases) and significant group x trial interactions ($p < 0.05$ for all cases except Rivet Crack where $p < 0.10$). Table 8.1 shows the percentage improvements following training (i.e., the group x trial interactions) for each fault type. It can be seen that the two faults trained in the visual lobe training had the largest improvement. For the faults not trained by visual lobe training, the improvement was greater where there was more similarity to the visual lobe fault. Neutral training had a smaller amount of transfer, while no training, i.e., spending equivalent time on another computer task, had no beneficial effect.

Group	Rivet Faults		Area Faults	
	Loose Rivet	Rivet Crack	Dent	Corrosion
1. Loose Rivet Training	50.6	41.4	15.0	15.8
2. Dent Training	13.8	13.0	41.6	48.2
3. Neutral Training	5.8	18.5	16.3	26.2
4. No Training	3.9	5.0	-4.9	-12.7

Table 8.1 Percentage Improvement in Mean Search Times After Training for the Four Training Groups

Providing training, even just repeated practice, in rapidly detecting a fault in peripheral vision, did indeed increase the size of the area in which that fault could be detected in a single glimpse, i.e., the visual lobe. This increased visual lobe was not merely a result of increased familiarity with the experimental visual lobe task, as it transfers to a more realistic inspection task, visual search. For each fault type there was a 20-30% increase in lobe size over just five practice trials. There was a close correspondence between the training on actual faults (Groups 1 and 2) and improvement in search times, and even some improvement for training on a neutral fault, i.e., one which did not appear in any search tasks. No training, as expected, produced no effect.

8.6.2 How Effective is Feedback in Changing Search Strategy?

The objectives of this experiment were to evaluate the effectiveness of providing different types of feedback on the inspection search strategy. Performance feedback is traditional, i.e., how many defects were detected, or how long it took to detect all of the defects, but it is possible to give feedback on the process, or strategy, by which the inspector achieved these results. This may or may not help the inspector: evaluation is needed. Within this "cognitive" feedback, there are different ways in which the information can be presented to the inspector. Here we compared process measure feedback (e.g., how much of the area was covered; what percentage of fixations overlapped) to visual feedback of the scan path used by the inspector. The former gives hard numbers, the latter a visual pattern. The literature is silent on which is the better form of cognitive feedback, or whether either is better than traditional performance feedback. Thus, further evaluation is required.

All 24 subjects received familiarization training followed by a visual search task (Trial 1) which consisted of 75 search areas, each with either zero, one or two of the four faults (rivet crack, loose rivet, dent, corrosion). Following this visual search task the subjects were assigned to one of four groups:

Control Group Three trials of 25 search areas with no feedback

Process Group Three trials of 25 search areas with feedback or process measures after each trial

Visual Group Three trials of 25 search areas with on-line visual feedback of search patterns during each trial.

Performance Group Three trials of 25 search areas with feedback on speed and accuracy after each trial.

After these training interventions, subjects were given a second visual search task (Trial 2) of 75 search areas with no feedback. Comparison of Trial 1 with Trial 2 allowed an evaluation of the relative improvement with either practice only (control group) or the various types of feedback.

Both process measures and performance measures were analyzed for the four groups on the two trials. For all of the process measures, there was a group x trial interaction, showing that certain groups improved more than others. Table 8.2 shows the percentage changes for each group from Trial 1 to Trial 2.

	CONTROL GROUP	PROCESS GROUP	VISUAL GROUP	PERFORMANCE GROUP
Number of Fixations	+6.6	-54.1	-30.9	-27.8
Interfixation Distance	-5.2	+15.3	- 6.8	0
Percentage Overlap	+5.7	-55.1	-50.5	-18.0
Percent of Area Control	+2.1	- 7.0	+ 1.9	- 0.9

Table 8.2 Percentage Changes in Process Measures after Training for Feedback Experiment

None of the changes for the control group were significant, showing that more practice did not change search strategy. The process group showed less fixations more widely spaced, and with less overlap, but the area covered decreased. The visual group showed a similar, if smaller, effect but one which did not result in a decreased coverage. Finally, the performance group showed no change in interfixation distance or area covered, but did give a reduced number of fixations more widely spaced. Clearly, cognitive feedback had the major effect on search strategy.

Performance measures, in contrast, showed trial effects for search times and stopping times but not for percentage defects detected. Table 8.3 shows the percentage changes in each measure for each group.

	CONTROL GROUP	PROCESS GROUP	VISUAL GROUP	PERFORMANCE GROUP
Search Time	0	-26.0	-15.2	-37.1
Stopping Time	-4.9	-50.4	-35.4	-51.1
Percent Detected	-1.2	- 8.1	+ 1.6	- 1.0

Table 8.3 Percentage Performance Changes by Group for Feedback Experiment

As with process measures, the control group showed no effect of their practice. The process group was considerably faster at search, but appeared to reduce their stopping time too much, giving a decrease in defects detected. The visual group had smaller reductions in search and stopping times, and no change in percent defects detected. The performance group was able to speed up the most, and reduce their stopping times the most without sacrificing accuracy. Clearly, performance feedback enhances performance.

When feedback, or knowledge of results, was provided, behavior and performance changed in predictable ways. Subjects responded to the feedback given by improving most those aspects of the task included in the feedback. Thus, cognitive feedback helped subjects optimize their search strategy, while performance feedback gave the largest performance gains. All feedback groups changed their strategy in a similar manner, by having less fixations with less overlap. However, the dangers of feedback were illustrated when the process group made dramatic changes in strategy, resulting in slightly reduced coverage. This meant that their speed increase was not achieved with constant detection performance like the other groups, but with poorer detection performance. (A current extension of this experiment is evaluating the combination of feedback types to determine whether provision of both cognitive and performance feedback will yield larger improvements). Finally, it should be noted that more practice without knowledge of results (the control group) gave no improvements in strategy or performance. Only practice with feedback makes perfect.

8.6.3 How Effective is Feedforward in Changing Search Strategy?

Guidance or feedforward (Section 8.3.3) is a powerful tool in helping the trainee concentrate on the appropriate visual cues in the task. In airframe inspection, it comes from two sources: (1) general knowledge of the physics of aircraft structures and the environmental conditions which act to cause faults, and (2) specific guidance (e.g., on workcards, from co-workers) on which faults to expect in which parts of the structure. However, there is a danger with alerting an inspector to one type of defect and/or one area: other defects and areas may be de-emphasized giving poorer performance. The objective of this experiment was to evaluate general specific and combined feedforward in an aircraft inspection task. To measure whether improved performance on the cued defect was being obtained at the expense of other faults, two scenarios were devised, one emphasizing corrosion defects and the other emphasizing rivet defects.

Twenty-four subjects were given the familiarization training and then performed one visual search task under each scenario (Trial 1). Each task consisted of searching 55 search areas for the same four defects. The subjects were divided into the following four groups:

Control Group No feedforward information

Prescriptive Guidance Specific, prescriptive information on both scenarios, i.e., which type of defect was most common

Descriptive Guidance General, descriptive information on both scenarios, i.e., the recent history of the aircraft's use

Combined Guidance Both types of guidance

Scenario 1 emphasized corrosion defects, either by naming specific areas where corrosion was expected (lower part of fuselage) or by general history (aircraft employed carrying chemicals, and based at coastal airport). Scenario 2 emphasized rivet defects, but without any more detailed information on the location of the rivet defects. After this information, subjects inspected 55 more areas under each scenario (Trial 2).

The results showed no significant group or trial differences, or interaction, for the process measures for Scenario 1 and only a trial effect for percentage area covered for Scenario 2. As this latter change was less than 2%, there were essentially no effects of feedforward on search strategy.

For performance measures, there were group, trial and interaction effects on search time for Scenario 1, and group and trial effects for search and stopping times in Scenario 2. Table 8.4 shows the percentage changes between Trial 1 and Trial 2.

	Control Group	Prescriptive Group	Descriptive Group	Combined Groups
Scenario 1				
Search Time	+14.8	-23.4	-23.7	-30.8
Stopping Time	+ 7.3	-10.6	- 6.5	-31.1
Percent Detected	- 4.7	- 9.3	+ 1.6	+ 2.1
Scenario 2				
Search Time	-13.5	-11.3	-13.4	+ 0.7
Stopping Time	-28.8	-15.2	-17.1	-14.4
Percent Detected	0	+ 1.6	+ 2.8	+ 9.8

Table 8.4 Percentage Performance Changes by Group for Feedforward Experiment

For Scenario 1, performance improved in terms of speed for all groups except the control group, while accuracy remained constant except for a **decrease** by the prescriptive group. This decrease was almost entirely due to reduced detection of the rivet defect, i.e., the one which was **not** cued. Scenario 2 gave peculiar results. Not only did the control group show the largest speed gains, but the combined group was the only condition to post improvements in accuracy. Even this accuracy gain was for the non-cued area faults!

It appears that feedforward information is difficult for subjects to use effectively. Strategy changes were almost all nonsignificant, while performance changes, even though significant, were mixed. Speed may improve, but accuracy may get worse (Scenario 1) or better (Scenario 2) for defects which are specifically called out. Much more needs to be known about the effects of feedforward on aircraft inspection before it can be recommended with any confidence. Even the calling out of specific defects on workcards, long thought to be a pre-requisite to effective inspection (e.g., Drury, et al., 1990) may need to be evaluated more closely.

8.7 DECISION MAKING ISSUES

When a defect has been located (visual search) a decision must be made as to its severity to determine the correct response (ignore, record for later repair, record for immediate repair). This decision is sometimes as simple as judging the free play in a control linkage, but more often it is a complex judgement. For example, a dent must be judged for size, depth and position, or corrosion for location, extent and severity. Inspectors gradually develop a mental picture (schema) corresponding not to any particular defect previously seen, but rather to a prototype of a defect at an action level. The two experiments reported here used a progressive part-training scheme to classify rivets (Section 8.7.1) or corrosion (Section 8.7.2). In each case there was a comparison between active and passive training. In each case a determination was made also as to whether the learning transfer from a decision task to a more complete inspection task involving both search and decision. The experiments differed in that the first concerned the accurate perception of each separate attribute of a defect, while the second examined integration of attributes into an overall schema of the defect.

8.7.1 Perception of Multiple Defect Attributes: Active or Passive Training?

The experimental objective was to compare well-designed active and passive training schemes for the task of correctly classifying individual attributes of a defect. The task was to judge rivets on a panel, where each rivet could have two levels of severity on each of three attributes: edge smoothness, out-of-round, and flatness. Eight combinations (combinations of two levels of each of three attributes) plus the six single-attribute defects gave a total of fourteen different defects.

Twelve subjects were assigned to one of two groups for training:

Passive Group Subjects saw each defect five times in the center of the screen, followed by progressively more combinations of defect attributes, with the correct classification shown beside each defect.

Active Group As for passive group, except that subjects had to enter the classification of each defect (with immediate feedback) rather than merely reading the classification.

After training, each subject was presented with fifteen examples of each defect (210 total defects). The defective rivet appeared in the center of the screen, with a classification response required of the subject. Following this decision task, an inspection task was given, again with 210 defects. In the inspection task, the subject first had to locate the defective rivet among the other rivets in a search area, and then give the classification response.

Significant differences between active and passive training for the percentage correct decisions were found for both the decision and inspection tasks, as shown in Table 8.5.

	PASSIVE TRAINING	ACTIVE TRAINING
Decision Task	79.0	83.8
Inspection Task	71.0	85.5

Table 8.5 Percent Correct Decisions for Attribute Perceptions

The active training scheme produced a clear advantage in accuracy in both tasks. Indeed, it gave a greater advantage when the decision was embedded in a more complex inspection task involving search and decision. Analysis of the search times in the inspection task showed no difference between the two training schemes, indicating that decision training does not improve search performance, only decision performance once search for the defective rivet has been completed.

Clearly, an active training scheme is preferred, even when compared to an equally well-designed progressive-part passive scheme. The inspector's active involvement in learning is essential.

8.7.2 Integration of Multiple Defect Attributes: Active or Passive Training?

In addition to merely classifying each attribute of a defect correctly, inspectors often need to combine information from more than one attribute when making a judgement. The objective of this experiment was to study the development of such schema, or combinations of attributes, under active and passive training schemes.

The task used areas of corrosion, each of which had three attributes: density, quantity and color. Density and color could be at three levels on the computer display, while quantity could be at two levels, giving eighteen combinations in all. Subjects had to reach an overall judgement of severity as low, moderate or high depending upon the particular combinations of levels of the attributes.

As in the previous experiment, two groups of six subjects each were used:

Passive Group Subjects saw each of the 18 defects five times in the center of the screen, followed by combinations of defect attributes. The correct classification (L, M or H) was shown beside each defect.

Active Group As for passive group except that subjects has to enter L, M or H for each defect, with immediate feedback.

The decision task consisted of 120 defects, each shown in the center of the screen, with the subject responding L, M or H after each defect. For the inspection task, each of the 120 defects was embedded in a screen consisting of the same rows and columns of rivets used in the previous experiment. Again, the subject had to first locate the defect and then classify it as L, M or H severity.

There were significant group differences on both decision and inspection tasks for percentage correct responses, and for information transmitted in bits/response. As in the previous experiment, there was no significant group effect on search times in the inspection task. Table 8.6 shows the mean values.

	PASSIVE TRAINING	ACTIVE TRAINING
Percent Correct, Decision	77.4	87.8
Percent Correct, Inspection	73.5	86.3
Information Transmitted, Decision	0.76	1.06
Information Transmitted, Inspection	0.74	0.99

Table 8.6 Performance by Group, Integration Experiment

Active training was again significantly better on all measures, but here there was no extra improvement on the more complex task. In both decision and inspection, errors were roughly halved when the actively trained group was compared to the passively trained group. Clearly, active participation of the inspector is a key element in learning to integrate information from many attributes.

8.8 TRAINING METHOD FOR AIRCRAFT STRUCTURAL INSPECTION

In this section we outline a general training method that uses the key conclusions of the research and indicates how it can be applied to enhance training on a particular inspection task. The conclusions can be summed up as:

1. Visual lobe training improves mean search times and is generalizable across all faults within a fault set.
2. Feedback of process and performance measures can improve search strategy and reduce search time.
3. Feedforward information helps modify search strategy.
4. Active and progressive part-training help improve classification performance.

Figure 8.2 describes a general methodology for developing training programs for aircraft inspection. This section elaborates on the "training method" part of the methodology, giving as an example, the inspection task during a B-check on a DC-9.

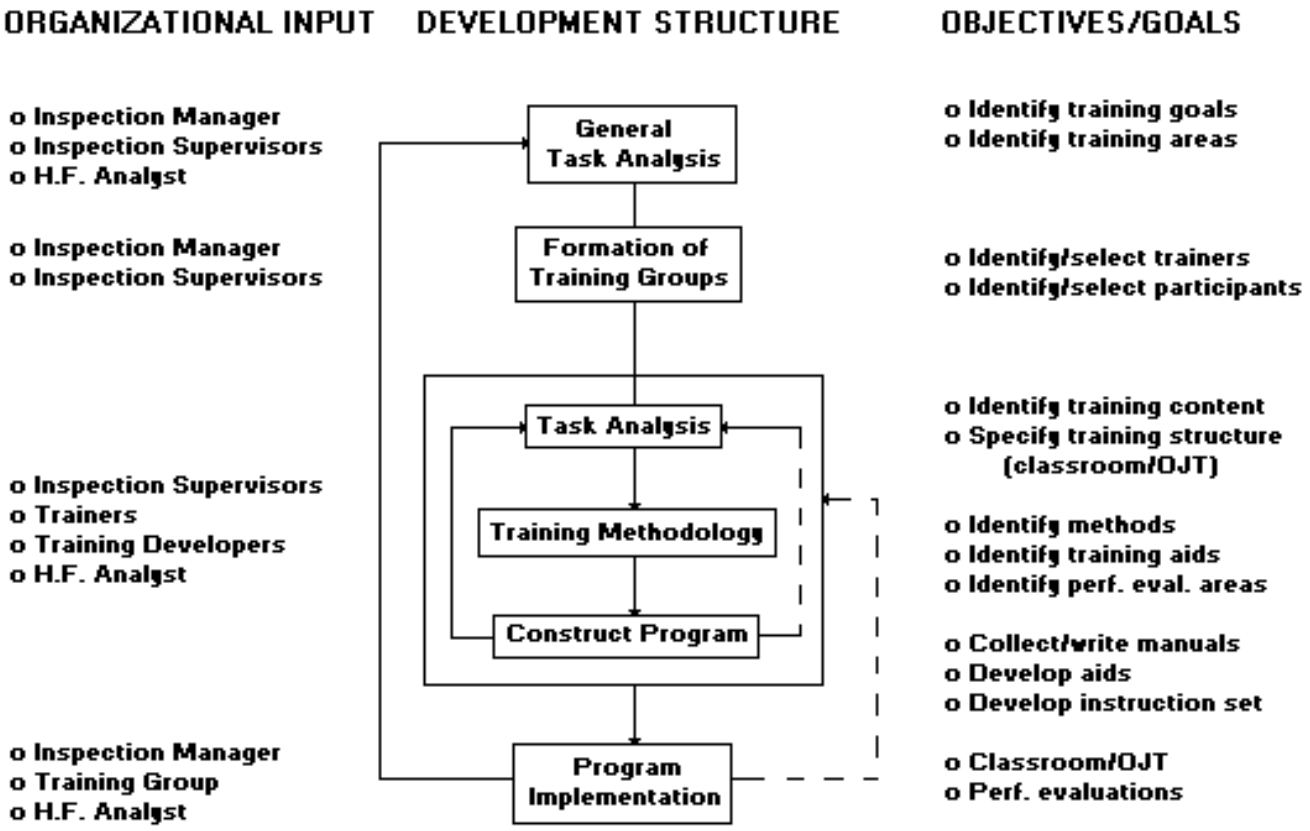

Figure 8.2 Model for Training Program Development in Commercial Aviation

This training methodology uses:

1. A mix of classroom and structured OJT
2. Visual lobe training for specific faults
3. Feedback of process and performance measures
4. Feedforward information
5. Active training for defect classification.

The methodology is explained using a section of a B-check for nose landing gear and wheel well inspection. There are three major components to this inspection:

1. Wheel well, doors, adjacent components
2. Nose gear assembly and installation
3. Nose gear tire and wheel assembly.

Table 8.7 presents a condensed overview of this entire B-check. The entire inspection has been broken down into two parts: structure and defects. The structure explains the component to be inspected, and the defect column lists the non-conformities to look for. This allows us to identify (a) the aircraft knowledge that the inspector should have, and (b) the defects that are being looked for.

WHEEL WELL, DOORS, ADJACENT COMPONENTS		NOSE GEAR ASSEMBLY & INSTALLATION		NOSE GEAR TIRES & WHEEL ASSEMBLY	
Structure	Defects	Structure	Defects	Structure	Defects
1. Wheel well hydraulic lubing conduits	- Condition - Corrosion - Fluid Leakage	1. NLG shock stout, bracestrut, torque arm, ground sensing mechanism, cables, actuating cylinder, linkages, spring	- corrosion - visual damage - nicks & dings** - fluid leaks - security	1. Wheel hubs values, tie bolts	- condition - corrosion
2. Wheel well doors linkages springs, stop cables, drive rods and hinges	- condition - visual damage - corrosion - security	2. Landing gear shock strut	- check for normal extension - cleanliness - clean exposed portion of piston with red hydraulic oil & wipe dry	2. Tires	- excessive wear - oil soaking - correct pressure - only after 2 hrs of parking - reinflate with NL only
3. Downlock markings	- general condition - cleanliness	3. Nose steering mechanism	- condition - leakage - worn cables - release of nose steering bypass - check spring landed to steering position	3. Water deflector assembly	- damage - security of installation
4. NLG alignment spotlight	- check	4. Torque links	- loose bushings & bolts - worn bushings & bolts		
5. NLG taxi light	- cleanliness - filament condition - security of assembly	5. Landing gear lock pins & red warning streamers	- condition - secure attachment of streamers to lock pins - length of streamers should be 24-32" long		
6. NLG doors	- check doors are closed - check doors are secure - procedure given				**<0.005" repair 0.005-0.03 blend, smooth & paint >0.003 notify eng.
7. Aircraft wheel checking placard *location given	- condition - security				
8. Nose tire pressure placard *location given	- condition - security				
9. Uplock and downlock proximity sensors	- condition-clean if necessary - security				

Table 8.7 Nose Landing Gear and Wheel Well Inspection (B-Check)

8.9 CLASSROOM TRAINING

This should consist of the following components:

1. Information on Area. The trainees should learn the names and locations of all relevant parts of the area (listed under the structure column in Table 8.7) to be inspected. Active training methods used should make the trainee name and locate all the relevant parts/areas. This training should also include functional knowledge about the various components, combined with adequate feedback on performance.
2. Information on Workcard Usage. This part should familiarize the trainees with the workcard. Steps include showing them how to use the workcard, knowledge of various procedures, e.g., checking depth of nicks or digs, releasing of nose steering bypass, etc. Information should be imparted on how to write non-routine repair cards. Again, an active training method is appropriate.

3. Examples of Defects in Each Area. A defect list must be generated from the workcard, giving a listing of all the defects that an inspector using the workcard must look for (Table 8.7). An effort should be made to collet samples, photographs, video tapes of all defects. An active training method where the trainee identifies, and classifies, each defect should be followed. Cognitive feedback should be provided during the training.

4. Visual Lobe Training. Visual lobe training can be provided on a simulator, similar to the one used in the evaluations (Section 8.6) for some of the visual defects like corrosion, visual damage, fluid leaks and worn parts. Now that actual photographs can be scanned readily into computer systems, defects can be placed easily in many places on the scanned visual image of the area to be inspected. Thus, creating a realistic simulator for visual lobe training is possible.

8.10 STRUCTURED ON-THE-JOB TRAINING

A structured on-the-job training methodology imparts a controlled training atmosphere in a work setting. Since it is expensive to produce a realistic simulator of the whole inspection task, we are constrained to have some training done on the job. The OJT method should involve the show-tell-do routine that includes demonstration by the expert inspector on an efficient way to inspect followed by the trainee inspecting the aircraft with subsequent feedback from the experienced inspector. This needs to have both performance and cognitive aspects, i.e., whether the search was successful, and whether it was performed using the most effective strategy. The experienced inspector should also provide feedforward on each area to the trainee in terms of what defects to look for, defect criticality, past history, etc.

In the space available in this report, more depth cannot be included concerning the detailed application of the research findings to aircraft inspection. However, the level chosen for presentation here does demonstrate the principles involved and how they can be applied with minimal hardware requirements.

8.11 CONCLUSIONS

This research program has used observations of the current training of visual inspection, and the principles of effective training to derive experimental evaluations of specific interventions. The experiments had (generally) highly successful outcomes, showing that many of the interventions can indeed be applied to visual inspection training. An example is provided which outlines how these findings can be applied to an existing task. The next challenge is to devise and implement detailed inspection training programs based on these findings and evaluate these new programs on the hangar floor. As a side-benefit of the research, a simulation program is now available to allow rapid evaluation of other training interventions without disruption of on-going inspection activities.

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