USING HUMAN FACTORS TO IMPROVE AIRCRAFT INSPECTION PERFORMANCE AND REDUCE ERRORS: STUDY OF INDIVIDUAL DIFFERENCES

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1.1 INTRODUCTION

This report is divided into five major sections. The Background outlines the role of training in inspection and individual differences in inspection performance. The next section details the methodology used to conduct the individual differences study. These results are then discussed in further detail. Finally, the conclusion outlines the implications of this study for improving inspection performance and aviation safety. This research was conducted with various industry partners to ensure its relevance and applicability to the aviation maintenance community.

1.2 BACKGROUND

In order for the Federal Aviation Administration (FAA) to provide the public with continuing safe, reliable air transportation, it is important to have a sound aircraft inspection and maintenance system.14 This system is a complex one with many interrelated factors, including both human and machine components. The linchpin of this system, however, is the human, who is less than 100% reliable. Recognizing this fallibility, the FAA (under the auspices of National Plan for Aviation Human Factors) has pursued human factors research, focusing on the aircraft inspector and the aircraft maintenance technician (AMT).10,14,15,41,42 This research has indicated that individual differences, pacing, and training play a significant role in determining the effectiveness of inspection and maintenance. As a result, further study in these areas is needed to develop interventions to make inspection/maintenance procedures more reliable and/or error tolerant.

The aircraft inspection/maintenance system, and consequently its effectiveness, is impacted by several factors.10,14 One is the variety of geographically dispersed entities, ranging from large international carriers, repair and maintenance facilities through regional and commuter airlines to the fixed-based operators associated with general aviation (Figure 1.1). A second is that inspection is regulated by the FAA, as is maintenance. However, while the adherence to procedure and protocols is closely supervised, monitoring the efficacy of these procedures is much more difficult. A third is the age of the fleet, an area in which the Office of Aviation Medicine and the FAA Technical Center have recently concentrated their efforts. The widespread use of older aircraft, which is expected to continue in the future, requires an intensive inspection and maintenance program. Fourth, the more experienced inspectors and mechanics are retiring and being replaced by a much younger, less experienced work force. Not only do the new inspector's lack the knowledge or skills of the far more experienced inspectors they are replacing but they have limited exposure to various defects and aircraft types. Fifth, inspector reliability is fundamental to effective inspection and maintenance. Since 90% of all inspection in aircraft maintenance tends to be visually conducted by inspectors, it is critical that it be performed effectively, efficiently and consistently over time.

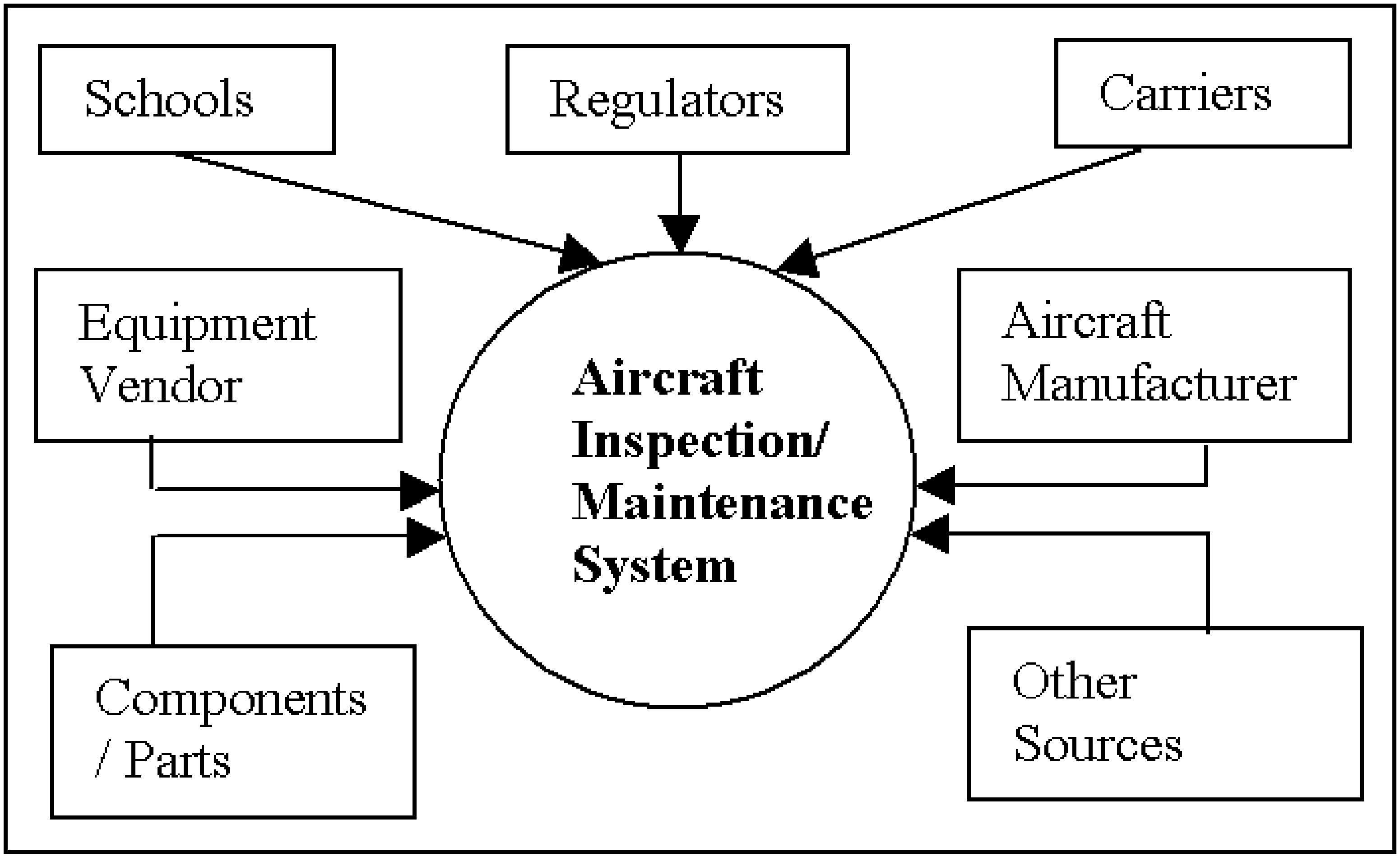


Figure 1.1 Aircraft Inspection Maintenance System

One of the most important factors impacting this reliability involves the stress of the time constraints imposed by the procedure involved in inspection and maintenance. Aircraft for commercial use have their maintenance scheduled by a team that includes the FAA, aircraft manufacturers and start-up operators. These schedules are then taken by the carrier and modified so that they suit individual requirements and meet legal approval. Within a carrier's schedule there will be checks at various intervals, often designated as flight line checks, overnight checks, and A, B, C and D, the heaviest, checks. The objective of these checks is to conduct both routine and nonroutine maintenance of the aircraft, including scheduling the repair of known problems; replacing parts after a certain air time, number of cycles or calendar time; repairing defects discovered previously through reports logged by pilot and crew, line inspection and those deferred from previous maintenance; and performing scheduled repairs. Inspections themselves often lead to repairs/ maintenance, if a defect is discovered during this process. In the context of today's aging fleet, inspection takes on an even more vital role. Scheduled repairs account for only 30% of all maintenance compared to 60-80% in the younger fleet, an increase attributed to the number of age-related defects.14 In such an environment the importance of the role of the inspector cannot be overemphasized.

In addition, the scheduling involved in inspecting individual aircraft adds to the stress placed on inspectors and AMT's. As the aircraft arrives at the maintenance site, the inspection and maintenance schedule is translated into a set of job or work cards containing the instructions for the work to be done. Initially, the aircraft is cleaned and access hatches opened so that inspectors can view the different areas. This activity is followed by a heavy inspection check. Since such a large part of the maintenance workload is dependent on the discovery of defects during inspection, it is imperative that the incoming inspection be completed as quickly as possible after the aircraft arrives at the inspection maintenance site. Furthermore, there is pressure on the inspector to discover any critical defects necessitating lengthy follow-up maintenance early in the inspection process. Thus, there is a heavy inspection workload at the commencement of each check because it is only after the discovery of defects can the planning group estimate the expected workload, order replacement parts and schedule maintenance items. As a result, maintenance facilities frequently resort to overtime, leading to an increase in the total number of inspection hours and prolonged work hours. This is compounded by the fact that much inspection, including routine inspections on the flight line, is carried out in the night shift, between the last flight of the day and first flight on the next.

The pressure caused by time constraints doesn't end after the initial inspection. After a defect is detected, written up as a Non-Routine Repair (NRR) Record, translated into a set of work cards and rectified by the maintenance crew, it may generate additional inspection, typically referred to as "buyback" inspections, to ensure that the work meets necessary standards. Thus, initially, the workload on the inspector is very high with the arrival of an aircraft. As the service on the aircraft progresses, the inspection workload decreases as the maintenance crew works on the repairs. The inspection load again increases towards the end of service, compounded by frequent interruptions as AMT's call in inspectors to conduct buybacks of completed work.

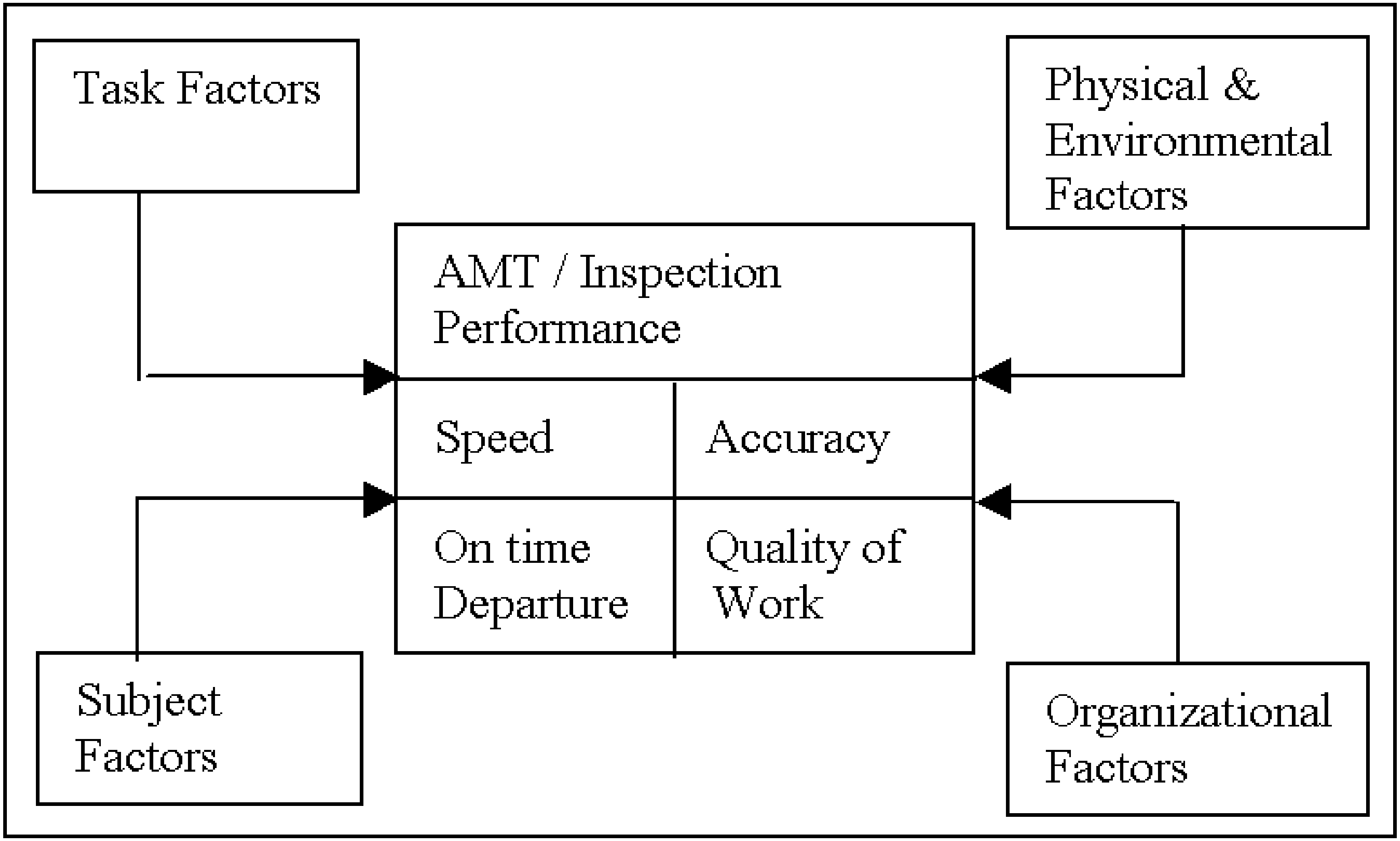


Figure 1.2 Factors Impacting Aircraft Inspection Performance

Task analysis of aircraft inspection supports the stress caused by its complexity: the inspector has to search visually for multiple defects occurring at varying severity levels and locations in addition to being sensitive to efficiency (speed measure) and effectiveness (accuracy measure), performance measures impacted by task and other factors if they are to optimize their performances (Figure 1.2).10,45

The inspection task is further complicated due to the wide variety of defects being reported in older aircraft, a trend expected to continue into the future given the widespread use of these aircraft. Consequently, a more intensive inspection program is required for them. However, even the introduction of newer aircraft will not reduce the inspection workload, as new airframe composites create an additional set of inspection variables.

The problem of inspection is further compounded since the more experienced inspectors and mechanics are retiring and are being replaced by a much younger and less experienced work force. Not only do the unseasoned AMT's lack the knowledge or skills of the far more experienced inspectors/AMT's they are replacing, they are not trained to work on a wide variety of wide-bodied aircraft. Moreover, analysis of aircraft inspection activity has reported large individual differences and this can be a critical factor that can potentially impact the effectiveness of inspections. Literature on inspection has identified a battery of Individual differences tests, which can serve as predictors of inspection performance. Before a decision can be made on which tests are appropriate it is necessary to clarify the skills required while performing aircraft inspection tasks. Task analyses of inspection activities guidance on this matter.14,15,25 It can be seen that the aircraft inspection process requires a large amount of mental processing and a large amount of information transmission together with extensive use of short-term and long-term memory. In addition there could potentially be definite time constraints on performing the job. Table 1.1 summarizes the various tests that have been used in the past as predictors of individual differences in inspection abilities indicating. The Significance column shows the success achieved in predicting inspection performance for each test.

Table 1.1 Tests used as predictors of Individual Differences

Individual Difference	Test	Measures	Significance
Student subjects vs. inspectors	---	Student or industrial inspectors	None18
Age	Demographics survey	Age	Good27,32
Experience	Demographics survey	Years of work experience	Good3,32
Gender	Demographics survey	Gender	Good32,43
Visual Acuity	---	20/20 vision	High33,48
Lobe Size	Measure of fixation point	Area around fixation point	Good17
Aptitude Skills	Harris Inspection Test	Identify unmatching objects	High(electronics)26
	WAIS	IQ test	Good17
	Short Term Memory	Memory – short-term	Weak17
	Gordon Test	Photographic memory	Good17
Cognitive	*EFT	Identify embedded context	High17
Behavior	Eysenck	Introversion/extroversion	Mixed17,47
	Guilford-Zimmerman	Sociability,stability restraint	Low48
	MMPI	Guardedness, anxiety	Low48
	MFFT	Impulsives/reflectives	High40
	*Locus of Control	Introversion/extroversion	High13,38
	*Certainty Equivalence	Risk seekers, risk aversion	N/A36

	***Myers-Briggs**	**Introversion,sensing,thinking**	**N/A34**

Appendix A also provides a summary description of each test. Drawing from the task analyses of aircraft inspection, and results of earlier studies on the use of individual differences test for inspection tasks, the following four tests were selected for this study: the Myers-Briggs Test, the Embedded Figures Test, the Locus of Control Test, and the Responsible Risk Taking Inventory Test.17,34,37,44

In addition to the individual differences a critical factor known to affect aircraft inspection performance is the time available for inspection. Inspectors may have different amounts of total time based on the type of maintenance checks (e.g., ramp inspections, A, B, C or D checks) with the least amount of time available for ramp checks and the maximum for D checks. Literature on inspection pacing is rich, discussing the effects of pacing for inspection tasks that have both the search and decision making components.2,6,31 A common conclusion drawn from these studies that can guide us in understanding human performance in aircraft inspection is that pacing exerts stress which, in turn, reduces inspection accuracy. However, most of the efforts focused on pacing in inspection have looked at inspection tasks typical of those in the manufacturing industry or artificial tasks typical of laboratory environments; none have looked at aircraft inspection per se. This being the case, it is critical that we conduct a study that expressly looks at and identifies interventions to improve aircraft inspection performance under paced and unpaced environments.

Training also been shown to be a powerful intervention strategy improving inspection performance when applied to both novice and experienced inspectors.9,22,48 Existing training for inspectors in the aircraft maintenance environment tends to be mostly on-the-job (OJT). Nevertheless, this may not be the best method of instruction because, for example, for feedback may be infrequent, unmethodical, and/or may not be provided in a timely manner (see FAA14,20). Moreover, in certain instances feedback is economically prohibitive or infeasible due to the nature of the task. Because the benefits of feedback in training have been well documented, and for other reasons as well, alternatives to OJT are sought.48 Furthermore, training for improving visual inspection skills of aircraft inspectors is generally lacking at aircraft repair centers and aircraft maintenance facilities. However, the application of training knowledge to enhance these skills has been well documented in the manufacturing industry. Training has been shown to improve the performance of both novice and experienced.9,48 Visual inspection skills can be taught effectively using representative photographic images showing a wide range of conditions with immediate feedback on the trainee's decision.48 Using realistic photographic images as a training aid in controlled practice with feedback has also been shown to be superior to only OJT.29,48

Thus, off-line training/retraining with feedback has a role to play in aircraft inspection training. One of the most viable approaches for delivering training given the many constraints and requirements imposed by the aircraft maintenance environment is computer-based training, which offers several advantages over traditional training approaches: it is efficient while at the same time facilitating standardization and supporting distance learning. With computer technology becoming cheaper, the future will bring an increased application of this advanced technology in training. Over the past decade, instructional technologists have applied numerous training devices to a variety of technical applications with the promise of improved efficiency and effectiveness. Examples of such technology include computer-based simulation, interactive videodiscs, and other derivatives of computer-based applications. Compact disc read only memory (CD-ROM) and Digital Video Interactive (DVI) are two other technologies which will provide us with the "multi-media" training systems of the future. Many of these training delivery systems such as computer-aided instruction, computer-based multi-media training and intelligent tutoring systems are already being used today, thus ushering in a revolution in training.

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury.[7] They used keyboard characters to develop a computer simulation of a visual inspection task. Similar simulations have also been used by other researchers to study inspection performance in a laboratory setting. Since these early efforts, Latorella et al. and Gramopadhye, Drury and Sharit have used low fidelity inspection simulators using computer-generated images to develop off-line inspection training programs for inspection tasks.[21,29] Similarly, Drury and Chi studied human performance using a high fidelity computer simulation of a printed circuit board inspection.[12] Another domain, which has seen the application of advanced technology, is that of inspection of x-rays for medical practice.

However, most of the work in the application of advanced technology to inspection training has focused on developing simulators for running controlled studies in a laboratory environment with advanced technology finding limited application in industrial, and specifically, aircraft inspection tasks. In light of this situation, a computer based training system focused on improving inspection skills for aircraft inspection tasks was developed as part of previous FAA funded efforts. These efforts yielded the Automated System of Self Instruction for Specialized Training (ASSIST) inspection-training software. A follow-up study conducted to evaluate the usefulness of ASSIST revealed that inspectors' knowledge of the aircraft inspection task, inspection performance on a simulated aircraft inspection task and inspectors' performance on real-world aircraft structural inspection task had improved significantly following training.[24]

Despite the effectiveness of ASSIST, questions still remain unanswered. We still do not know whether the training was equally effective for all inspectors or if certain individual characteristics as measured by individual differences test can throw new light into understanding post training inspection performance. In addition, we need to determine if training is equally effective under both paced and unpaced situations. Unless we develop answers to these questions, we will continue to design ad hoc and generalized training programs, with the hope that they will improve performance for all aircraft inspectors under all situations. It is critical that we move beyond designing and using these “one size fits all” training strategy to improving aircraft inspection performance.

In response to this need this research proposes to address the broader issue of training, individual differences and pacing in aircraft inspection. The general objective of this research was to expressly address the issue of training, pacing and individual differences in aircraft inspection. Specifically the study tries to evaluate the effectiveness of training using ASSIST in improving aircraft structural inspection performance under paced and unpaced conditions and relates changes in post-training performance to individual differences as measured by individual differences tests.

1.3 METHODOLOGY

1.3.1 Subjects

The subjects for this study consisted of 18 inspectors from an aircraft maintenance facility who were paid their full hourly rate by the company for their participation. Those selected had different levels of inspection-related work experience (six subjects with less than one year of experience, six between one and 10 years, and six with more than 10 years of experience). The subjects were randomly assigned to one of the following two groups, the control group or the trained group, so that each had subjects with an equal distribution of work experience:

- Control Group: Subjects assigned to this group received no training prior to taking both Trail Block 1, the unpaced criterion visual inspection task, and Trial Block 2, the paced criterion visual inspection task.
- Trained Group: Subjects in this group received general inspection and criterion task training with feedback on performance measures, speed and accuracy, prior to taking Trial Blocks 1 and 2.

1.3.2 Experimental Design

The study used a 2 X 2 design which consisted of two groups, control and trained, with nine subjects nested in each and two trial blocks, paced and unpaced, with the latter treated as a repeated measure (Table 1.2).

Equipment for Computer Simulation

The experiment was conducted using Hewlett Packard personal computers with a Windows NT Workstation 4.0 operating system and an Intel Pentium II processor operating at 300 Mhz. The subjects viewed the stimulus material at a resolution of 800x600 pixels/inch from 20 inches and responded to the stimulus material using a two-button mouse.

Stimulus Material

The stimulus material used was ASSIST, a computer-based inspection training software consisting of three modules - General Inspection, Simulation, and Instructor's, which was developed for aircraft inspection training.24 This multimedia computer-based program developed to train aircraft inspectors on inspection skills was used to simulate the inspection tasks and to collect performance data.

Table 1.2 ASSIST Protocol

	Consent form	Demographic survey	Individual Differences Test				ASSIST							Knowledge Test	Hangar Floor Test
			Myers-Briggs test	Embedded Figures test	Locus of Control test	Responsible Risk Taking Inventory test	Simulation trial & demo	Simulation test		Training general	Training simulator	Simulator Test			
								Unpaced	Paced			Unpaced	Paced		
Description of Protocol Stage		**7 questions on topics such as age, experience, certification, and training**	**85 questions used to obtain a personality type code.**	**18 questions to test for the ability to separate an individual figure from a more complex stimulus of which it forms a part**	**30 questions used to measure internal and external characteristics, introversion and extroversion**	**39 questions used to measure the amount of risk people will take when making decisions**	**Parameter set: -No feedback** (Small introduction to the ASSIST software and the simulated inspection environment)	Parameter set: 1st test- -Unpaced -No feedback 2nd test- -paced using mean of 1st test -No feedback		The ASSIST General Module (All five sub-modules)	Parameter set: 32 screen scenario- -Unpaced -Feedback	Parameter set: 1st test- -Unpaced -No feedback 2nd test- -Paced using mean of 1st test -No feedback		Section I: Short answer questions on General aircraft inspection	Demonstration test

												Section II: 30 multiple choice questions total (taken from the ASSIST software)	
9 subjects Trained	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
9 subjects Control	**X**	**X**	1.4 X	1.5 X	1.6 X	**X**	**X**	**X**	**N/A**	**N/A**	**X**	**X**	**X**

Procedure

At the outset all the subjects completed a consent form (Figure 1.3) and a demographics questionnaire (Figure 1.4) which solicited information on the subjects' backgrounds, ages and experience in inspection. Next, all subjects were administered four individual differences tests: the Embedded Figures Test (Figure 1.5), the Myers-Briggs Test (Figure 1.6), the Locus of Control Test (Figure 1.7), and the Responsible Risk Taking Inventory Test (Figure 1.8).17,34,37,44

INFORMED CONSENT STATEMENT FOR AUTOMATED SELF-PACED SYSTEM FOR INSTRUCTIONAL SUPPORT AND TRAINING (ASSIST)

INFORMATION

You have been invited to participate in a research study entitled The ASSIST Evaluation Study. If you agree to participate, you will be one of eighteen subjects at your facility who will be participating in the study. Your participation will be on an individual basis.

Prior to any activities, you will be asked to fill out some personal demographic information. ALL INFORMATION WILL BE STRICTLY CONFIDENTIAL.

There are two distinct stages to this research. In the first stage, you will perform an on-the-job test and a computer-simulated test of aircraft inspection. You will then receive training from a computer-based multimedia inspection-training tutorial. In the second stage, you will perform another on-the-job test and another computer-simulated test of aircraft inspection.

You will also be asked to complete a multiple-choice test both before and after training. The scores on your test will not be revealed to anyone other than yourself (upon request) and the investigators conducting this research.

This study is not to measure your individual ability as an inspector, but rather to measure the effects of our training method.

The terminology used throughout this research study is meant to be general in nature and not specific to Delta Air Lines. If you have questions on the terminology given, please see the training administrators.

ESTIMATED TIME FOR STAGE 1 and TRAINING = 4 HOURS

At the conclusion of the study you will be asked to fill out a questionnaire giving us your opinion of the training.

ESTIMATED TIME FOR STAGE 2 = 3 HOURS

CONSENT

I have been given the opportunity to ask questions about this study, answers to questions (if any) have been satisfactory.

The information in the study records will be kept confidential and will be made available only to persons conducting the study unless I specifically give permission in writing to do otherwise. In any results of this study that are published, I will not be identified.

In consideration of all of the above, I give my consent to participate in this research study. I understand that I may drop out of this study at any point if I so choose.

I acknowledge receipt of a copy of this informed consent statement.

SIGNATURE OF SUBJECT

DATE__________________________________

SIGNATURE OF WITNESS ____

SIGNATURE OF INVESTIGATOR __________________________________

SIGNATURE OF INVESTIGATOR ______________________________

Figure 1.3 Consent Form

Name ____

1. Sex ________Male ________Female

2. Age ________<20 ________21-30 ________31-40 ________41-50 ________50+

1. How long have you been an aircraft inspector?

________<1 yr. ________1-10 yrs. ________10 yrs. +

2. How long have you been in the aircraft maintenance industry?

<1 yr. 1-10 yrs. 10 yrs. +

3. What shift are you currently working?

________1st ________2nd ________3rd

4. Which of the following certificates/licenses do you have? (Select more than one if appropriate)

________Airframe certificate ________Power Plant certificate

________Repairman certificate ________FCC license

Inspection authorization certificate

5. Where did you receive the majority of your technical training?

________Military ________Technical Schools ________Company training

6. Your primary job function as an inspector is:

______ HMV ______ Letter check

Figure 1.4 Demographics Questionnaire

GROUP EMBEDDED FIGURES TEST

By Philip K. Oltman, Evelyn Raskin, & Herman A. Witkin

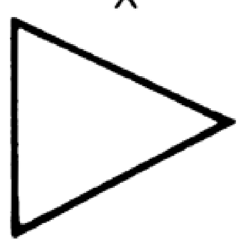
Name ______________________________ Sex ________

Today's date ______________ Birth date ______________

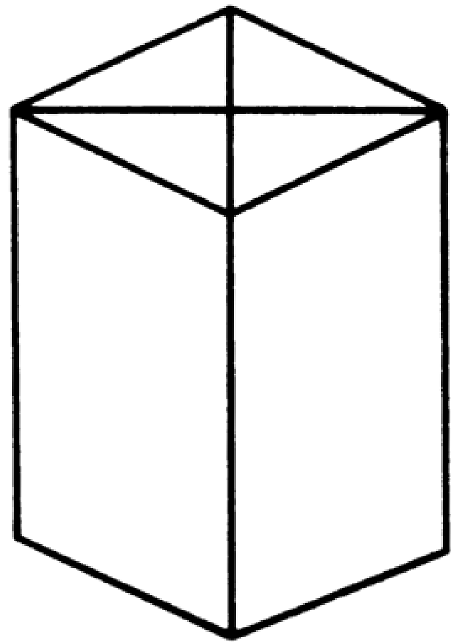
INSTRUCTIONS: This is a test of your ability to find a simple form when it is hidden within a complex pattern.

Here is a simple form which we have labeled "X":

X



This simple form, named "X", is hidden within the more complex figure below:



Try to find the simple form in the complex figure and trace it *in pencil* directly over the lines of the complex figure. It is the SAME SIZE, in the SAME PROPORTIONS, and FACES IN THE SAME DIRECTION within the complex figure as when it appeared alone.

Figure 1.5 Embedded Figures Test

Part I. Which Answer Comes Closest to Telling How You Usually Feel or Act?
Make an "X" in the appropriate square.

1. **Are you usually**
   - ☐ a "good mixer,"
   or
   - ☐ rather quiet and reserved?

2. **If you were a teacher would you rather teach**
   - ☐ fact courses,
   or
   - ☐ courses involving theory?

3. **Is it a higher compliment to be called**
   - ☐ a person of real feeling,
   or
   - ☐ a consistently reasonable person?

11. When you are with a group of people, **would you usually rather**
   - ☐ join in the talk of the group,
   or
   - ☐ talk with one person at a time?

12. **Do you admire more the people who are**
   - ☐ conventional enough never to make themselves conspicuous, or
   - ☐ too original and individual to care whether they are conspicuous or not?

13. **Do you more often let**
   - ☐ your heart rule your head,
   or
   - ☐ your head rule your heart?

20. **In a large group, do you more often**
   - ☐ introduce others,
   or
   - ☐ get introduced?

21. **Would you rather be considered**
   - ☐ a practical person,
   or
   - ☐ an ingenious person?

22. **Do you usually**
   - ☐ value sentiment more than logic,
   or
   - ☐ value logic more than sentiment?

Figure 1.6 Myers-Briggs Test

Name ______________________________

LOCUS OF CONTROL INVENTORY

Instructions: Read each statement carefully; then indicate the extent to which you agree with it by writing a number in the blank provided. There are no right or wrong choices; just choose the one that is right for you. If the responses do not adequately indicate your own opinion, use the number closest to the way you feel. Use the following key:

Strongly Agree	Generally Agree	Agree Somewhat	Agree Only Slightly	Seldom or Never Agree
4	3	2	1	0

________ 1. I determine what matters to me in the organization.

________ 2. The course of my career depends on me.

________ 3. My success or failure depends on the amount of effort I exert.

________ 4. The people who are important control matters in this organization.

________ 5. My career depends on my seniors.

________ 6. My effectiveness in this organization is determined by senior people.

________ 7. The organization a person joins or the job he or she takes is an accidental occurrence.

________ 8. A person's career is a matter of chance.

________ 9. A person's success depends on the breaks or chances he or she receives.

________10. Successful completion of my assignments is due to my detailed planning and hard work.

________11. Being liked by seniors or making good impressions on them influences promotion decisions.

________12. Receiving rewards in the organization is a matter of luck.

________13. The success of my plans is a matter of luck.

Figure 1.7 Locus of Control Test

Name ______________________________

Responsible Risk-taking Inventory

Scale	1	2	3	4	5	6	7	8	9
	complete disagreement			moderate agreement				complete agreement	

___ 1.I reach out to new people easily.

2. I adapt my work to fit my personality. ___

___ 3. I trust people a lot.

4. I am proud to "show off" good work. ___

___ 5. I often stand up for people who are not popular.

6. I am rewarded for my good suggestions. ___

___ 7. I try to work closely with people.

8. I often challenge old polices and views. ___

___ 9. I am sometimes hurt by people who I have supported.

10. I am flexible in how I do my work. ___

___ 11. I single out those who need special recognition.

12. I often explore new ways to do my work. ___

___ 13. I feel it is important that people believe in you.

14. I try to make new things happen. ___

___ 15. I like to be part of a "give-and-take" team effort.

16. I like the chance to prove myself—to show what I can really accomplish on my own. ___

___ 17. I feel followers build relationships as much as leaders.

18. I often find others copying my ideas. ___

Figure 1.8 Responsible Risk Taking Inventory Test

In the simulation training portion, subjects were provided inspection training on the computer-simulated aircraft inspection task (Figures 1.9 through 1.12). Subjects were tasked with completing the inspection of the Aft-Cargo bin of an L-1011. Initially, subjects were provided with a work card -- work instructions identifying the inspection task to be completed (Figure 1.13). Then, the subjects were presented with a series of photographic images that constituted a portion of the Aft-Cargo bin of an L-1011 aircraft (Figure 1.14). Each photographic image displayed on the computer screen consisted of a single search area. Subjects could navigate from one area to the next by using the "navigational –aid" provided in the software. As each area was displayed, subjects visually searched the area for defects and reported their identification by clicking the mouse on them. Subjects could use four separate tools – a mirror, flashlight, magnifying glass and paint scraper--to aid them in their search. Upon identification of the defects, subjects completed a non-routine card similar to the one they would complete during the actual inspection in the hangar (Figure 1.15).

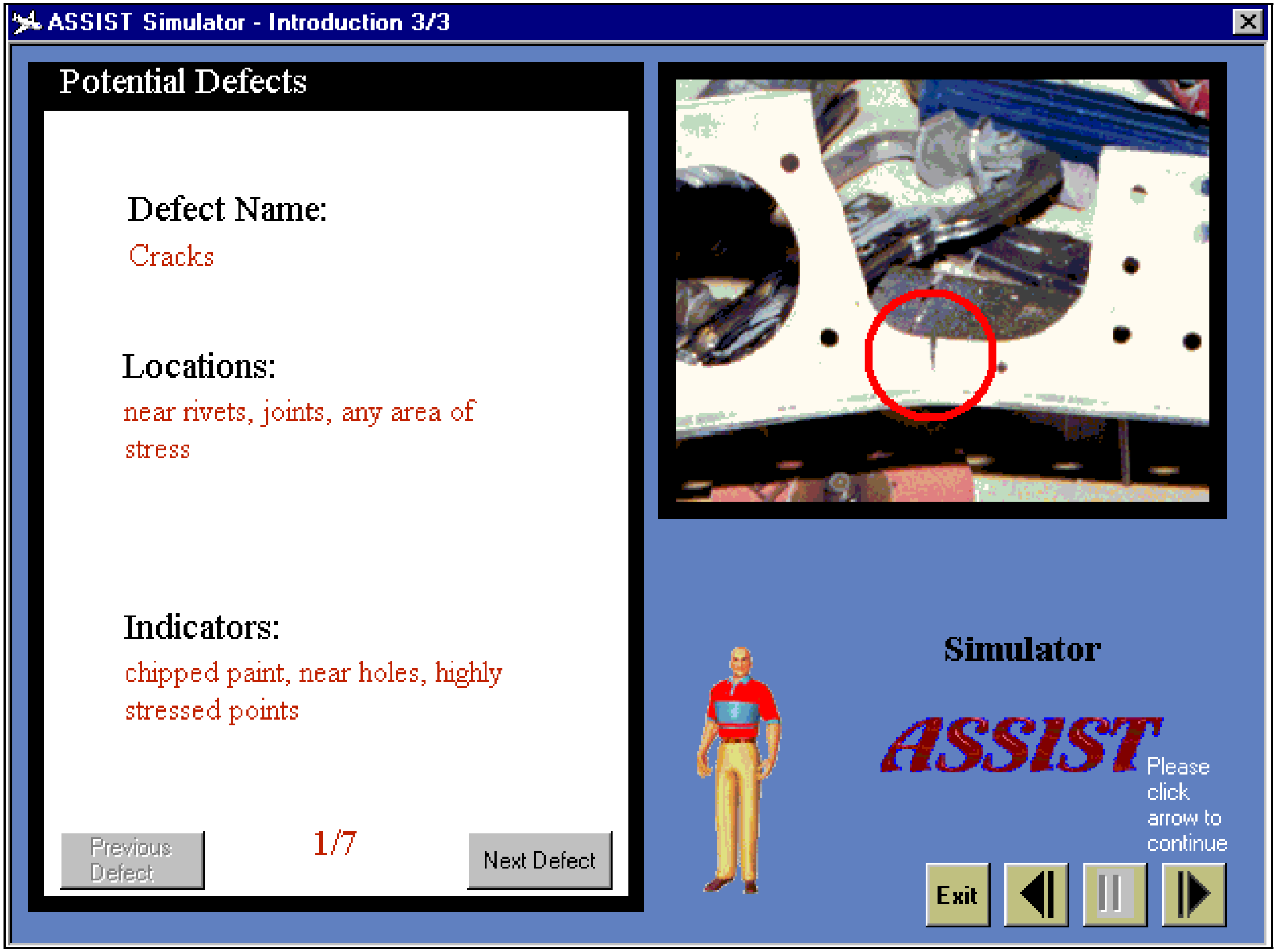


Figure 1.9 The Crack Defect Simulated in ASSIST

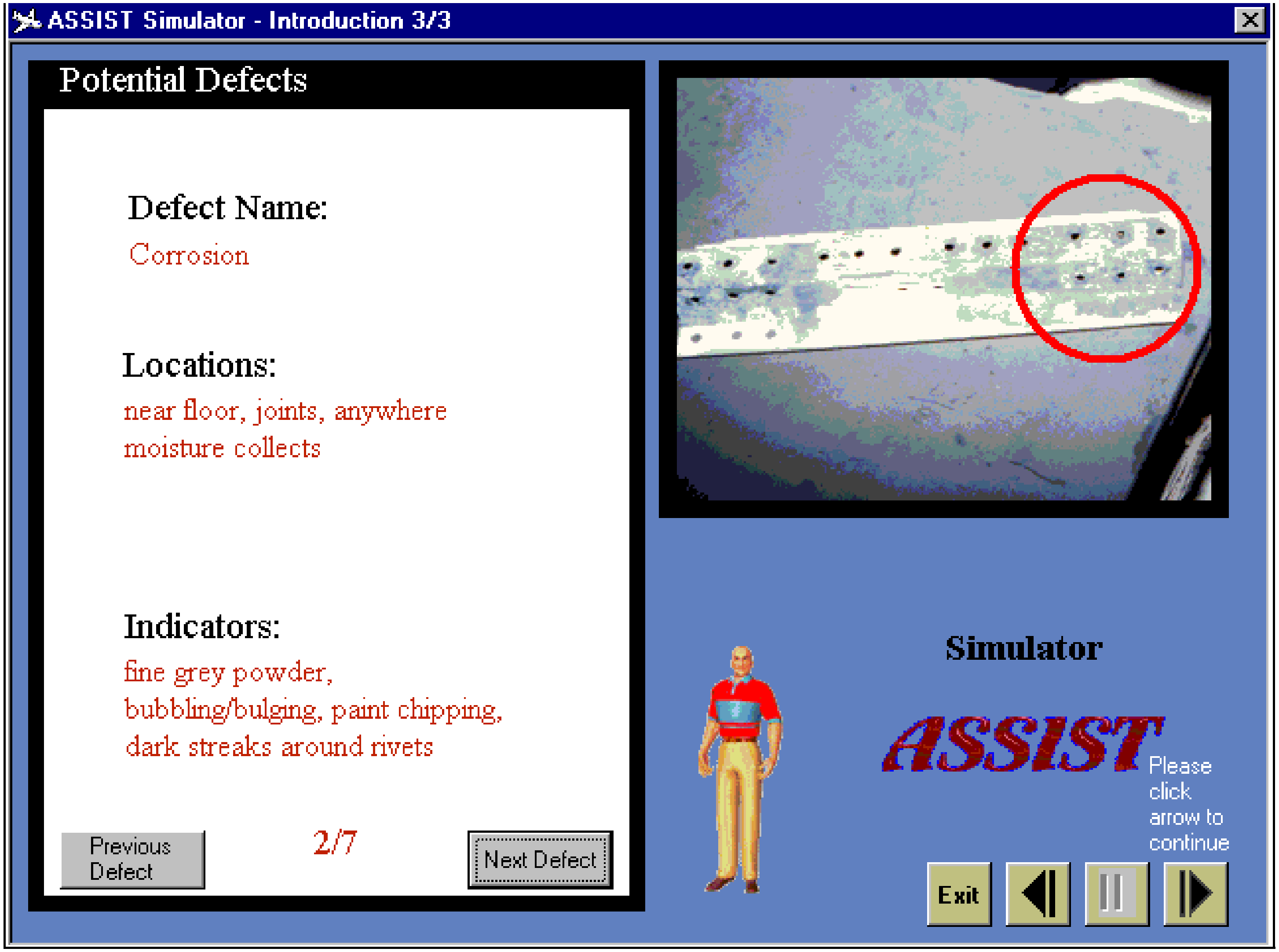


Figure 1.10 The Corrosion Defect Simulated in ASSIST

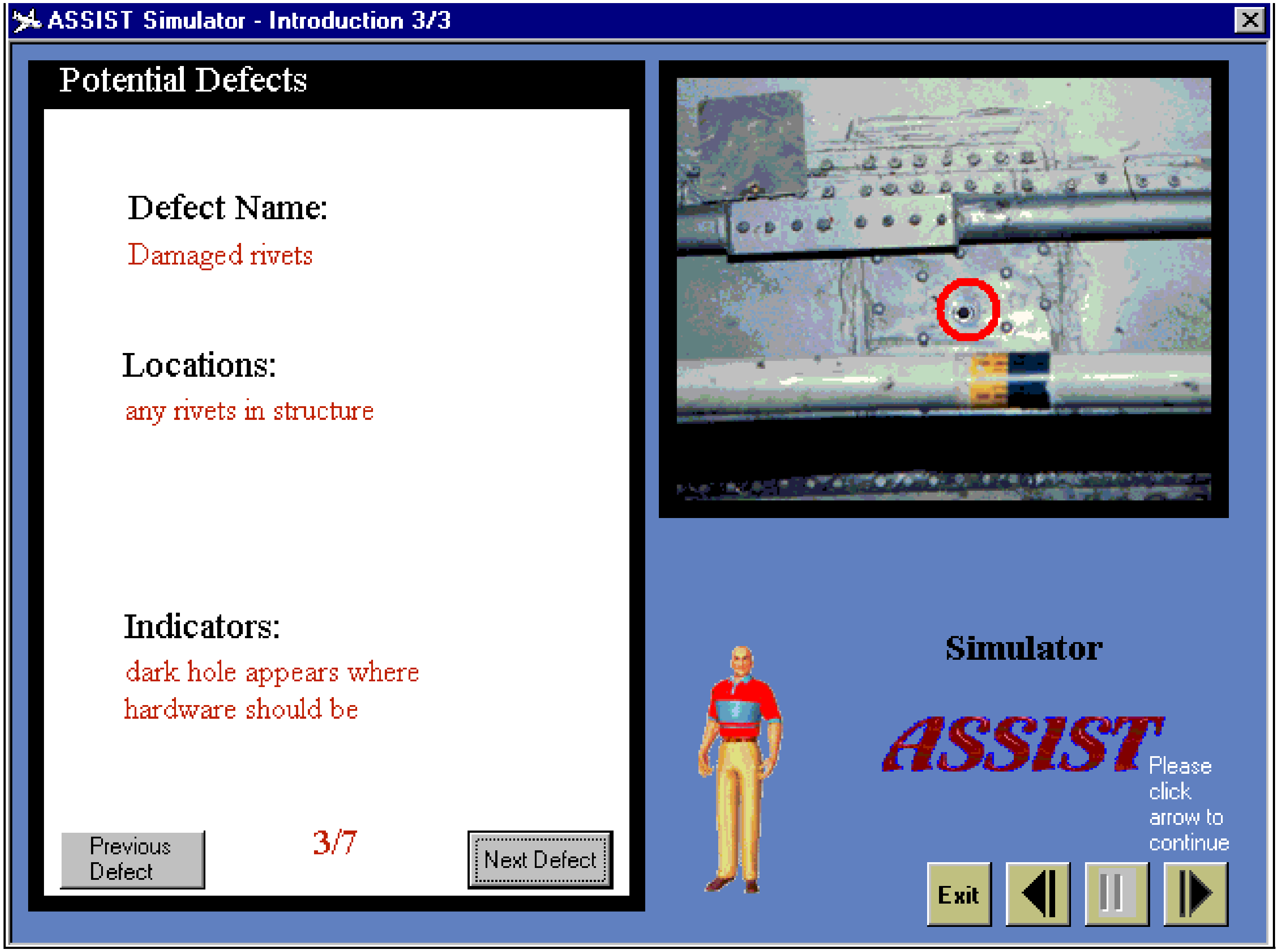


Figure 1.11 The Damaged Rivet Defect Simulated in ASSIST

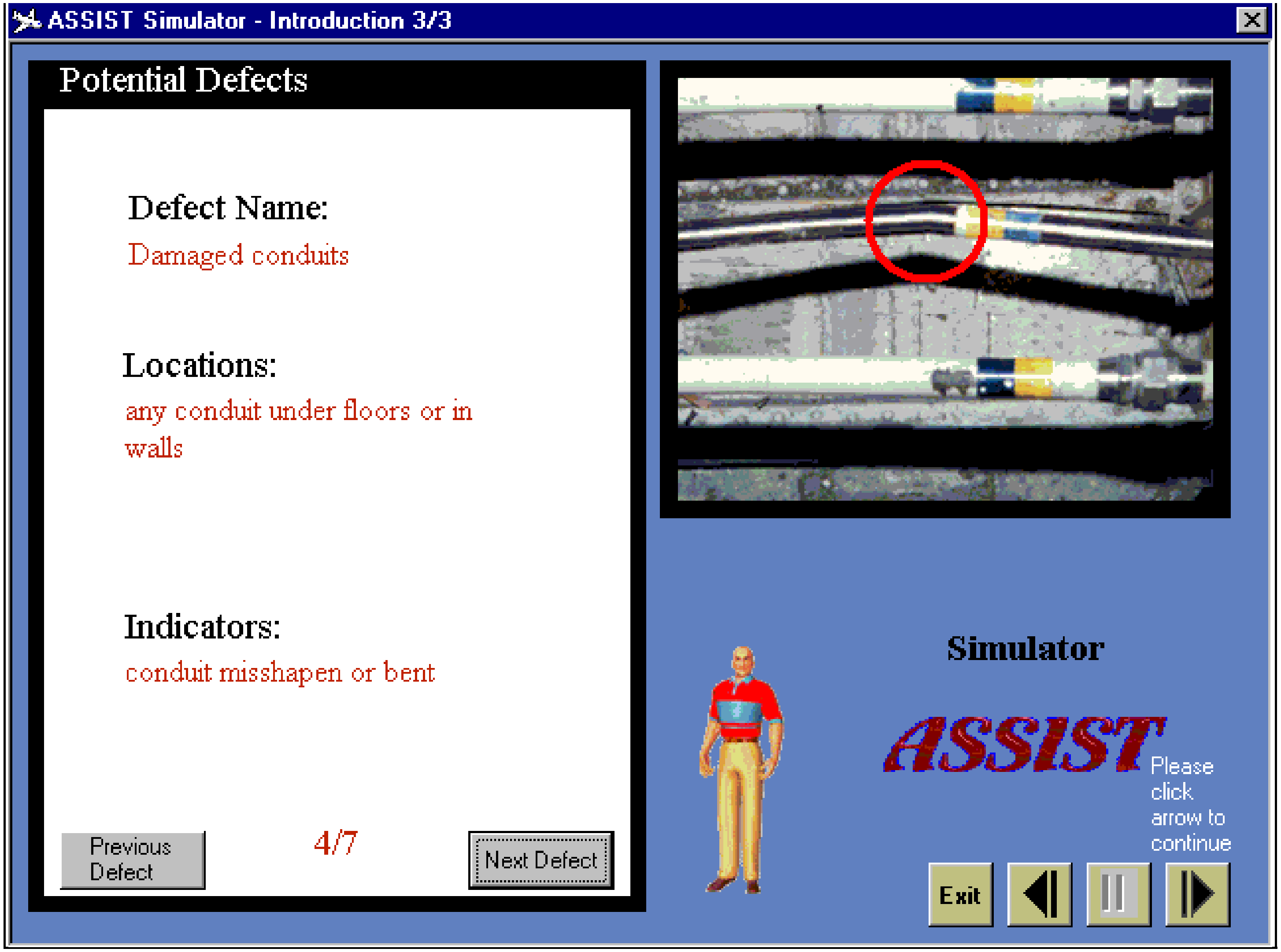


Figure 1.12 The Damaged Conduit Defect Simulated in ASSIST

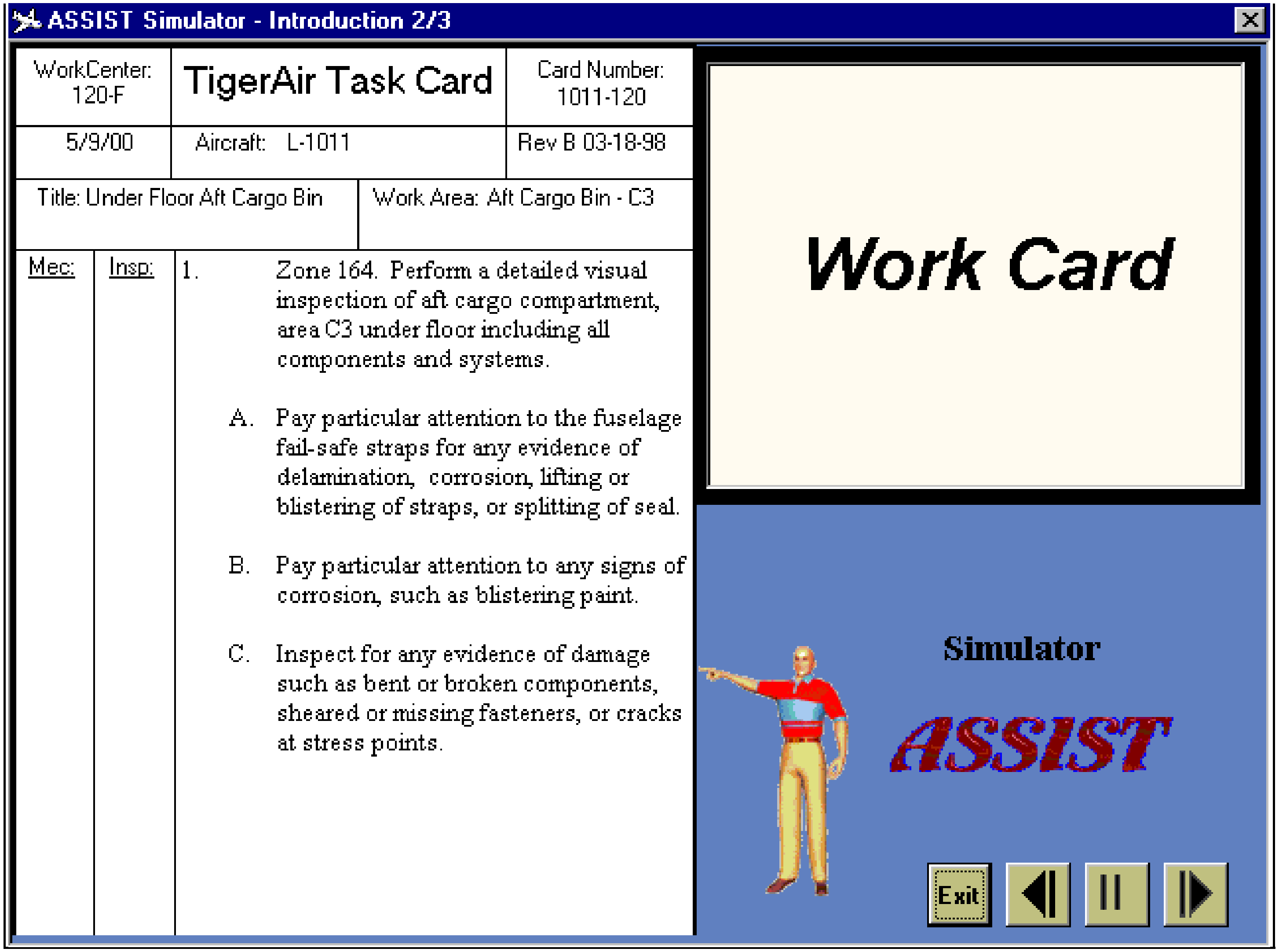


Figure 1.13 Work Card Used to for the Simulation in ASSIST

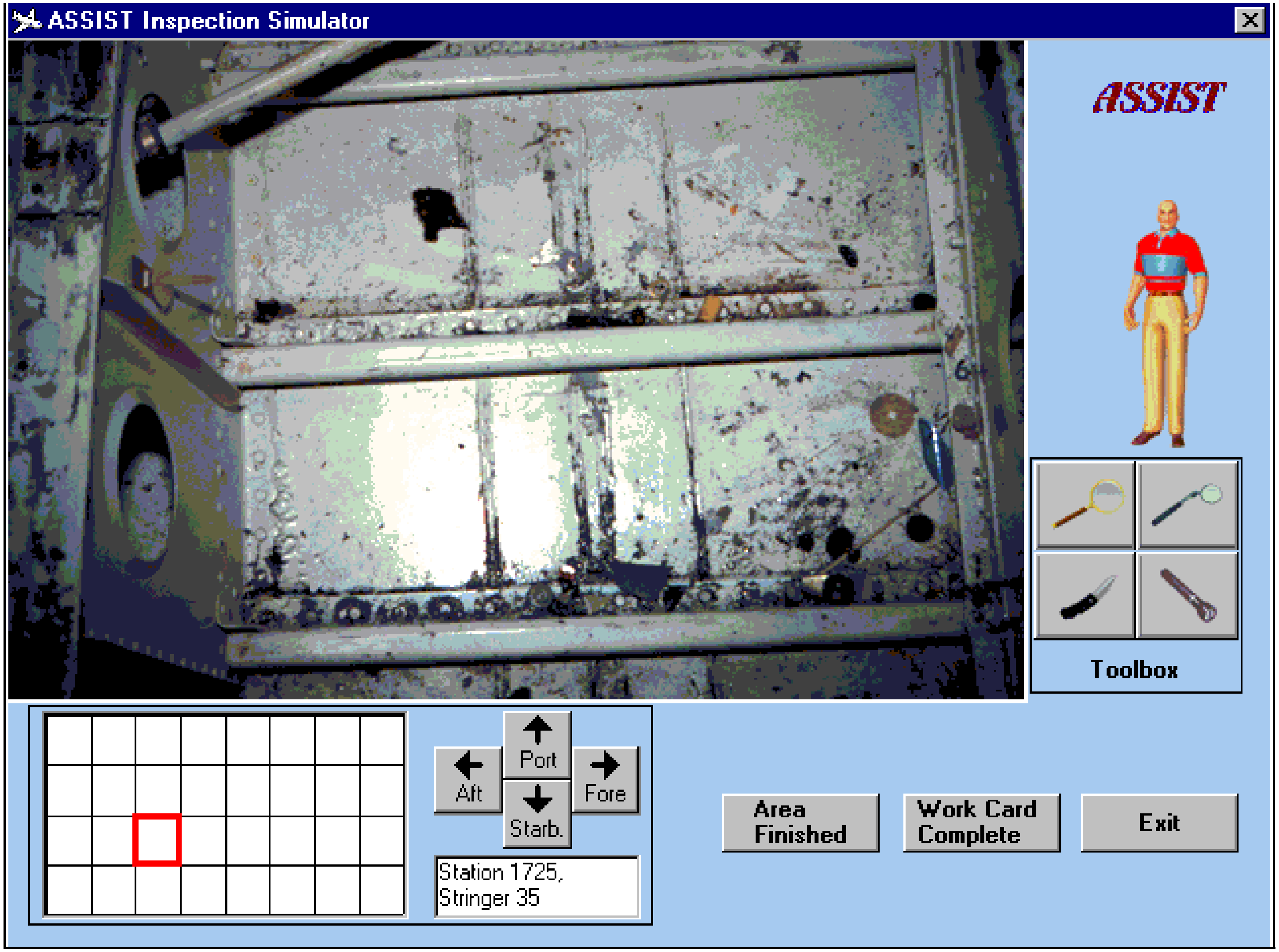


Figure 1.14 Simulation Module Containing a Picture of the Aft-Cargo Bin

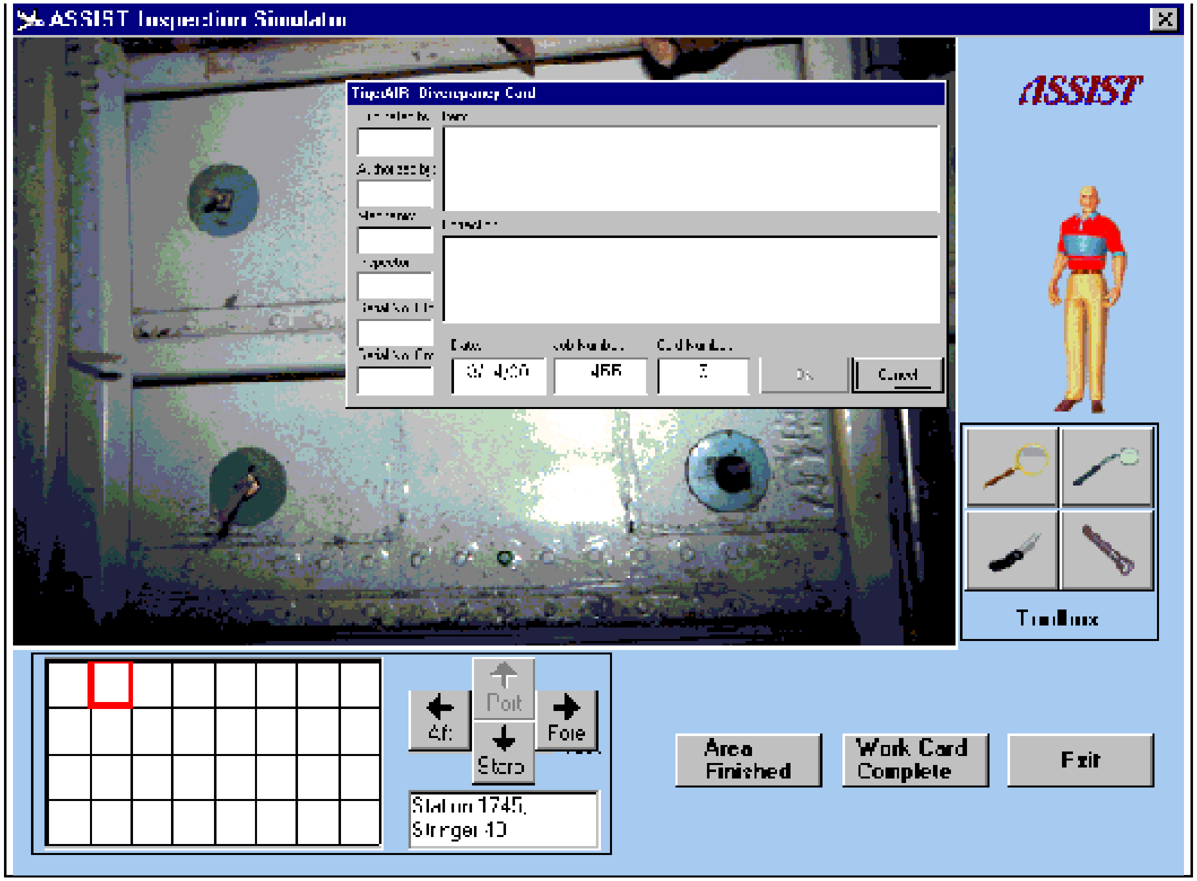


Figure 1.15 Non-routine card used to Write-up Defects Found in the Simulator

In the training mode, subjects were provided with immediate feedback on their performance following the inspection of each search area, including feedback on missed defects, false alarms (areas incorrectly identified as having defects), the time to complete inspection and the correctly completed non-routine card (Figure 1.16). The elements of the simulation module are shown in Table 1.3.

Table 1.3 ASSIST Simulation Module

Sub-module	Content	Method	Delivery System
1. Introduction	**Introduction and observe simulation example of 6 trials**	**Pre-training and feedforward**	**CBT**
2. Practice simulation test	**Perform sample simulation test of 9 trials with feedback**	**Active and feedback**	**CBT**

3. Simulation test	**Perform simulation test of 32 trials with or without feedback**	**Active and feedback**	**CBT**

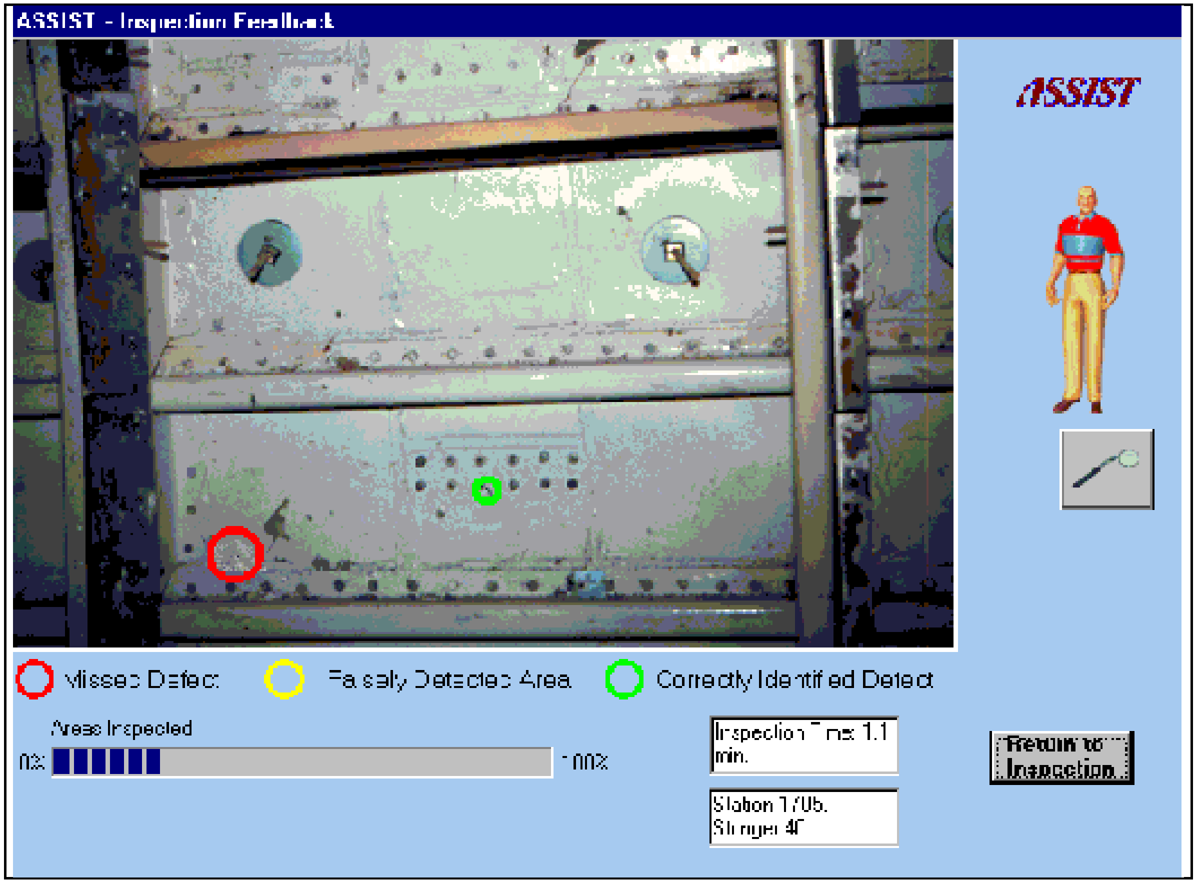


Figure 1.16 Feedback Provided in the Simulation Module

After completing the training, subjects in the training group and those in the control group performed the criterion inspection tasks in both the paced and unpaced modes (Trial blocks 1 & 2). The visual inspection tasks consisted of 32 distinct search areas (trials) within a distinct and logical portion of the Aft-Cargo bin of an L-1011 (a single trial block) wherein subjects searched for seven computer-simulated airframe structural defects: cracks, corrosion, damaged rivets, damaged conduit, delaminated terrastrap, dent and loose hardware. The probability, location and defect mix were all pre-specified using the parameter file. Of the 32 trial areas that made up each of the two trial blocks, 4 contained two defects, 9 one, and 19 zero. Initially, subjects performed the inspection task in the unpaced mode and then in the paced-mode so that the results of Trial block 1 could be used to determine the actual pacing conditions for Trial block 2. All subjects served as their own control and were paced at their own unpaced Trial block 1 times.

Data Collection

Data was collected on the following measures:

- Demographics: Age and experience.

- Scores on individual differences tests:
  - Myers-Briggs Test 34
  - Group Embedded Figures Test (GEFT) 35
  - Locus of Control Test (LOC) 37
  - Responsible Risk Taking Inventory Test 44
- Performance measures:
  - Mean inspection time - the average time in minutes for each trial block,
  - Mean percent detected - the average percentage of defects correctly detected,
  - Mean false alarm rate - the average number of defects falsely identified,
  - Mean non-routine workcard score - the average score* from the non-routine workcard write-up.

1.4 RESULTS

Data reduction was performed on the raw data, and analysis of variance (ANOVA) was conducted on the following performance means: mean inspection time (Appendix B), mean percent detected (Appendix C), mean false alarm rate (Appendix D), and the mean score from the non-routine workcards (Appendix E). Means and standard deviations were also calculated for the performance measures (Appendix F). Following the analysis of variance, a *post-hoc* analysis was performed on the data using correlation and factor analysis. First, the correlation analysis was completed, and then the results from the correlation table were subjected to a factor analysis using varimax rotation of orthogonal factors.

1.4.1 Speed Measures

ANOVA conducted on mean inspection time showed a significant main effect of pacing with no significance for training or interaction effect (Table 1.4).

Table 1.4 Summary ANOVA indicating the F values

	Training	Pacing	Training*Pacing
Mean inspection time (min)	**0.01**	**20.56****	**0.12**

Mean percent detected	**11.61****	**16.10****	**2.38**
Mean false alarm rate	**9.41****	**5.95***	**1.43**
Mean non-routine workcard score	**10.11****	**10.78****	**3.49**
*** $p < 0.05$** ****$p < 0.01$**			

1.4.2 Accuracy Measures

ANOVA on mean percent detected revealed significant main effects of pacing and training with the interaction effect not significant. ANOVA performed on the mean false alarm rate also showed a significant main effect of pacing and training but not for the interaction effect. ANOVA on the mean non-routine workcards scores revealed a significant main effect for both pacing and training with no interaction effect. (Table 1.4)

1.4.3 Correlation and Factor Analysis

Following analysis of variance, correlation analysis was performed on the demographic and pretest measures and on the performance measures for both the untrained and trained groups separately and another with both the groups combined. This analysis was performed for the mean values to identify the degree of association between the performance measures, scores on individual differences tests, age, and experience with the significant correlation's highlighted. The correlation analysis was performed with the data from the nine trained subjects (Appendix G) and a second from the nine untrained subjects. Based on these results, the Myers-Briggs scores were eliminated from further study because of the lack of correlation with performance measures.

Having completed this step, the intercorrelation matrix of the correlation measures was then subjected to a factor analysis using varimax rotation of orthogonal factors. Four factor analysis tests were performed on the following: all 18 subjects (Appendix H), the nine trained subjects (Appendix I), the nine untrained subjects (Appendix J), and the demographic and pretest measures for all 18 subjects (Appendix K).

1.5 DISCUSSION

The objective of the study was twofold: first, to compare the effects of computer-based training (CBT) and specifically ASSIST for inspection tasks under different pacing conditions and second, to relate these results to differences in individual abilities as measured by the individual differences tests. Most importantly, as the data indicated, ASSIST was effective because the trained group performed better than the untrained group. The results of this study are encouraging as to the effectiveness of computer-based inspection training and specifically ASSIST in improving performance. Performance of the training group significantly improved on the criterion inspection task, the inspection of Aft-Cargo bin of L-1011, following training. Of greatest interest was the increase in the percentage of defects detected and the reduction in the number of misses for the training group compared with that for the control group. The training group detected a significantly greater number of defects and missed fewer. This has implications for on the job performance where detection of defects and having a low number of misses are critical to improving inspection performance and ultimately aviation safety. Furthermore, inspectors assigned to the training group also reported higher scores on the non-routine cards following training compared to the control group. These scores measure the correctness and appropriateness of the information entered by the inspector using the non-routine cards following the identification of defects. Subjects responses entered on the non-routine card were scored based on a "standard or correctly completed non-routine card." The information entered on these cards is critical for follow-up maintenance action because incorrect entries or incorrect information can result in erroneous maintenance action. In addition to this, ASSIST was equally effective for both paced and unpaced conditions. Additionally, the results showed that age, computer experience, and the Responsible Risk Taking Inventory Tests scores were correlated to performance on the inspection tasks. The most salient findings are discussed below for the various inspection performance measures.

Analysis of performance measures revealed that training was equally effective, for both paced and unpaced trials, in improving performance when measured in term of accuracy scores, percentage detected and nonroutine workcard scores. That is, the trained group performed better under both paced and unpaced conditions. This bodes well for the use of the ASSIST training program for different types of inspection checks that are constrained by time for example, RAMP checks -- conducted under highly paced situations and the different letter checks - A,B,C, and D -- a less paced situation in which the inspector has a fixed amount of time to inspect the aircraft varying from overnight, 2 days, 1 month, and 4 months respectively. Since inspection performance of the trained group improved in both paced and unpaced situations, it is anticipated that inspectors who undergo training and are typically assigned to RAMP checks will also benefit from this training program under time pressures as well as inspectors, who are under less time pressures, assigned to letter checks. Further analysis of the three accuracy measures, percent correctly detected, non-routine workcard scores, and false alarms, revealed that the trained group performed better on percent correctly detected and non-routine workcard scores. Accuracy results also revealed a high number of false alarms for both paced and unpaced trials, indicating the inspectors were prone to identify non-defects as defects. While this tendency is more desirable than defects not being identified, it is more efficient to the airline industry to reduce the number of false alarms. Nonetheless, in the aircraft maintenance environment, safety is of paramount importance, and at least the training program is a first step towards a higher safety count. The next step would be to identify strategies to reduce the false alarms without affecting the hit rate and, in turn, safety.

Upon further analysis of the correlation table, partial effects were detected with regard to the speed-accuracy trade-off theory (SATO), which states that as time increases, hit rate and false alarms increase. In the unpaced condition, those subjects who spent more time had an increase in false alarms rate yet didn't show a similar increase in hit rate; while under the paced condition, the reverse was true: maximum time spent yielded more hits without an increase in false alarms. This result can be explained by typical search behavior models, which show that defects are detected early in the search process because the time to find defects is exponentially distributed rather than normally.11 Thus, the more time spent on searching, the more false alarms will be identified since this tendency takes place in the later half of the search process.8 In unpaced situations, then, there are more false alarms because there is more time, while under paced conditions there is a time constraint to search, leading to early detection of defects without extra time to identify false alarms.

Additional analysis was conducted looking at the effect of ASSIST in relation to the individual abilities measured by the demographics survey. As the results indicated, the younger inspectors, who had more computer experience performed better on the accuracy measures, both percentage detected and non-routine workcard score, than the older, ones. This finding may be due to the subject population: the younger, less experienced subjects had more computer experience and, hence, their performance on simulated inspection tasks may be an artifact of their computer experience rather than their inspection skills. Although the use of computers may be a matter of concern, demographics in the airline industry are changing. The pool of potential inspectors with computer experience is increasing; therefore, the future aircraft maintenance workforce will come from younger technicians with updated computer skills. However, it is critical that airline industry take steps to reduce the computer experience gap. Another supporting factor of the effectiveness of ASSIST is based on an extension of this study that looked at the transfer effects of simulation-based training on hangar floor performance using inspection of an aft-cargo door. The study revealed that of all subjects who underwent computer-based training on the ASSIST program those with superior computer experience reported the greatest gains showing superior performance on the representative hangar floor task.[24] These results indicated that inspectors with superior computer experience took the greatest advantage of computer-based training and used it most effectively to improve their performance on the inspection task in the hangar floor.

Analysis of the four individual differences tests revealed inequality of effectiveness in terms of their usefulness in understanding the inspection performance of individuals. Most importantly, the Myers-Briggs Test did not show any significance in relation to the inspection performance measures. Typically these tests, used extensively in environments such as business, counseling, and education, are used to build teams, develop leadership, and determine lifestyle pursuits, where successful results of the tests include improved work and personal relationships, in turn increasing productivity.[34] Even though the test may apply to other functions the inspector performs, such as problem solving, delegation, and communication, it may not be applicable to tasks involving specific inspection skills such as visual search and decision making that are critical to performing the inspection task.

The most unexpected finding was the lack of correlation with the Locus of Control Test and the performance measures. A high score on this test categorizes an internal person, one who feels that he controls his own destiny, while a low score indicates an external person, who feels what happens to him is due to luck or chance. Freeman, Eskew et al., and Sanders et al., all found significant findings for Locus of Control Tests between performance measures in inspection tasks.[13,16,38] Specifically, Eskew et al. found Locus of Control to be related to pacing in their study, indicating that self-paced internals scored fewer false alarms than self-paced externals while machine-paced internals scored more false alarms than machine-paced externals.[13] Eskew summarized that although Locus of Control showed potential as a selection tool for inspectors, its success depended upon the particular situation, with the level of pacing and relative importance of misses and false alarms also being considered.[13] Although this aircraft inspection study included an unpaced and paced task, all inspectors completed the paced task, indicating that subjects were able to compensate for time pressures by investing additional resources to ensure completion. This ability which can be explained by using the resource allocation theory states that people learn to compensate for constraints by discovering strategic ways to allocate limited resources in the most optimal fashion.[47]

The Group Embedded Figures Test (GEFT) showed no correlation between it and the performance measures. The GEFT and the Embedded Figures Test (EFT), both measuring the ability to separate an individual figure from a more complex stimulus of which it forms a part, determine the field independent-dependent score.32 Field dependency is defined as “a tendency for the organization of the field as a whole to dominate perception of its parts” while field independence is “a tendency for items to remain discrete from the organized field in which they are contained”.49 Gallwey, who conducted several geometrical-type studies, found that the EFT was a good predictor of several performance measures including stopping time, missing rate, size errors, decision errors, and classification errors.17 These results were expected since the EFT uses geometrical patterns; however, it is questionable whether it would work as well on different types of tasks. Since Gallwey concluded that EFT worked so well in his study, he believed it was applicable to other non-geometrical tasks.17 The lack of correlation between the GEFT and the performance measures in the aircraft inspection study could be due to the differences between this study and standard laboratory inspection tasks in which the inspector is looking for a particular figure embedded within a complex figure. This finding implies that the inspection task in the aircraft maintenance environment is not as simplistic as a geometric-figures task, especially since aircraft inspection is not only skill-based, as in Gallwey's studies, but also knowledge-based depending on where the defects occur; for instance, cracks develop near rivets and corrosion typically occurs in the bottom of the aircraft due to condensation that tends to seep and stagnate in the lowest part. 14,15,17

Analysis of the Responsible Risk Taking Inventory (RRTI) test revealed a negative correlation between the workplace risk score and the two accuracy measures, percent correctly detected, non-routine workcard scores and performance on the hangar floor test. The RRTI, which reveals both a personal and a workplace risk, with a high score indicating a more risky behavior than a low one, showed that those classified more risky in the workplace detected fewer defects, scored lower on the non-routine workcards and had lower accuracy performance on the hangar floor test. According to this result, the airline industry can formulate two obvious strategies to select and hire less-risky inspectors, or the more appropriate one being to train inspectors to be less risky. According to Thapa et al., feedforward information can be used to train inspectors to be less risky.46 However, efficiency and safety, two critical yet separate goals of the airline industry, are not mutually exclusive since an airline will not continue to be profitable if it has a poor safety record. Nonetheless, safety is of greater importance than efficiency, and training inspectors to be less-risky inspectors could be a step towards improving safety.

After the correlation analysis was developed, the intercorrelation matrix of the performance measures, demographic data, and individual differences tests was subjected to a Factor Analysis using varimax rotation of orthogonal factors. Appendix I and J, respectively, show the factors that emerged for the trained and untrained group. For the trained group, Factor 1, with a total variance of 56%, loaded negatively on RRTI Tests and positively on performance measures appearing to represent a "risk" factor. Factor 2, with a total variance of 25%, represents a "skills" factor, loaded negatively in GEFT and paced time and false alarms. Factors 3 and 4 represent an "experience" and "locus of control" factor, with total variances of 24 and 22% respectively. For the untrained group, Factor 1, with a total variance of 39%, represents a "performance" factor loaded on time and accuracy. Factor 2, with a total variance of 34%, loaded heavily on the RRTI tests and negatively on unpaced false alarms, appearing to represent the "risk" factor. And finally, Factors 3 and 4 represent the "experience" and "locus of control" factors, respectively.

In general, the results have demonstrated that the usefulness of computer-based training and specifically ASSIST results in improved performance under unpaced and paced conditions. Specifically, the following conclusions can be drawn from this study:

- Inspection performance: The trained group performed better than the untrained group on accuracy measures, percentage detected, and the non-routine workcard score.
- Pacing: Training was equally effective for both paced and unpaced inspection conditions.
- Accuracy measures: Under unpaced conditions, the false alarm rate increased while under paced conditions, accuracy improved.

- Age and Experience: Younger inspectors who had superior computer experience were more comfotable using computer based training and had higher accuracy scores on the simulation test, which translanted into superior performance on the hangar floor .

- Individual Differences Tests: The Myers-Briggs Test, Locus of Control Test, and GEFT showed no significance with performance measures. However, the Responsible Risk Taking Inventory test is a good predictor in identifying less risky inspectors since in this study subjects who scored lower on risky behavior measures scored higher on accuracy measures.

The results of this study have obvious implications on the future use of training programs, specifically computer-based training. This training was effective; however, the goal of future training programs must be to reduce false alarms. Perhaps one approach could start with a generic program addressing certain components, after which inspectors would complete sections classifying them as either risky or less-risky then target certain modules in order to develop an adaptive training program based on risk preferences in which the more risky people were taught to behave less so. Once the inspectors are calibrated, the program could have specific modules that focus on lowering false alarms. Basically, the training program would be adapted to the needs of the inspector. As the result of this study indicated, computer-based training has much promise to be used as a very effective tool, but only if its potential is realized in a way which is consistent with the existing knowledge of the aircraft maintenance environment to ensure both a safer and more profitable airline.

1.6 CONCLUSIONS

The results of this research throws new light into devising training programs for improving aircraft inspection performance and ultimately aviation safety. The findings from the experiment were integrated into a set of recommendations for use of practitioners in the aviation industry and improving aircraft inspection performance.

To summarize the experimental findings:

1. Training was equally effective in improving inspection performance under both paced and unpaced situation which bodes well for the use of similar content in training for inspection under different inspection situations.

2. Age, experience and Individual Differences as measured by the Responsible Risk Taking Inventory are correlated with inspection performance.

The above results have implications for improving and standardizing inspection performance. Drawing from the results of the study the following generalizations can be made for improving inspection performance that can be used by the practitioner of human factors in aircraft maintenance environment.

1.6.1 Standardization of Work Instruction

It is seen that the lack of standardization of work instruction (both written and oral) can critically impact the manner in which inspection is conducted. This can be magnified by the individual differences reported across inspectors in their ability to perceive risks and costs. Work instructions can impact the following:

1. search of an area for defects --how to inspect, how long to inspect, identification of critical items

2. decisions made by inspectors on defects identified – write ups for non-routine cards, when to mark it and write it up, deferred item, etc

3. use of inspection support material/standards – tools, job-aids, manuals, air-worthiness directives, support equipment.
4. transfer of work during shift change

To ensure standardization of work instruction both written and oral it is critical that the inspectors follow a standardized work protocol. As a starting point practitioners can follow the detailed protocol outlined by Gramopadhye and Kelkar.[25] The flow chart of the standardized protocol is shown in Figure 1.17.

1.6.2 Adaptive Training

It is clear that any training to further improve inspection performance needs to be sensitive to individual differences and hence needs to be adaptive in nature. The results of the study have implications for two of the three components for a typical training program: the content, which refers to what type of material is presented, and the method, which refers to how the material is presented, for example, feedforward, feedback or active training. Using the results of the individual differences tests which indicate post-training performance, salient traits of inspectors can be identified and then a program can be developed to fit the individual's needs under a specific situation.

An example used to illustrate how to develop such a training program for inspecting the nose landing gear and wheel well assembly of an aircraft is used as outlined by Gramopadhye, et al.[23] Table 1.5 shows this inspection process broken down into (1) the structures, or the components to be inspected, and (2) the defects, or the nonconformities, to identify for the three search areas: wheel well, nose gear assembly, and nose gear tire. The basic elements of the training program are outlined in the next section.

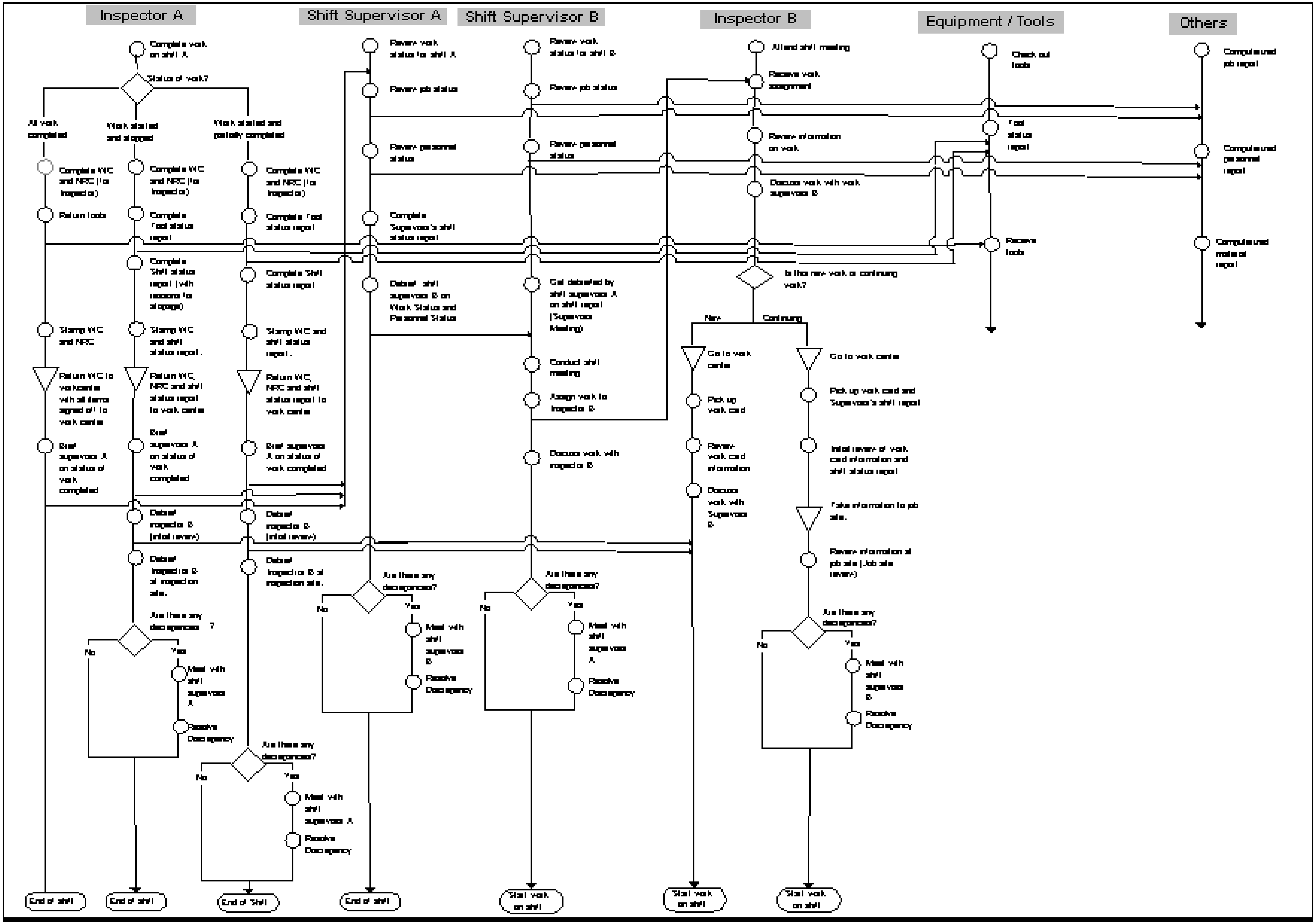


Figure 1.17: Standerdized Shift Change Protocol

Table 1.5 Nose Landing Gear and Wheel Well Inspection (B-check)

Wheel Well, Doors, Adjacent Components		Nose Gear Assembly & Installation		Nose Gear Tires & Wheel Assembly	
Structure	**Defects**	**Structure**	**Defects**	**Structure**	**Defects**
1. Wheel well hydraulic tubing conduits	• Condition • Corrosion • Fluid leakage	1. NLG shock stout, bracestrut, torque arm, ground sensing mechanism, cables, actuating cylinder, linkages, springs	• Corrosion • Visual damage • Nicks & dings • Fluid leaks • Security	1. Wheel hub valves, 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 hours of parking • Reinflate with NL
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 and bolts • Worn bushings and 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	• Closed doors • Secured doors (procedure given)				

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 • Security				

The Training Program

The training program should consist of the following five steps:

1. Pretesting. The first step in the training program is to administer the pretests to categorize subjects based on their individual abilities. For this example, the Responsible Risk Taking Inventory Test is given to measure risky behavior and a survey is conducted to determine the amount of computer experience for each subject.

2. Computer Training. Based on the classification of the computer experience, only those subjects with limited experience would be administered training to increase their computer knowledge. They would actively participate in tasks on the computer with feed-forward information including what skills they would be learning and practicing and then feedback on their progress.

3. General Training. After all subjects are brought to the same level of computer experience, they would then be administered the generalized training program in ASSIST, consisting of the following modules: role of inspector, safety, aircraft review, factors affecting inspection, information on the area, information on workcard usage, examples of defects in each area, inspection procedure, and a final test. Throughout the training, subjects would receive feed forward information and participate through active training by studying the modules and taking a test at the end. They would also receive feedback information on what they learned and how they performed on the test.

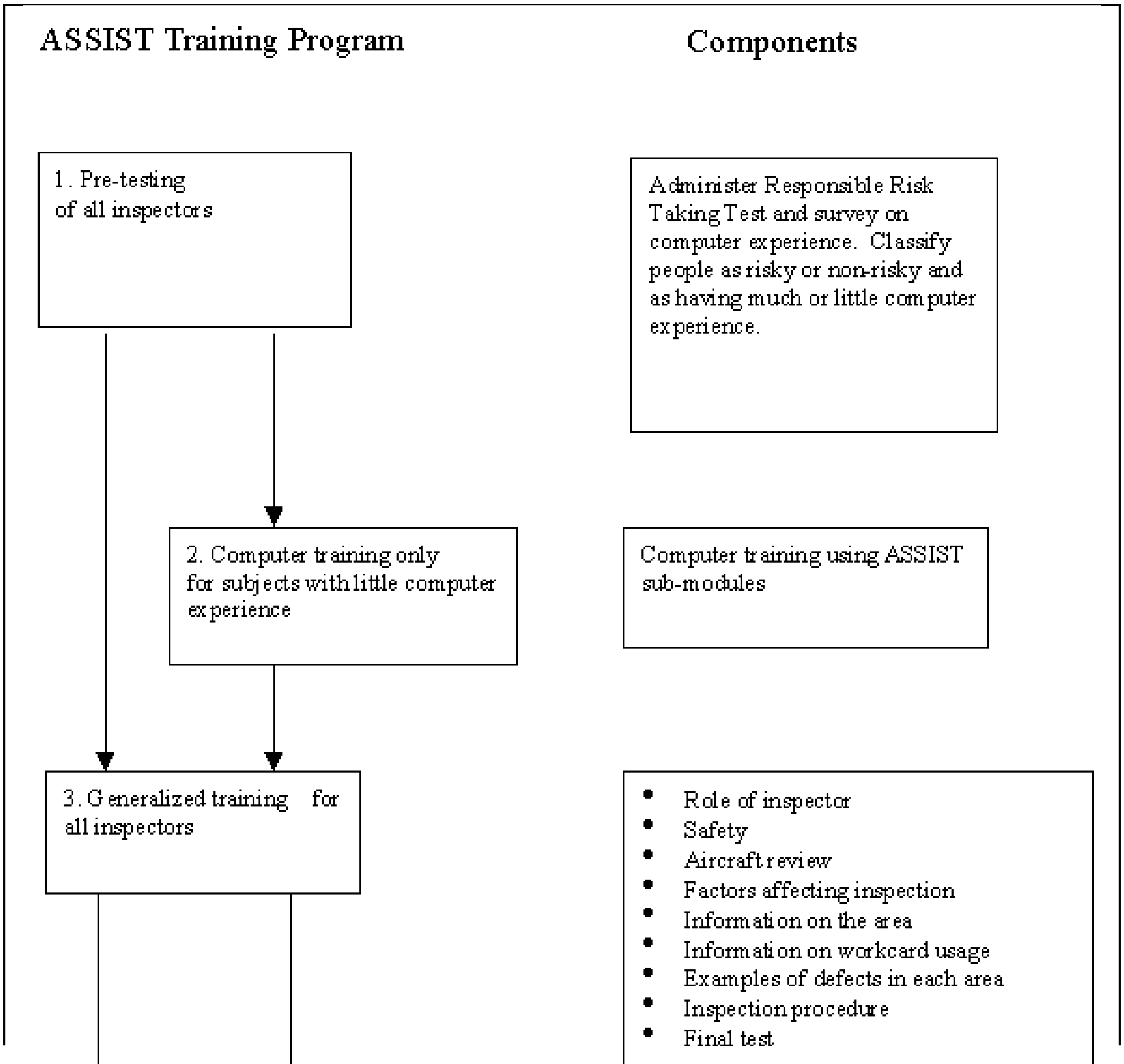
4. Risk Training. Following the generalized training, the subjects who were classified by the pretest as risky would be administered active training with feed forward information to reduce their risk tendencies by reviewing different inspection scenarios to determine their optimal search time. Since risky people have a tendency to take less time searching, they would receive feed forward information telling them how long to spend searching, then feedback information telling them how long they actually spent along with their accuracy levels.

5. Simulated Task Training. After the risky subjects are at the same level as the non-risky ones, subjects would be given feedforward information consisting of the optimal time they should take to inspect, the defects to look for, and the likely locations where they would occur. Then, all subjects would be administered the simulation training program in ASSIST under various paced environments reflective of RAMP, A,B,C, and D checks, where RAMP checks represent the highest pacing level and D checks, the lowest. Using active and schema training, various scenarios would be used to represent RAMP, A, B, C, and D checks, which are essentially time pressures and situations where different defects are occurring. Feedback information would include the time taken to find the defects, the subject's accuracy level, the defects detected and those missed, and search areas missed. Table 1.6 and Figure 1.18 outline the steps, content, method, and delivery system of the training program described above.

Table 1.6 ASSIST Training Program

Step	Content	Method	Delivery System
1. Administer pretests and categorize subjects based on scores	• Responsible risk taking inventory • Computer experience	•	Survey
2. Computer training only for subjects with little computer experience	• Extra computer training using ASSIST sub-modules	• Feedforward • Feedback • Active	Computer-based (CBT)
3. Generalized training for all subjects	• Role of inspector • Safety • Aircraft review • Factors affecting inspection • Information on the area • Information on workcard usage • Examples of defects in each area • Inspection procedure • Final test	• Feedforward • Feedback • Active	CBT
4. Risk training only for subjects classified as risky from pretest	• Different scenarios emphasizing the optimal time to spend inspecting	• Feedforward • Feedback • Active	CBT

5. Simulated inspection training under paced and unpaced conditions	• Different scenarios using RAMP, and A,B,C, and D checks	• Feedforward • Feedback • Schema • Active	CBT



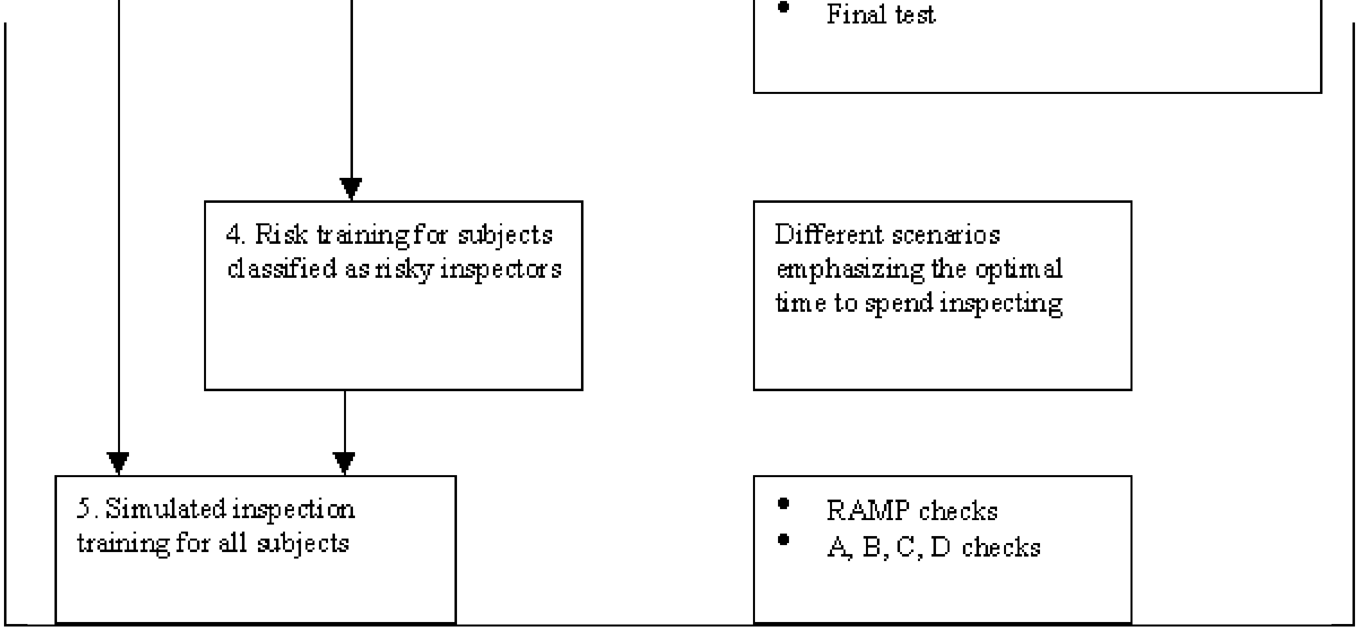


Figure 1.18 ASSIST Training Program

In summary, this research has shed new light on understanding the effectiveness of aircraft inspection training and the usefulness of individual differences tests in improving aircraft inspection performance and reducing errors. The results have both theoretical and practical implications. These findings change the ideas behind the theory of developing training programs, by using individual differences tests and pacing, leading to a more efficient and effective program. The improvements in inspection performance will then lead to reduced errors and improved aviation safety.

1.7 ACKNOWLEDMENTS

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1.9 APPENDICES

1.9.1 Appendix A - Selection Tests

Vision tests measure the visual capabilities of the individual by quantitatively measuring eye characteristics such as accommodation and acuity.38 The three vision tests investigated here are visual acuity, lobe size, and contrast sensitivity.

1. *Visual acuity*. This is the ability to discriminate fine detail that is then expressed as a ratio, such as 20/20, called Snellen Acuity. Normal 20/20 vision is assumed to be the ability to resolve a target detail of 1 minute of arc at 20 feet.38 Static foveal acuity is the measure of the minimum angle subtended by the test object at the eye that can be resolved. If a people have good acuity, one minute of angle or less, there is a high chance that they will be a good criterion inspector.32 Visual acuity is an important predictor but was not used in this study since all inspectors have to go through visual acuity testing and have 20/20 or corrected vision.

2. *Lobe size*. The area around the point of fixation in which the probability of detecting the presence of a target item is defined when it is viewed within the retinal field during a single eye pause, or fixation is the lobe size. The visual lobe is affected by such factors as the adaptation level of the eye, the target characteristics, the background experience, and motivation.28 Studies have shown that subjects with larger visual lobes are more efficient detecting faults early in the search process.39 While Gallwey found lobe size to be a good predictor for error classification in an inspection task.17

3. *Contrast Sensitivity*. By this is meant the ability to discern spatially distinct luminance differences tested with Sine-wave grating of various sizes or spatial frequencies measured in number of cycles per degree (cpd). Humans are most sensitive to frequencies in the 3-5 cpd range.5 High spatial frequencies (>10 cpd) are for fine detail and reading, low spatial frequencies (<2 cpd) for coarser detail.1 Ginsburg found contrast sensitivity to be significant in predicting performance on some visual tasks better than visual acuity.19

Aptitude tests, for example intelligence tests, measure overall performance over a broad range of mental capabilities such as verbal and numerical skills.30 The Harris Inspection Test, the Weschler Adult Intelligence Scale, Short-Term Memory, and the Gordon Test of Mental Imagery Control have been used to measure aptitude.

1. *The Harris Inspection Test*. This is a pencil and paper test intended for electronic circuit diagrams, identifies which objects on paper are not the right size, shape, or conformity. This test was found to be significant in electronic inspection tasks, with a correlation of .55 found with experienced inspectors of small complex electronic and mechanical assemblies.11,26

2. *The Weschler Adult Intelligence Scale (WAIS).* This scale measures intelligence (IQ) in three areas – verbal comprehension, attention concentration, and analysis -- is a measure of mental processing speed. Significance with the attention-concentration subset -- arithmetic, digit span, digit symbol -- was found to be a very good predictor of search errors.17

3. *Short-term memory*. Used to identify a person's ability to retain information temporarily, from 30 seconds to a few minutes, short-term memory was found to be a weak predictor of inspection performance.17

4. *The Gordon Test of Mental Imagery Control*. This tests for photographic memory. Gallwey found the Gordon Test of Mental Imagery Control was good at predicting the probability of success – wherein a high score of mental imagery indicates a high probability of success.17

Cognitive tests measure the mental processes, skills, strategies, and use of information, the basic mechanisms involving attention, thoughts, and decision making by which people perceive, think, and remember.47 Six cognitive tests -- the Embedded Figures test (EFT), the Eysenck Personality Inventory, the Guilford-Zimmerman Temperament Survey, the Minnesota-Multiphasic Personality Inventory (MMPI), the Matching Familiar Figures test (MFFT), and the Locus of Control -- have been used in inspection performance studies with varying degrees of significance.

1. *The Embedded Figures Test (EFT).* The ability to separate an individual figure from a more complex stimulus of which it forms a part, determines the field independent-dependent score.32 Field dependency is defined as "a tendency for the organization of the field as a whole to dominate perception of its parts" and field independence is "a tendency for items to remain discrete from the organized field in which they are contained".49 Gallwey found that EFT was a good predictor of many measures including stopping time, missing rate, size errors, decision errors, and classification errors.17 He concluded that field independents are much more likely to impose structure on a problem in reaching their solution.

2. *The Eysenck Personality Inventory*. This test classifies people as introverts and extroverts using five categories – neuroticism, extroversion, openness, agreeableness, and conscientiousness -- while the Guilford-Zimmerman Temperament Survey measures general activity, restraint, ascendance, sociability, and emotional stability.47 There are mixed findings using the Eysenck Personality Inventory Test to study inspection tasks.17 While conscientiousness was found to be effective in predicting performance in skilled and semi-skilled workers, found a low correlation with inspection performance and the Guilford-Zimmerman Temperament Survey.47,48

3. *The Minnesota Multiphasic Personality Inventory (MMPI).* Used to measure manifest anxiety, the degree of guardedness in responding, and falsification in responding.48 There is low correlation between inspection performance and the MMPI.48 Used to identify people with mental illness or personality disorders, it is not an appropriate test for employee selection.47

4. *The Matching Familiar Figures Test (MFFT).* Seeks to classify subjects according to time to first response and accuracy. Depending upon the time taken and the number of errors made, subjects are classified as (1) reflectives (longer times, fewer errors), (2) impulsives (shorter times, more errors), (3) fast-accurates (shorter times, fewer errors), (4) slow-inaccurates (longer times, more errors). Impulsives work faster, and reflectives are more accurate. Using MFFT, Schwabish and Drury classified individuals in terms of time and accuracy to evaluate the influence of different cognitive styles on visual inspection.40 Their data showed that subjects could be differentiated only on accuracy. The more accurate group was significantly faster than the inaccurates in detecting certain flaws in addition to making fewer size-judgement errors. However, the inaccurates detected more flaws.

5. *The Locus of Control (LOC).* This construct by Rotter has appeared widely in the literature and has generated much research in the work setting.37 LOC is used to characterize people as internal scorers and external scorers. It is suggested that internal scorers adapt better to high controlling situations while external scorers adapt better to highly externally controlling situations.16 Eskew and Riche, found LOC may be related to response-wise signal detection tasks and may be useful in selecting quality control inspectors.13 The significant findings for LOC tests conclude that self-paced internals had higher response criterion than self-paced externals, thus making fewer false alarms while machine-paced internals had a lower criterion and made more false alarms than machine-paced externals.13 Internals tend to make fewer errors on a vigilance task than externals, with internal scorers performing significantly better than externals on correct decisions and the number of misses with self-pacing.16,38

Three other cognitive tests that have not been used in inspection performance are human vigilance, certainty equivalence, and Myers-Briggs Type Indicator (MBTI).

1. *Human vigilance*. This is a situation where an operator is required to detect intermittent, unpredictable, and infrequent signals over a long period of time. The resulting loss in sensitivity due to fatigue is classified by the arousal theory and expectancy theory.4

2. *Certainty equivalence*. Also known as a risk test, measures the amount of risk people will take when making decisions. In many cases, people accept wide variations in consequences and much uncertainty. A preference scale is used to encode an individual's attitude toward risk, resulting in a preference curve that can be categorized as risk averse, risk neutral, and risk seeking. Risk behavior is known to effect inspection performance and accordingly it was selected for this study. 36,47

3. *The Myers-Briggs Type Indicator (MBTI).* This is used to obtain a personality type code based on the individual's preferred way of perceiving and judging, providing four bi-polar scales: extroversion-introversion, sensing-intuition, thinking-feeling, and judging-perceiving. Currently, this test has been used in such settings as counseling, education, and career guidance.34 The MBTI test is often used in the aircraft maintenance environment for other jobs to classify and select people and hence is used in this study.

1.9.2 Appendix B - ANOVA of Inspection Time

	DF	SS	F
BETWEEN SUBJECTS			
Training	1	0.98	0.01
Subj(training)	16	5314.75	
WITHIN SUBJECTS			
Pacing	1	1906.20	20.56*
Training*pacing	1	10.87	0.12

Pacing*subj(training)	16	1483.27	
* $p<0.05$			

1.9.3 Appendix C - ANOVA of Percentage of Defects Detected

	DF	SS	F
BETWEEN SUBJECTS			
Training	1	2934.03	11.61*
Subj(training)	16	4044.44	
WITHIN SUBJECTS			
Pacing	1	1056.25	16.10*
Training*pacing	1	156.25	2.38
Pacing*subj(training)	16	1050.00	
* $p<0.05$			

1.9.4 Appendix D - ANOVA of Number of False Alarms

	DF	SS	F
BETWEEN SUBJECTS			
Training	1	2100.69	9.41*
Subj(training)	16	3570.56	
WITHIN SUBJECTS			
Pacing	1	584.03	5.95*
Training*pacing	1	140.03	1.43
Pacing*subj(training)	16	1569.44	
* $p<0.05$			

1.9.5 Appendix E - ANOVA of Nonroutine Workcard Scores

	DF	SS	F
BETWEEN SUBJECTS			
Training	1	101.67	10.11*

Subj(training)	16	160.86	
WITHIN SUBJECTS			
Pacing	1	29.34	10.78*
Training*pacing	1	9.51	3.49
Pacing*subj(training)	16	43.53	
* p<0.05			

1.9.6 Appendix F - Means and Standard Deviations for Performance Measures

Group	ID	Inspection time (min)		Percentage correctly detected		Total score on non-routine work cards		Number of false alarms	
		Unpaced	**Paced**	**Unpaced**	**Paced**	**Unpaced**	**Paced**	**Unpaced**	**Paced**
	1	35.50	30.70	60.00	70.00	12.00	12.50	30.00	43.00
	2	57.38	13.50	60.00	65.00	11.50	11.50	29.00	27.00
	3	49.67	32.73	60.00	60.00	11.00	11.00	35.00	32.00
Trained	7	57.83	35.70	50.00	55.00	9.00	9.50	36.00	46.00
	9	37.73	29.75	50.00	55.00	10.50	11.00	35.00	42.00
	11	33.23	16.45	45.00	45.00	9.00	9.00	6.00	2.00
	13	39.52	30.28	50.00	70.00	9.50	14.00	29.00	39.00
	14	26.60	27.02	45.00	40.00	7.50	6.50	13.00	40.00
	17	38.98	39.22	45.00	65.00	9.00	11.00	23.00	73.00
	AVE	41.83	28.37	51.67	58.33	9.89	10.67	26.22	38.22
	STD	10.81	8.41	6.61	10.61	1.45	2.15	10.45	18.67
	4	63.14	30.47	30.00	65.00	5.50	13.00	27.00	32.00
	5	18.12	11.29	15.00	20.00	2.50	3.50	7.00	11.00
	6	21.58	19.24	35.00	35.00	7.00	6.50	2.00	5.00
Untrained	8	55.46	31.52	40.00	50.00	7.00	10.00	20.00	20.00

	10	69.37	33.70	35.00	40.00	7.00	7.00	24.00	12.00
	12	9.30	6.27	15.00	15.00	3.00	3.00	13.00	29.00
	15	48.35	46.50	30.00	60.00	4.50	10.50	15.00	34.00
	16	63.49	40.28	45.00	70.00	9.00	13.50	12.00	6.00
	18	40.50	29.17	20.00	45.00	4.00	8.00	14.00	22.00
	AVE	43.26	27.60	29.44	44.44	5.50	8.33	14.89	19.00
	STD	22.15	13.10	10.74	19.11	2.17	3.76	7.88	11.08

1.9.7 Appendix G - Correlation Analysis results (Trained Subjects)

	U-hit	**U-fa**	**P-time**	**P-hit**	**P-fa**	**Unrwc**	**Pnrwc**	**Age**	**Exper**	**GEFT**	**Loc**	**Risk1**	**Risk2**	**Know**	**Hanger**
U-time		**0.65**	**-0.01**	**0.38**	**0.02**	**0.41**	**0.29**	**0.34**	**-0.03**	**0.65**	**0.21**	**-0.61**	**-0.41**	**-.36**	**-.74**
		(.05)	(.97)	(.31)	(.95)	(.28)	(.46)	(.37)	(.92)	(.11)	(.59)	(.08)	(.27)	(.32)	(.02)
U-hit	**1.00**	**0.61**	**-0.16**	**0.58**	**-0.13**	**0.90**	**0.51**	**0.09**	**-0.71**	**0.38**	**-0.24**	**-0.44**	**-0.36**	**0.35**	**.73**
		(.08)	(.69)	(.10)	(.74)	(.01)	(.16)	(.82)	(.03)	(.40)	(.54)	(.23)	(.33)	(.34)	(.04)
U-fa		**1.00**	**0.45**	**0.61**	**0.41**	**0.58**	**0.56**	**0.53**	**-0.34**	**0.03**	**0.16**	**-0.42**	**-0.43**	**-.11**	**-.39**
			(.22)	(.08)	(.28)	(.10)	(.11)	(.14)	(.37)	(.94)	(.67)	(.25)	(.24)	(.78)	(.29)
P-time			**1.00**	**0.26**	**0.81**	**-0.17**	**0.14**	**0.38**	**-0.22**	**-0.32**	**0.39**	**0.31**	**0.08**	**-.44**	**0.43**
				(.50)	(.01)	(.66)	(.71)	(.32)	(.56)	(.49)	(.29)	(.41)	(.85)	(.23)	(.24)
P-hit				**1.00**	**0.39**	**0.68**	**0.98**	**0.03**	**-0.35**	**0.43**	**0.02**	**-0.63**	**-0.74**	**0.37**	**.77**
					(.29)	(.04)	(<.01)	(.95)	(.35)	(.34)	(.97)	(.07)	(.02)	(.31)	(.02)
P-fa					**1.00**	**-0.10**	**0.17**	**0.22**	**0.02**	**-0.37**	**0.13**	**-0.02**	**-0.11**	**-.31**	**0.42**
						(.79)	(.65)	(.56)	(.96)	(.41)	(.73)	(.97)	(.76)	(.41)	(.26)
Unrwc						**1.00**	**0.66**	**0.11**	**-0.62**	**0.40**	**-0.48**	**-0.62**	**-0.66**	**0.59**	**-.51**
							(.05)	(.77)	(.07)	(.37)	(.19)	(.07)	(.05)	(.09)	(.15)

Pnrwc							**1.00**	**-0.01**	**-0.29**	**0.43**	**0.06**	**-0.62**	**-0.78**	**0.51**	**-.46**
								(.97)	(.45)	(.33)	(.88)	(.07)	(.01)	(.16)	(.20)
Age								**1.00**	**-0.04**	**0.00**	**0.05**	**-0.09**	**-0.13**	**-.23**	**-.06**
									(.91)	(1.0)	(.89)	(.80)	(.73)	(.53)	(.86)
Exper									**1.00**	**-0.14**	**0.19**	**-0.17**	**-0.01**	**-.28**	**-.61**
										(.77)	(.63)	(.66)	(.98)	(.45)	(.05)
GEFT										**1.00**	**0.07**	**-0.50**	**-0.48**	**0.01**	**-.70**
											(.88)	(.25)	(.28)	(1.00)	(.08)
Loc											**1.00**	**0.31**	**0.35**	**-.58**	**0.01**
												(.42)	(.36)	(.09)	(.99)
Risk1												**1.00**	**0.90**	**-.33**	**-0.57**
													(.01)	(.37)	(.07)
Risk2													**1.00**	**-.45**	**-0.64**
														(.21)	(.05)

1.9.8 Appendix H - Factor analysis results (All subjects)

Measures	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Unpaced time	0.80				
Unpaced hits	0.69				
Paced time	0.71				
Paced hits	0.91				
Unpaced nrwc	0.66				
Paced nrwc	0.92				
Risk test 1		0.93			
Risk test 2		0.93			
Unpaced false alarms			0.77		
Paced false alarms			0.86		

Age				0.75	
Locus of Control				0.82	
Experience					-0.61
GEFT test					0.91
Percentage variance	41	27	22	20	17

1.9.9 Appendix I - Factor analysis results (Trained subjects)

Measures	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Risk test 1	-0.95			
Risk test 2	-0.96			
Paced hits	0.88			
Unpaced nrwc	0.80			
Paced nrwc	0.93			
GEFT test		-0.60		
Paced time		0.89		
Paced false alarms		0.92		
Experience			0.97	
Unpaced hits			-0.73	
Age				0.85
Locus of Control				0.75
Percentage variance	56	25	24	22

1.9.10 Appendix J - Factor analysis results (Untrained subjects)

Measures	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Unpaced time	0.70				
Paced time	0.95				
Paced hits	0.98				
Paced nrwc	0.95				
Risk test 1		0.94			
Risk test 2		0.94			
Unpaced false alarms		-0.91			

Unpaced hits			0.71		
Paced false alarms			-0.98		
Unpaced nrwc			0.86		
Age				0.80	
Experience				0.96	
Locus of Control					0.77
GEFT test					0.87
Percentage variance	39	34	27	22	16

1.9.11 Appendix K - Factor analysis results for demographic and pretest measures only (All subjects)

Measures	**Factor 1**	**Factor 2**	**Factor 3**
Risk test 1	0.95		
Risk test 2	0.96		
Age		0.88	
Experience		0.89	
Locus of Control			0.77
GEFT test			0.76
Percentage variance	21	18	13