USE OF COMPUTER BASED TRAINING TO IMPROVE AIRCRAFT INSPECTION PERFORMANCE

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1.1 EXECUTIVE SUMMARY

The Automated System of Self-Instruction for Specialized Training (ASSIST) is a computer-based training system for aircraft inspection. The product of this research and development is the software. ASSIST is published as two CD-ROMs and is available through the FAA website. This report describes the development process and the functionality of the software system.

1.2 INTRODUCTION

The Chapter is divided into four major sections. The first section provides the background information on the development of the Automated System of Self-Instruction for Specialized Training (ASSIST)—a computer based training tool for aircraft inspection. The section describes how previous years research efforts guided the development of the ASSIST program. The second section provides a detailed description of the ASSIST program. The third section introduces the reader to the evaluation effort and outlines the methodology used to evaluate this system. Sections on performance and usability analysis describe the results of the evaluation effort. The fourth section outlines the role of training in inspection and individual differences in inspection performance. This is followed by the methodology used to conduct the individual differences study and its detailed results. The research was jointly pursued with two industry partners – Delta Air Lines, Atlanta, GA and Lockheed Martin Aircraft Center, Greenville, SC to ensure that it was relevant and addressed the needs of the aviation community.

1.3 BACKGROUND

The aircraft and inspection/maintenance system is a complex one with many interrelated human and machine components.[8,12] The linchpin of this system, however, is the human. Recognizing this, the Federal Aviation Administration (FAA), under the auspices of the National Plan for Civil Aviation Human Factors, has pursued human factors research. In the maintenance area this research had focused on the aviation maintenance technician (AMT). Since it is difficult to eliminate errors altogether, continuing emphasis must be placed on developing interventions to make inspection and maintenance more reliable and/or more error tolerant. Inspection is affected by a variety of entities. These entities include large international carriers, regional and commuter airlines, repair and maintenance facilities, as well as the fixed-based operators associated with general aviation. An effective inspection is seen as a necessary prerequisite to public safety, so both inspection and maintenance procedures are regulated by the U.S. Federal Government via the FAA. Investigators conducting this study found that, while adherence to inspection procedures and protocols is relatively easy to monitor, tracking the efficacy of these procedures is not.

1.3.1 The Aircraft Maintenance Process

The maintenance process begins when a team that includes representatives from the FAA, aircraft manufacturers, and start-up operators schedule the maintenance for a particular aircraft. This initial process is called the Maintenance Review Board (MRB). These schedules may be, and often are, later modified by individual carriers to suit their own scheduling requirements. These maintenance schedules are comprised of a variety of checks that must be conducted at various intervals. Such checks or inspections include flight line checks, overnight checks, and four different inspections of increasing thoroughness, the A, B, and C checks and the most thorough and most time-consuming, D check. In each of these inspections, the inspector checks both the routine and non-routine maintenance of the aircraft. If a defect is discovered during one of these inspections, the necessary repairs are scheduled. Following these inspections, maintenance is scheduled to 1) repair known problems, 2) replace items because the prescribed amount of air time, number of cycles, or calendar time has elapsed, 3) repair previously documented defects (e.g. reports logged by pilot and crew, line inspection, or items deferred from previous maintenance), and 4) perform the scheduled repairs (those scheduled by MRB).

In the context of an aging fleet, inspection takes an increasingly vital role. Scheduled repairs to an older fleet account for only 30% of all maintenance compared with the 60-80% in a newer fleet. This difference can be attributed to the increase in the number of age-related defects.[8,12] In such an environment the importance of inspection cannot be overemphasized. It is critical that these visual inspections be performed effectively, efficiently, and consistently over time. Moreover, 90% of all inspection in aircraft maintenance is visual in nature and is conducted by inspectors, thus inspector reliability is fundamental to an effective inspection. As in any system that is highly dependent on human performance, efforts made to reduce human errors by identifying human/system mismatches can have an impact on the overall effectiveness and the efficiency of the system. Given the backdrop of the inspection system, the objective of this particular study was to use training as an intervention strategy to reduce inspection errors.

1.3.2 Using Human Factors to Improve Aircraft Inspection Performance

An analysis of the inspector's role in inspection has pointed to a number of issues (e.g. inspector-oriented issues, environmental design issues, workplace design issues, etc.).[8,15] These issues have been continually addressed by the FAA.[13] Research conducted under this program has identified several ergonomic changes to both the system and to the inspector. System changes have included improved work control cards and crew resource management interventions.[11,17] Inspector-oriented interventions are 1) selection and 2) training. The current research concentrates on training and specifically the use of advanced technology for training as an improvement strategy.

1.3.3 The Need for Computer-based Inspection Training

Aircraft inspection and maintenance are an essential part of a safe, reliable air transportation system. Training has been identified as the primary intervention strategy in improving inspection performance. If training is to be successful, it is clear that we need to provide inspectors with training tools to help enhance their inspection skills.

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.[16,18] For example, in OJT feedback may be infrequent, unmethodical, and/or delayed. Moreover, in certain instances feedback is economically prohibitive or infeasible due to the nature of the task. Thus, because the benefits of feedback in training have been well documented,[20] and for other reasons as well, alternatives to OJT are sought. 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 visual inspection skills has been well documented in the manufacturing industry. Training has been shown to improve the performance of both novice and experienced.[20,21] 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.[20] Using realistic photographic images as a training aid in controlled practice with feedback has also been shown to be superior to only OJT.[22]

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. Computer-based training offers several advantages relative to traditional training approaches; for example, computer-based training is more efficient, facilitates standardization, and supports distance learning. With computer technology becoming cheaper, the future will bring an increased application of advanced technology in training. Over the past decade, instructional technologists have offered numerous technology based training devices with the promise of improved efficiency and effectiveness. These training devices are being applied to a variety of technical training applications. 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.28 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.22,33 Similarly, Drury and Chi studied human performance using a high fidelity computer simulation of a printed circuit board inspection.29 Another domain, which has seen the application of advanced technology, is that of inspection of x-rays for medical practice. In summary, most of the work in the application of advanced technology to inspection training has focused on developing low fidelity simulators for running controlled studies in a laboratory environment. Thus, research efforts need to be extended in order to take full advantage of today's computer technology. Moreover, advanced technology has found limited application for inspection training in the aircraft maintenance environment. Presently, most of the applications of computer technology to training have been restricted to the defense/aviation industry for complex diagnostic tasks. The message is clear: we need more examples of the application of advanced technology to training for inspection tasks that draw upon the principles of training which we already know will work. In this vein, this report describes a university and industry collaborative research effort to develop an off-line computer based inspection-training system for aircraft inspectors. The specific objective of this research was to develop an inspection training system that would help improve the visual search and decision making skills of aircraft inspectors. The computer based inspection training program entitled "Automated System of Self Instruction for Specialized Training" (ASSIST) was developed in cooperation with Lockheed Martin Aircraft Center and Delta Air Lines (Figure 1.1). A brief description of the system follows.

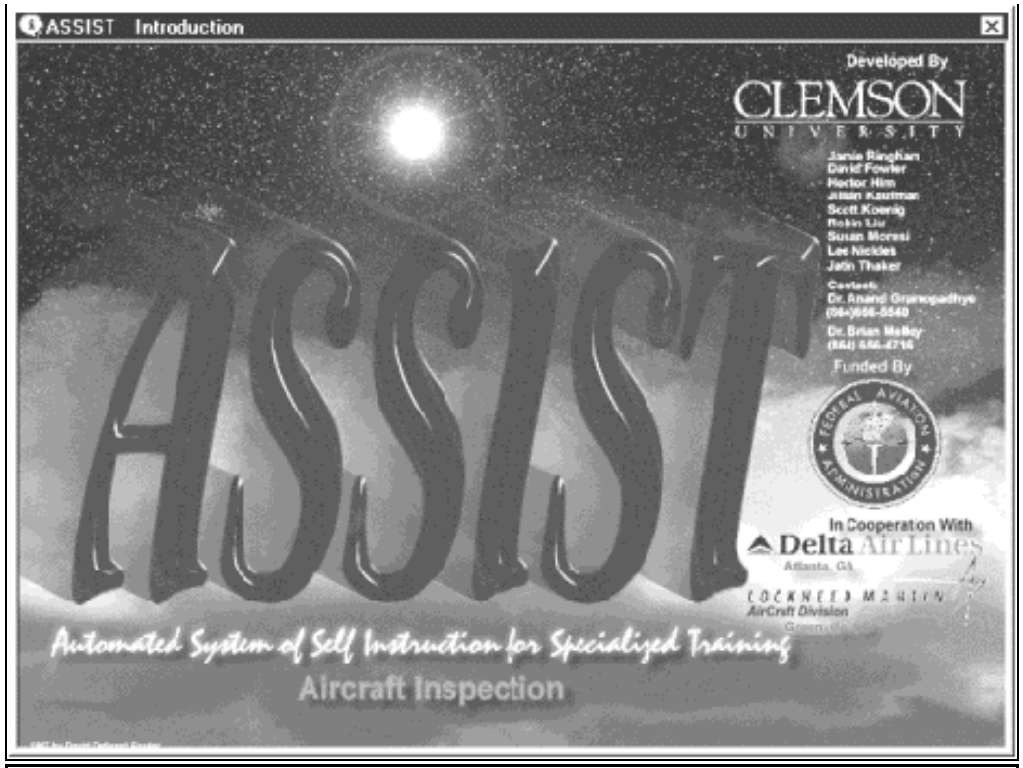

Figure 1.1 ASSIST Title Screen

1.4 DEVELOPMENT OF THE ASSIST PROGRAM - YEAR 1

The development of the ASSIST program followed the classic training program development methodology (Figure 1.2). It began with a thorough analysis of the requirements and needs (goals) of the training program. The task analysis, along with the trainee analysis, were used to compare the knowledge and skills required by the task with those possessed by the inspector to determine gaps which need to be addressed by the training program. Patrick has identified the training content, training methods and trainee as the important constituents of the training program.41 Drury includes the training delivery system as another component of the training program.42 Although a considerable amount has been written about designing training systems18,41 very little focuses directly on enhancement of visual inspection skills. Embrey states that for any training program to be effective, it should address the following three issues: attitude of the trainee at work, knowledge required to perform the job, and the specific skills required to perform the task.50 Specific training methods incorporated in development of the ASSIST program are described below.21,52

1. Pre-training: Pre-training provides the trainee with information concerning the objectives and scope of the training program. During pre-training, pretests can be used to measure (a) the level at which trainees are entering the program and (b) cognitive or perceptual abilities that can later be 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 proposes that training should be imparted in a top-down manner wherein 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 material.

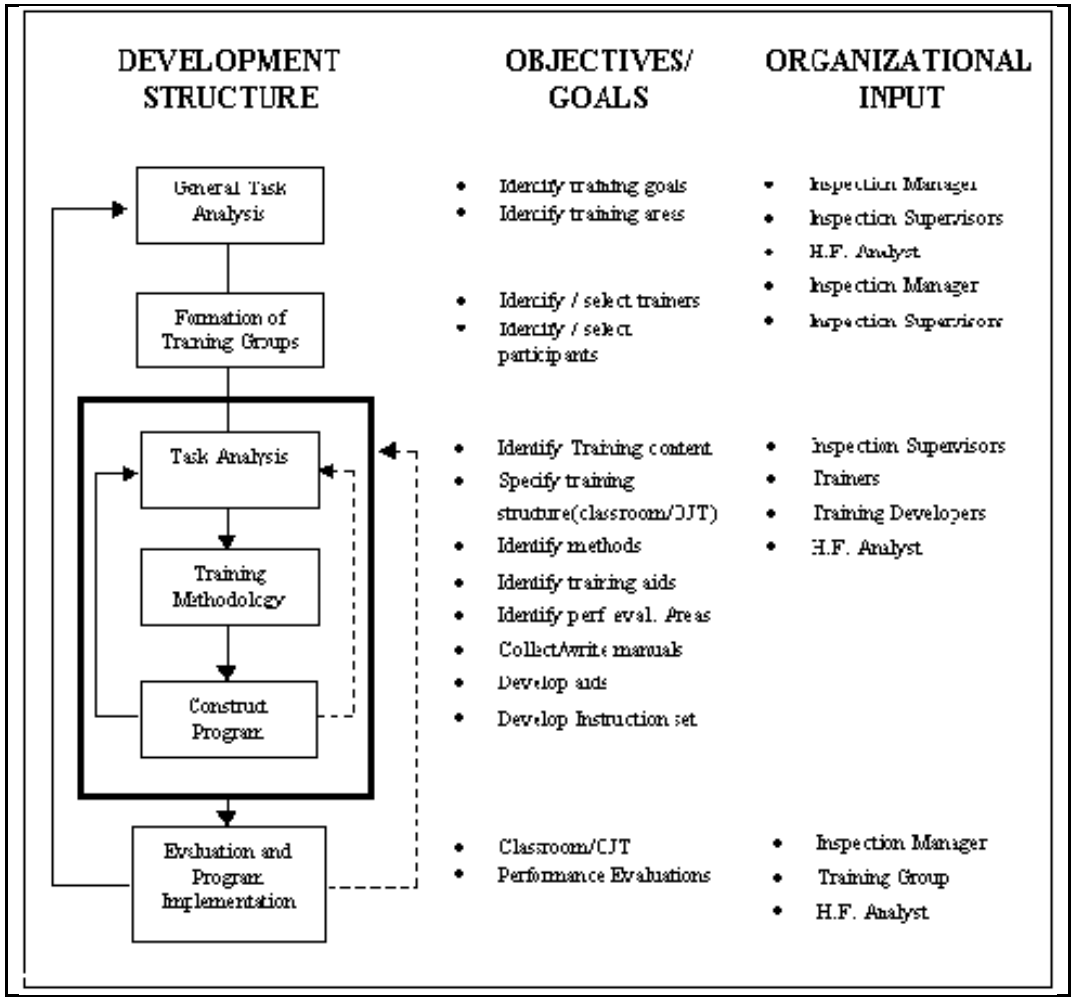

Figure 1.2 Model for Training Program Development in Commercial Aviation

2. Feedback: A trainee needs rapid, accurate feedback in order to know whether a defect was classified correctly or a search pattern was effective. Some attempt of performing the task followed by feedback with knowledge of results provides a universal method of improving task performance.[20] This applies to learning facts, concepts, procedures, problem solving, cognitive strategies and motor skills. The training program should start with immediate feedback, which should be gradually delayed until the "operational level" is reached. Providing regular feedback beyond the training session will help to keep the inspector calibrated. Gramopadhye, Drury and Prabhu classify feedback as performance and process feedback.[52] Performance feedback on 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, such as areas missed. Another type of feedback called "cognitive feedback" has emerged from the area of social judgement theory. Cognitive feedback is the information provided to the trainee of some measure of the output of his or her cognitive processes. For inspection tasks, process feedback is the same as cognitive feedback.

3. Active Training: In order to keep the trainee involved and to aid in internalizing the material, an active approach is preferred. In active training, the trainee makes an active response after each piece of new material is presented, e.g., identifying a fault type. Czaja and Drury used an active training approach and demonstrated its effectiveness for a complex inspection task.[28]

4. Progressive Parts Training: Salvendy and Seymour successfully applied progressive part training methodology to training industrial skills.53 In the progressive parts methodology, parts of the job are taught to criterion and then successively larger sequences of parts are taught. For example, if a task consists of four elements E1, E2, E3 and E4, then the following would follow:

- Train E1, E2, E3 and E4 separately to criterion
- Train E1 and E2; E3 and E4 to criterion
- Train E1, E2 and E3 to criterion and E2, E3 and E4 to criterion
- Train the entire task to criterion

This method allows the trainee to understand each element separately as well as the links between the various elements thus representing a higher level of skill. On the other hand, reviews of literature reveal that part task training is not always superior. The choice of whether training should be part or whole task training depends on "cognitive resources" imposed by task elements and the "level of interaction" between individual task elements.18 Thus, there could be situations in which one type of task training is more appropriate than the other. Naylor and Briggs have postulated that for tasks of relatively high organization or complexity, whole task training should be more efficient than part task training methods.56

1. Schema Training: The trainee must be able to generalize the training to new experiences and situations. For example, it is impossible to train the inspector on every site and extent of corrosion in an airframe so that the inspector is able to detect and classify corrosion wherever it occurs. Thus, the inspector will need to develop a "schema" which will allow a correct response to be made in novel situations. The key to the development of schema is to expose the trainee to controlled variability in training.

2. Feedforward Training: It is often necessary to cue the trainee as to what should be perceived. When a novice inspector tries to find defects in an airframe, the indications may not be obvious. The trainee must know what to look for and where to look. Specific techniques within cueing include match-to-sample and delayed match-to-sample. Feedforward information can take different forms such as physical guidance, demonstrations, and verbal guidance. Feedforward should provide the trainee with clear and unambiguous information, which can be translated into improved performance.

1.4.1 Task Analysis

The development of the ASSIST Program followed the classic training program development methodology. It began with a thorough analysis of the requirements and the needs or goals of the training program. The next step was to establish the training group and identify the trainers and participants who would be involved. Next, a detailed task analysis of the job was conducted to determine the knowledge, skills, and abilities necessary for the job in order to specify the behavioral objectives of the training program. These objectives became the basis for evaluating the training program. The next step was to define the criteria against which the inspectors would be trained and their performance measured to meet the quality goals. The abilities of the incoming trainees were compared to the requirements imposed by the task to determine the gaps and, hence, define the contents of a training program that would help close these gaps and meet the defined criteria. At this stage, the appropriate training delivery system, i.e., the instructional technique such as Tutoring, OJT or Computer-Aided Instruction had to be chosen. Once the training system was designed and developed, was evaluated to determine it met the ultimate goals. The designer choose criteria to be used for evaluation, identified a method and protocol for collecting evaluation data, and analyzed the data to draw conclusions about the effectiveness of the training program.

Following this step, a detailed taxonomy of errors was developed from the failure modes of each task in aircraft inspection (Table 1.1). This taxonomy, based on the failure modes and effects analysis (FMEA) approach, was developed because of the realization that a pro-active approach to error control is necessary for the identification of potential errors. Thus, the taxonomy was aimed at the phenotypes of error, that is, the observed errors.[36] Using the generic task description of the inspection system, the goal or outcome of each task was postulated (Table 1.1). These outcomes then formed the basis for identifying the failure modes of each task, and including the operational error data gained from the observations of inspectors and from discussions with various aircraft maintenance personnel, collected over a period of two years. Later the frequency of error was estimated, after which the consequences of the errors on system performance were deduced. The error taxonomy provided the analysts with a systematic framework to suggest appropriate content for the ASSIST training program. The ASSIST training program specifically focused on the search and decision- making components of the inspection task. These have also been shown to be determinants of inspection performance and the two most critical tasks in aircraft inspection.[9,10,21,62]

Table 1.1 Task and Error Taxonomy for Visual Inspection (e.g. decision component)

TASK	ERRORS	OUTCOME
DECISION		
4.1 Interpret indication.	Classify as wrong fault type.	All indications located are correctly classified, correctly labeled as fault or no fault, and actions correctly planned for each indication.
4.2 Access comparison standard.	Choose wrong comparison standards. Comparison standard not available. Comparison standard not correct. Comparison incomplete. Does not use comparison standard.	
4.3 Decide on if fault.	Type I error, false alarm. Type II error, missed fault.	
4.4 Decide on action.	Choose wrong action. Second opinion if not needed. No second opinion if needed. Call for buy-back when not required. Fail to call for required buy-back.	
4.5 Remember decision/action.	Forget decision/action. Fail to record decision/action.	

1.4.2 Structure of ASSIST

The overall structure of the ASSIST program is divided into three modules: General Module, Simulation, and Instructor's Module (Figure 1.3). The ASSIST training program is divided into the following subtasks: decision-making task, the training content of ASSIST that addresses this task, the method by which the content is presented, the module in which the content is presented, and the error addressed from task analysis, which is identified from the error taxonomy (Table 1.2).

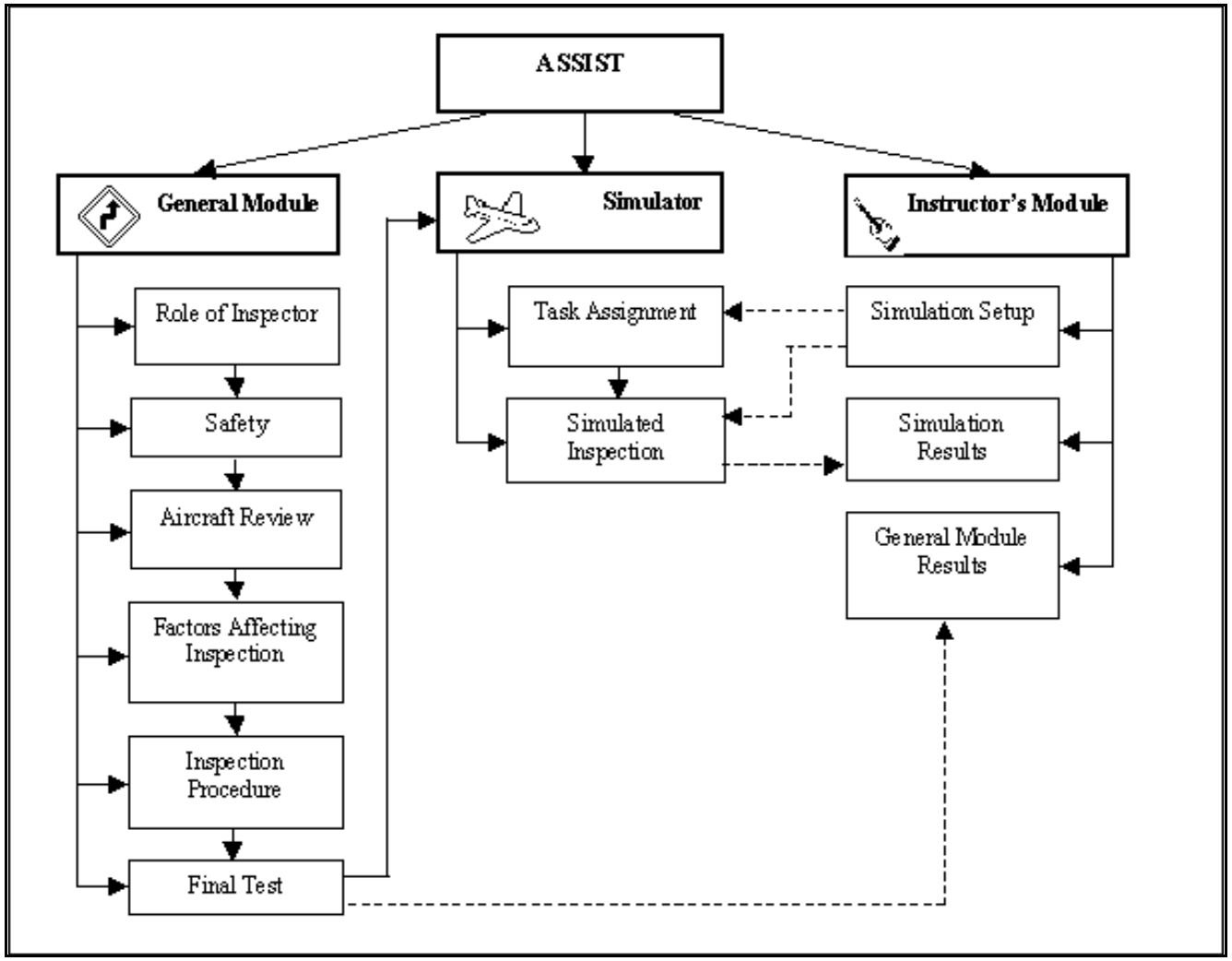

Figure 1.3 Components of the ASSIST Aircraft Inspector Training Program

Table 1.2 ASSIST Program: Showing Errors Addressed for the Decision Task
ASSIST TRAINING PROGRAM

TASK	CONTENT OF ASSIST	METHOD	PROGRAM MODULE	ERROR ADDRESSED FROM TASK ANALYSIS
DECISION				
4.1 Interpret indication	**Present examples of defects and identify in simulator**	**Active and Feedback**	**General Module, Simulator**	• **Classify as wrong fault type**
4.2 Access comparison standard	**Use simulator to access information on defects, locations, and action**	**Active and Feedback**	**General Module, Simulator**	• **Choose wrong comparison standards** • Comparison standard not available • Comparison standard not correct • Comparison incomplete • Does not use comparison standard
4.3 Decide on if it's a fault	Use simulator with real defects and feedback	Progressive parts, Active, and Feedback	Simulator	• Type I error, false alarm • Type II error, missed fault
4.4 Decide on action	Complete NR card with Feedback in correct way to fill out card	Active and Feedback	Simulator	• Choose wrong action
4.5 Remember decision/ action	Enter multiple defects and complete NR card with feedback	Active and Feedback	Simulator	• Forget decision/action • Fail to record decision/action

System Structure

ASSIST consists of three major modules: (1) the General Inspection Module, (2) the Inspection Simulation Training Module, and (3) the Instructor's Utilities Module. All system users interact through a user-friendly interface, which capitalizes on graphical user interface technologies and human factors research on information presentation (e.g., color, formatting, layout, etc.), ease of use, and information utilization.

System Specification

The ASSIST program needs at least a Pentium 100, with a 166 Pentium or faster suggested. A minimum hard drive space of 220 MB is required with at least 24 MB of memory, with 64 MB being the suggested memory. It runs on a Windows 95, or higher, operating system. The program also requires a SoundBlaster compatible sound card and 8X CD-ROM. The display requirements are 640 X 480 resolution with a high color (16 bit) palette. The system's input devices are a keyboard and a mouse.

General Module

The objective of the general module, which presents information through text, pictures, audio, and video, is to provide the inspectors with an overview of the following sub-modules: (1) role of the inspector, (2) safety, (3) aircraft review, (4) factors affecting inspection, and (5) inspection procedure. The module is based on presenting information through various media of text, pictures, audio, and video. At the end of each sub-module is a three-question quiz to reinforce the information learned. Development of the General Module was an iterative process involving regular feedback from industry partners on the content of each sub-module. Below are detailed descriptions of each sub-module.

Introduction

The Introduction sub-module allows the inspector to log in to the program (Figure 1.4). If this is the first time the inspector has used ASSIST, the inspector's record is created in the student database and a brief introduction to the program is shown. This introduction emphasizes the importance of the inspector's role in aircraft maintenance and the need for good training. If the inspector has used the ASSIST program before, the navigation sub-module is displayed.

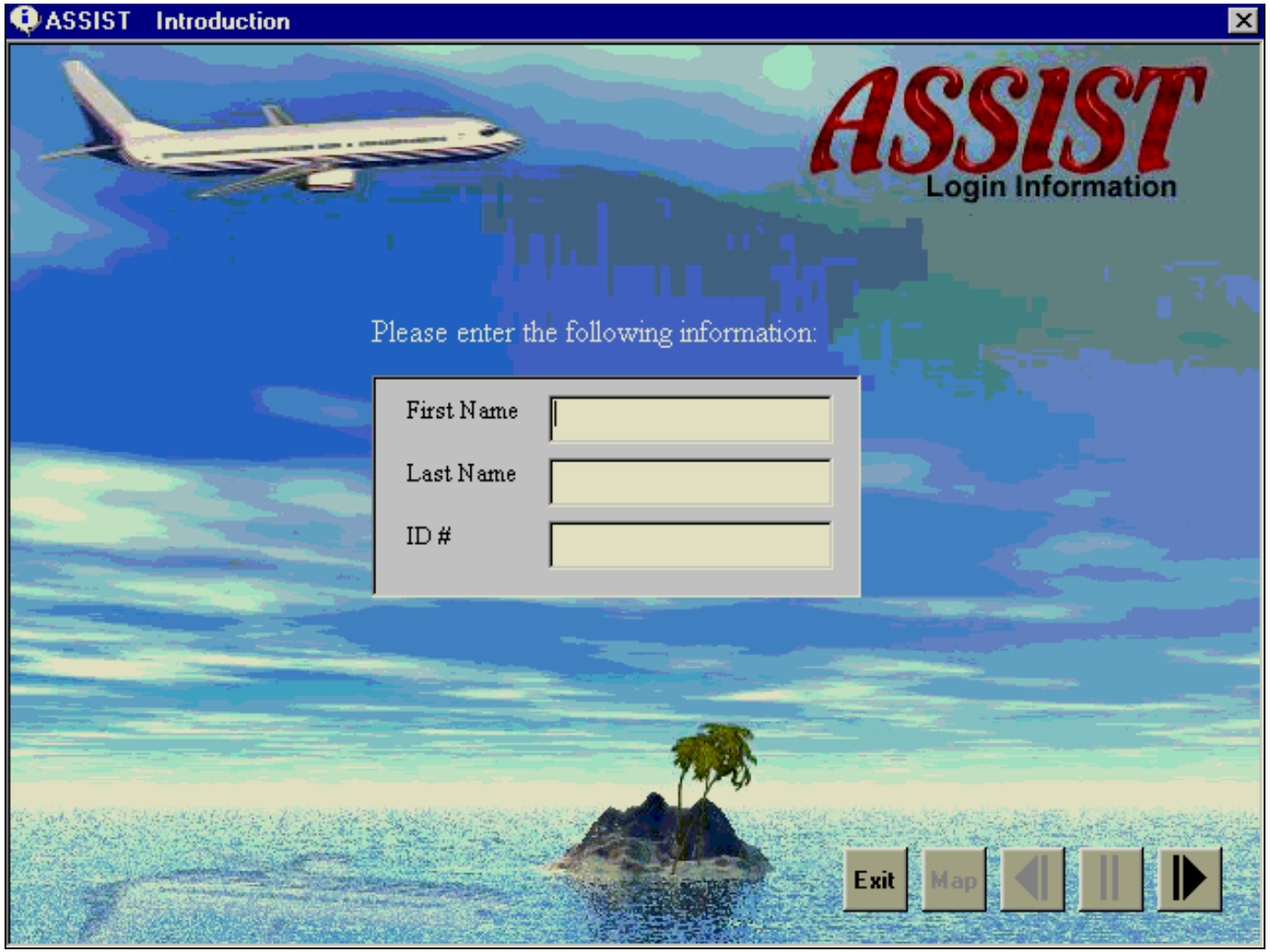

Figure 1.4 Login Screen for the ASSIST Training Program

Navigation

The Navigation sub-module allows the inspector to move between the sub-modules of the ASSIST program. It displays the five content sub-modules on the left of the screen and their parts in the center (Figure 1.5).

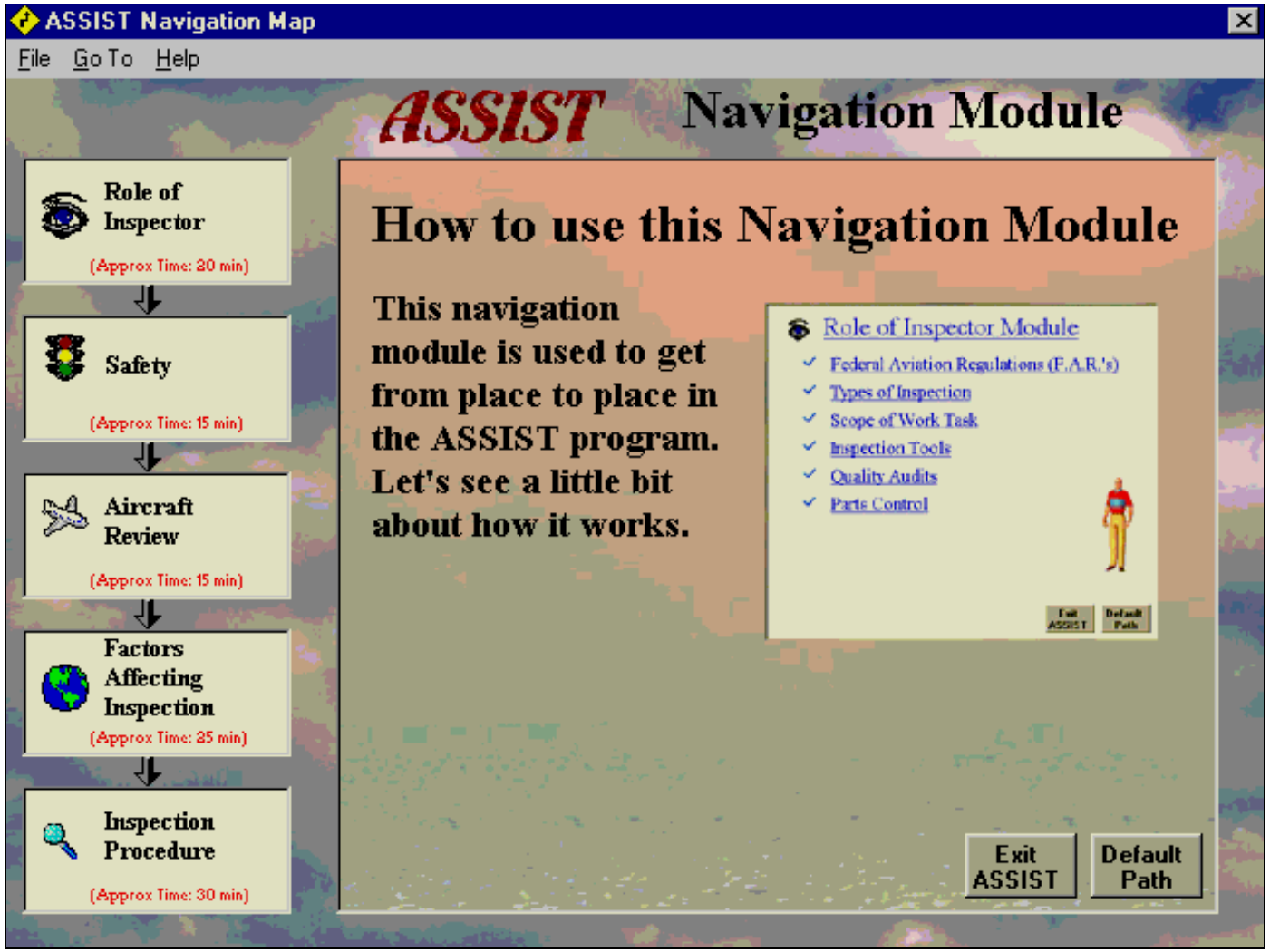

Figure 1.5 ASSIST Navigation Map for Moving within the General Module

Role of Inspector

The Role of Inspector sub-module covers topics dealing with the role and scope of the inspector's job including information on the definitions of an inspector according to the Federal Aviation Regulations (FAR), the scope of the inspector's work, the and inspection tools--flashlight, magnifying glass, scraping knife, and mirror (Figure 1.6).

Figure 1.6 Role of Inspector Sub-module Covering Inspection Tools

Safety

The Safety sub-module covers the two major areas of safety related to the inspector's general environment: safety in the maintenance hangar and safety issues specific to the inspector. Topics include hearing safety, accessing the aircraft, and foreign object damage (Figure 1.7).

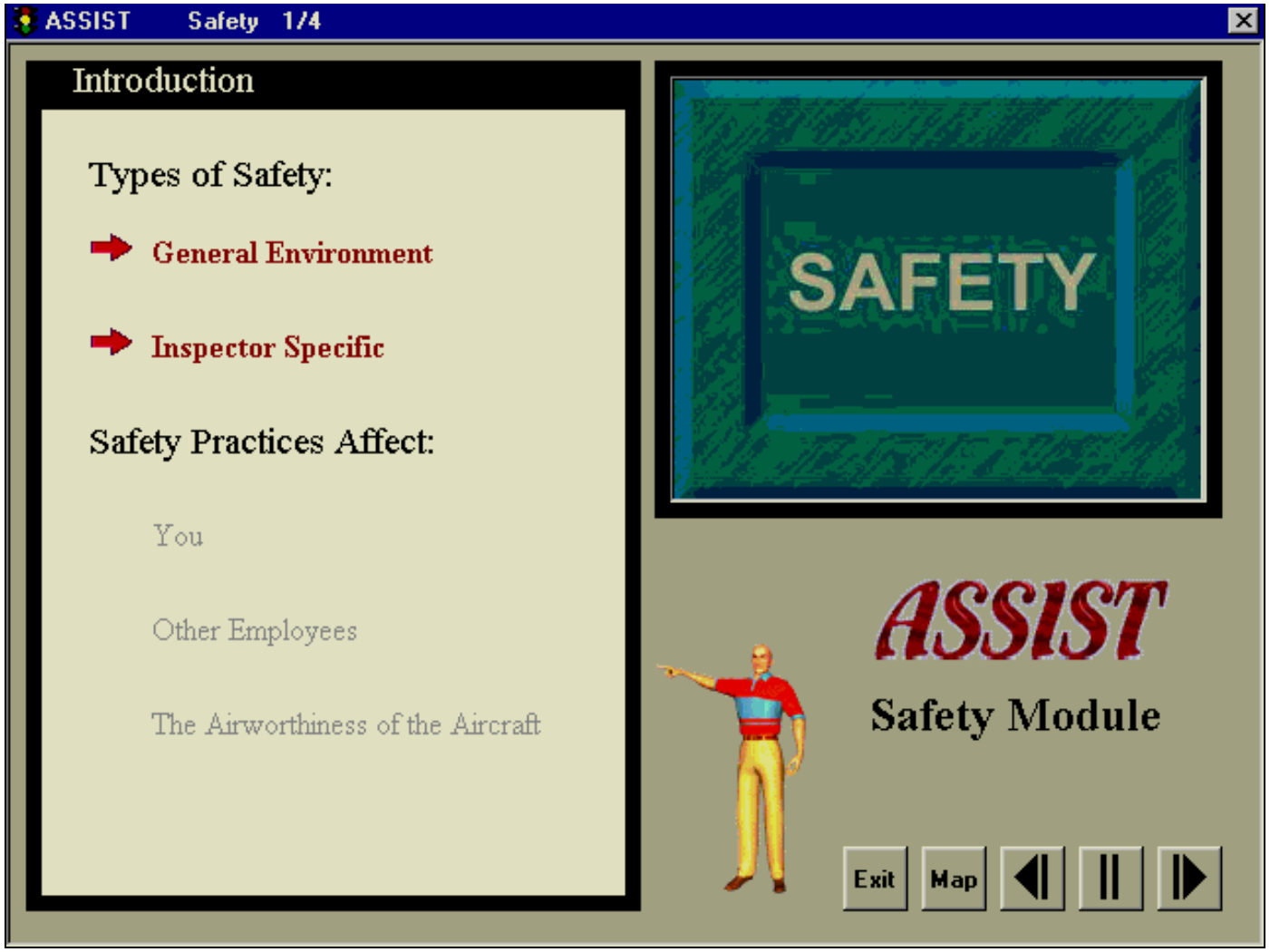

Figure 1.7 Introduction to the Safety Sub-module

Aircraft Review

The inspector goes through a review of various aircraft that are in production and in service today in the Aircraft Review sub-module. A general discussion of defects and their potential frequency in the aircraft is followed by a review of the major commercial aircraft from Airbus, Boeing, Lockheed-Martin, and McDonnell Douglas (Figure 1.8).

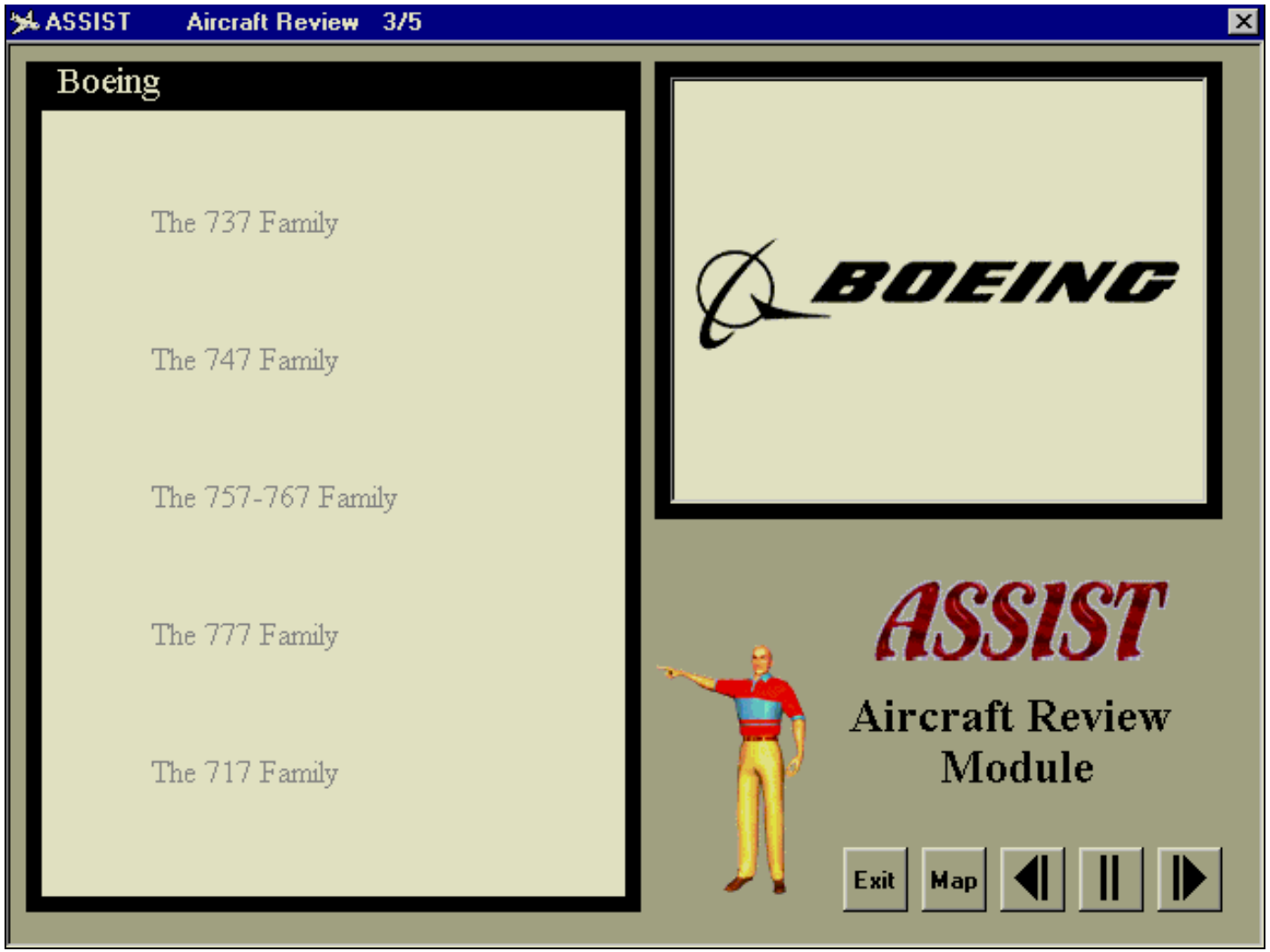

Figure 1.8 Aircraft Review Sub-module Covering Boeing Aircraft

Factors Affecting Inspection

The Factors Affecting Inspection sub-module covers the various factors that can affect the inspector, including environmental, subject, process, and information factors (Figure 1.9). Detailed information is presented for each.

Figure 1.9 Menu of Factors Affecting Inspection Sub-Module

Inspection Procedure

The Inspection Procedure sub-module covers information pertaining to the inspection task itself, including the levels of inspection, the terminology, the appearance of the defect, and the procedures for inspection (Figure 1.10).

Figure 1.10 The Sample Walkthrough Section of Inspection Procedure

Final Test

After completing all sub-modules, the inspector takes the Final Test at the end of the General Module (Figure 1.11). This test contains 20 multiple choice questions covering all the topics in the General Module. The results are stored in a database, which can be accessed by the instructor for later analysis.

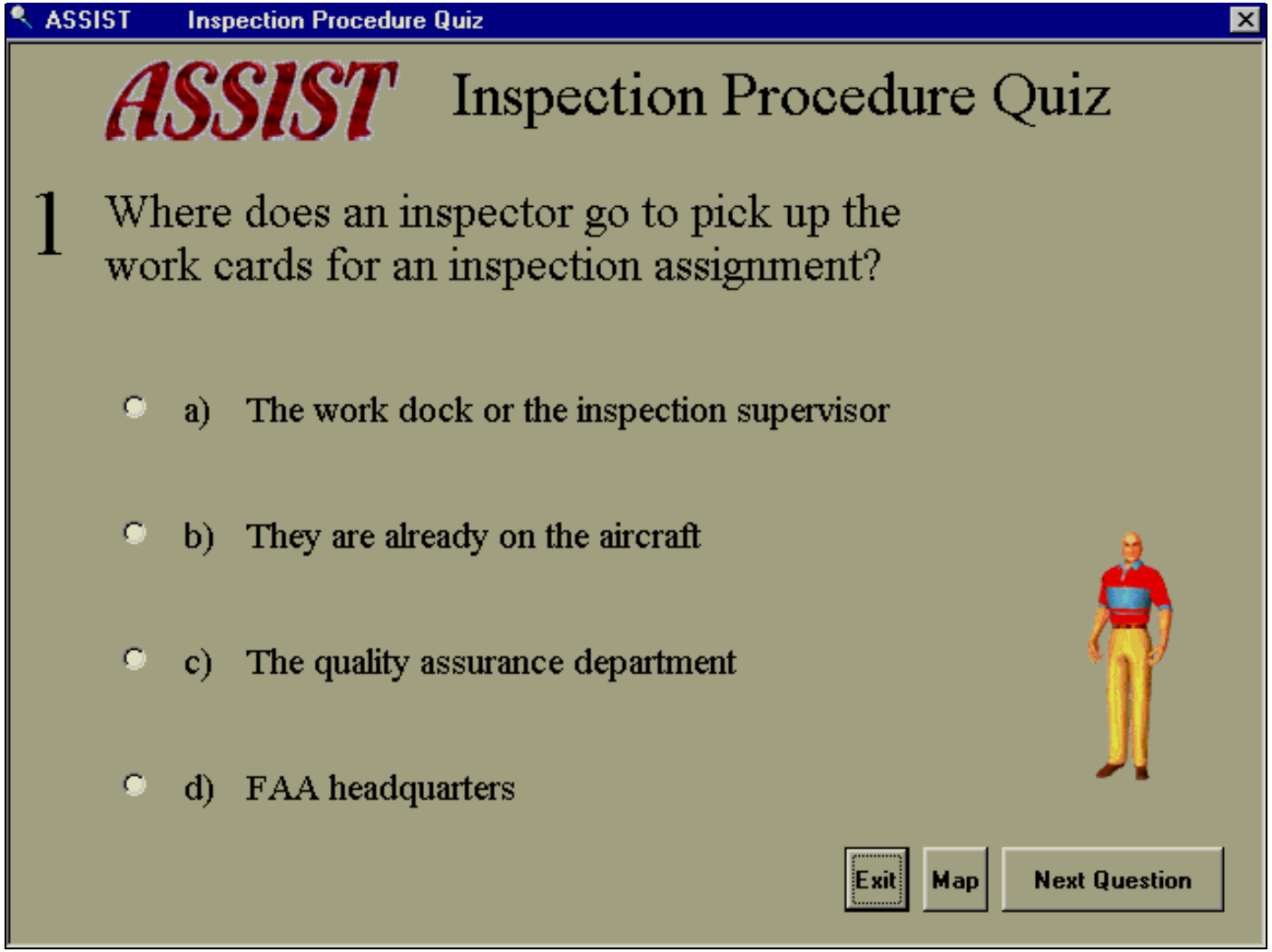

Figure 1.11 Sample Question from the Final Test of the General Module

Inspection Simulation Training Module

This module of the training program provides inspection training on a simulated aircraft inspection task: the Aft-Cargo bin inspection of a Lockheed Martin L-1011. By manipulating the various task complexity factors—the shape of the viewing area, the spatial distribution of faults, the fault probability, the fault mix, the fault conspicuity, the product complexity, the and fault standards--the instructor can simulate different inspection scenarios. The simulation module uses actual photographs of the airframe structure with computer-generated defects.

Introduction

The introduction provides the trainee with an overview of the various facets of the program, the work card for the inspection assignment, and a representation of various faults (Figure 1.12).

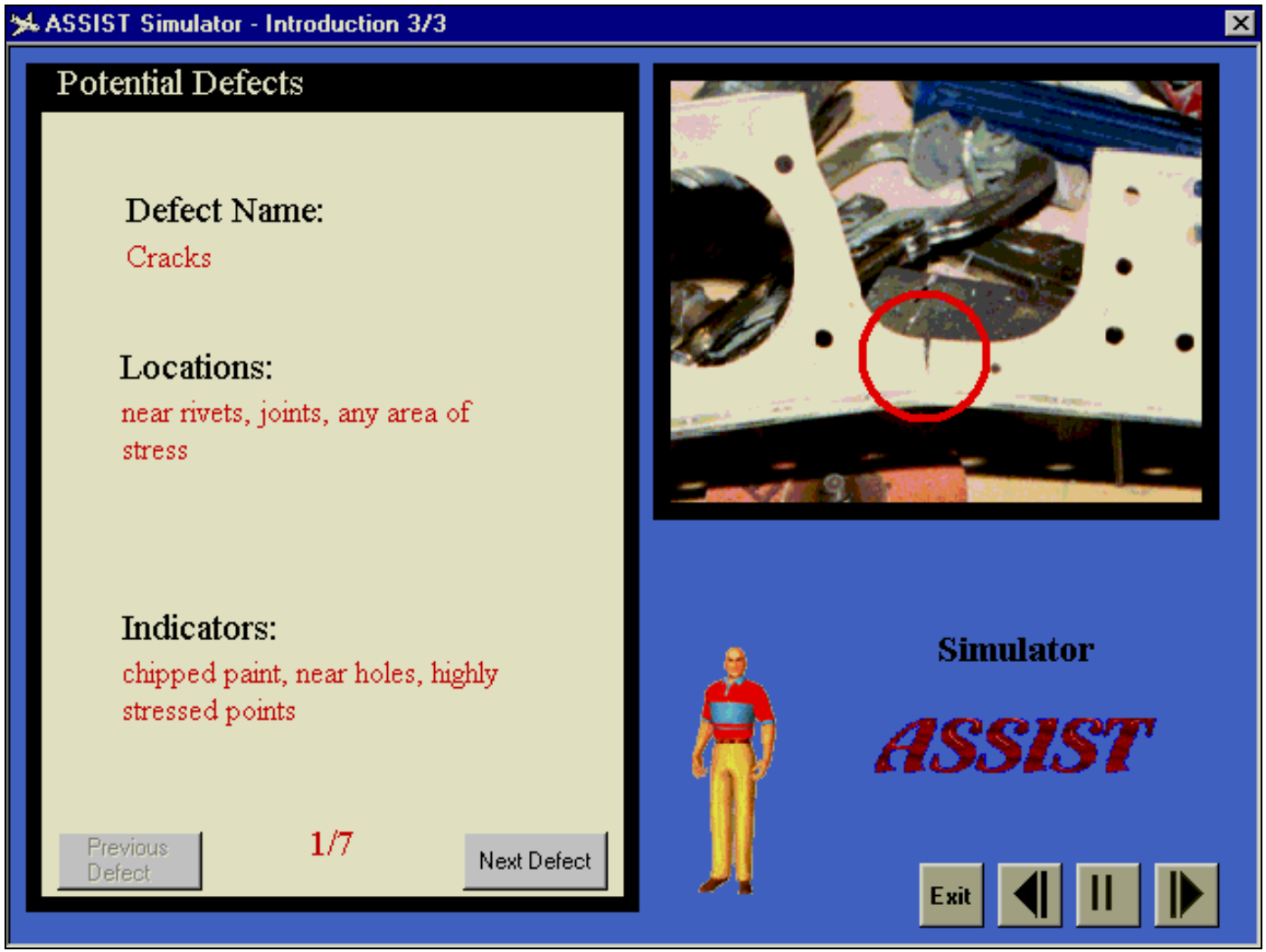

Figure 1.12 Potential Defects that may Occur in the Simulator

Testing

The testing module is designed to operate in two separate modes: with and without feedback, with the non-feedback mode simulating the actual visual inspection task as it would take place on a hangar floor. In either mode, the inspector first locates the defect and then indicates it by clicking on the fault. Subsequently, the inspector classifies the defect by filling out a Non-routine Card. In feedback mode, the inspectors are provided with feedback on their performance on the search and decision-making components of the inspection task. The trainee is also provided with feedback at the end of the performance. The program also features paced and unpaced modes. The paced mode allows the inspection to continue for only a specified period of time, while the unpaced mode allows the inspection task to be unbounded by time. In the simulator, the inspector can use four inspection tools: scraping knife, magnifying glass, mirror, and flashlight (Figure 1.13). These tools appropriately change the inspection image and potentially reveal defects that would not be seen by the unaided eye.

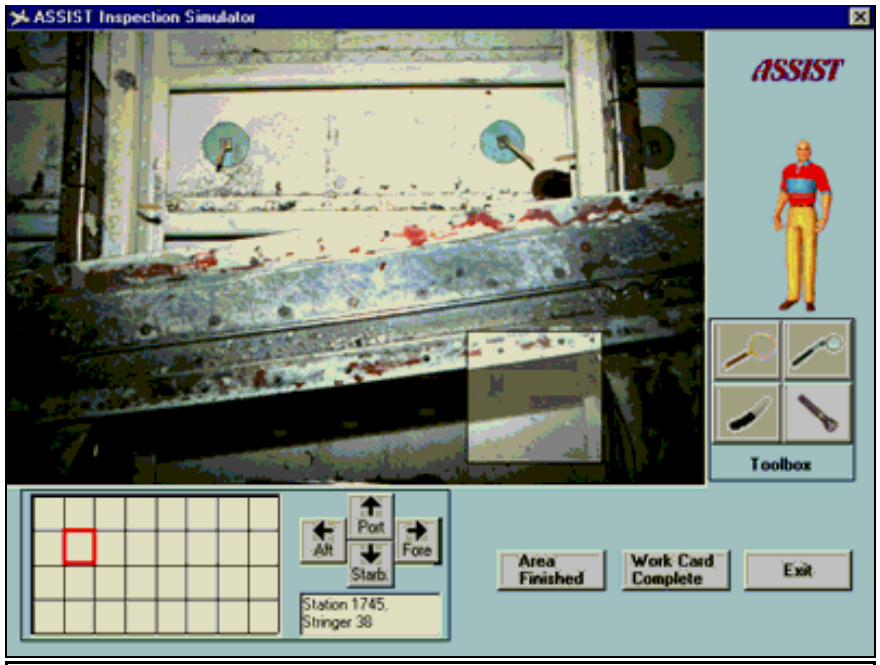

Figure 1.13 Using the Flashlight in the ASSIST Inspection Simulator

The Instructor's Utilities Module

The module is designed as a separate, stand-alone tool that is linked to the other modules of the system. It gives the instructors access to the results of the final test in the general module and the simulator allowing them to review the performance of a trainee who has taken several training and/or testing sessions (Figure 1.14). The module is designed as a separate stand-alone tool that is linked to the other modules of the system. Performance data from the simulator is stored on an individual image basis and summarized over the entire session so that results can be retrieved at either level. The utility allows the instructor to print or save the results to a file, thus providing the instructor with a utility where a specific image along with its associated information can be viewed on the computer screen.

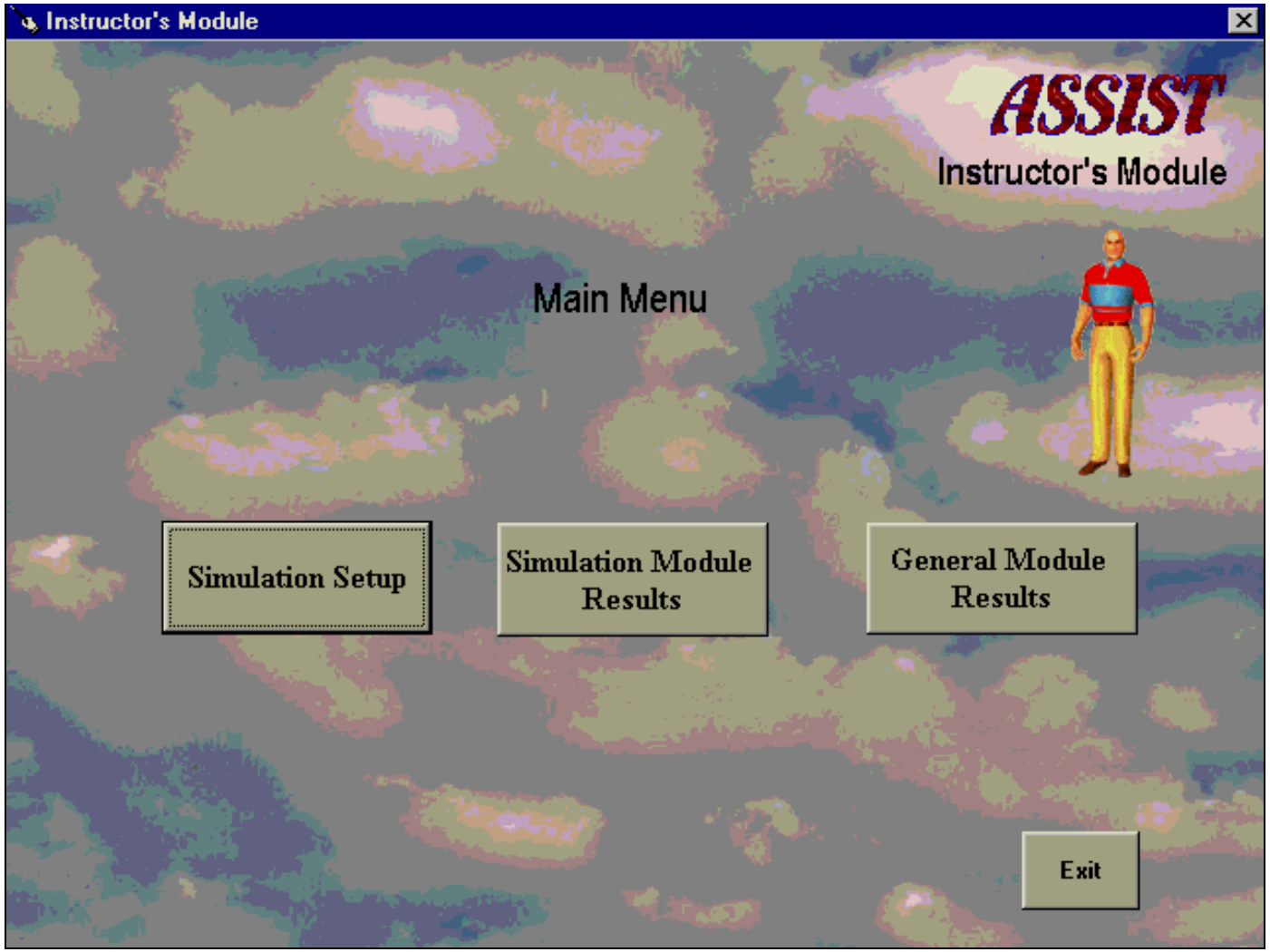

Figure 1.14 Main Menu of the Instructor's Module

In addition, this module has a simulation setup utility, allowing instructor to create different inspection scenarios by manipulating the inspection parameters (Figure 1.15). This utility allows the instructor to change the probability of defects, the defect mix, the complexity of the inspection task, and information provided in the work card, thereby varying the feedforward information provided. In addition, the inspector can chose the feedback (Figure 1.16) or non feedback mode and the pacing of the inspection.

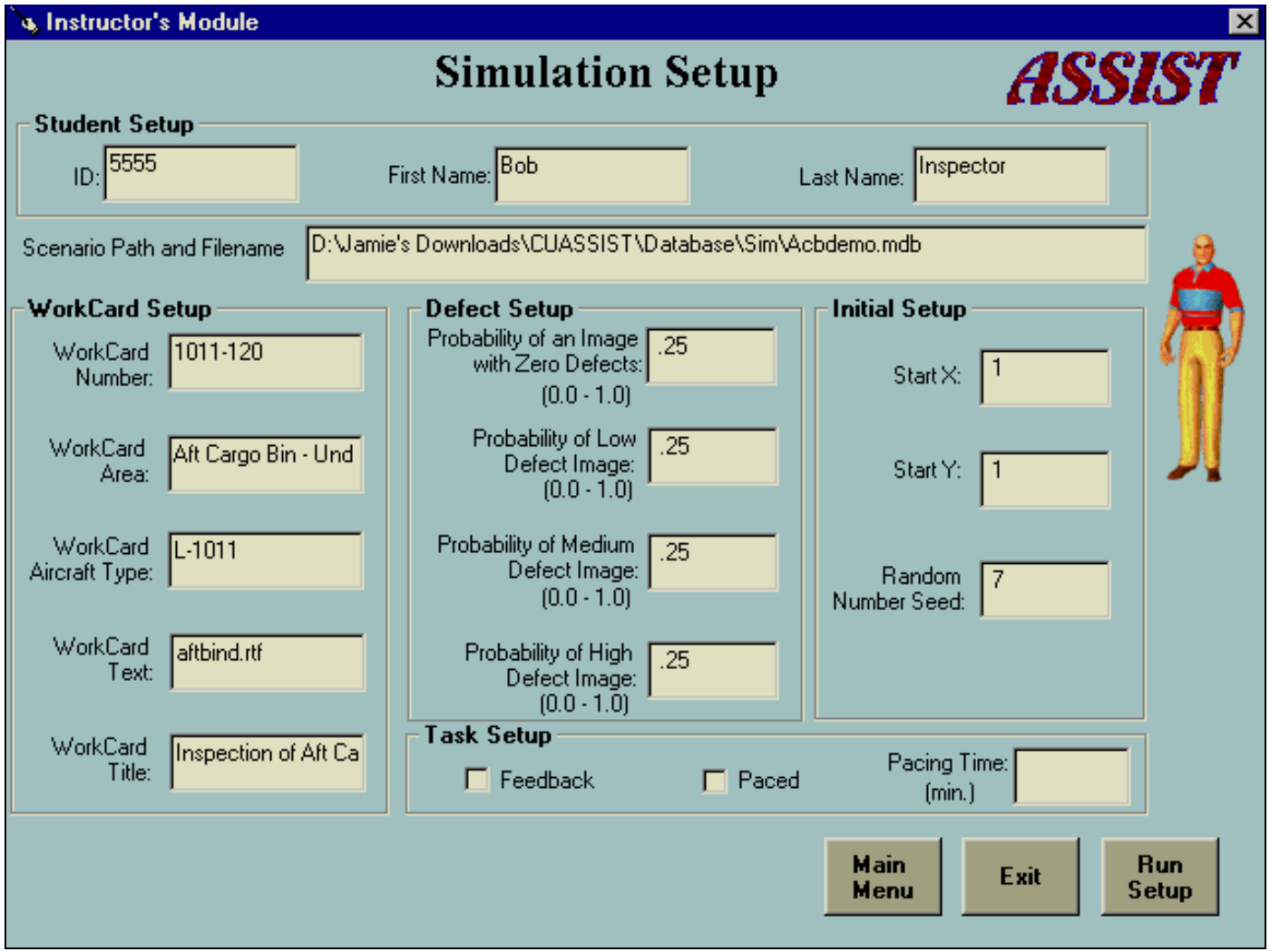

Figure 1.15 Simulator Setup Utility

Figure 1.16 Feedback Information Given by the ASSIST Program

Inspection Training Session

The training program was designed to use the general principles listed earlier in the context of this particular inspection job as derived by the task analysis. A major prerequisite was that it be a progressive part training scheme to enable the inspectors to build their repertoire of knowledge and skills in an orderly manner. A typical training session proceeded as follows:

1. Initial Overview: Initially, the subjects used the introduction module, wherein they were introduced to the navigation map and familiarized with the operational aspects of the computer program.

2. General Module Training: In the general module the subjects were provided with information on the following five topics: the role of the inspector, safety, aircraft review, the factors affecting inspection, and the inspection procedures. Using the navigation map, the subjects either directly went to a particular topic or sub-topic or followed the default path through the topics. At the end of each topic, a brief quiz was administered to review the subject's understanding of the material. The subjects were provided with feedback and correct answers. On completion of the topics in the general module, the subjects took the final test, consisting of questions selected from a database covering material from each topic within the general module.

3. Simulation Module: In the simulation module, subjects were initially introduced to the workings of the simulator. Following this step, the subjects were presented with a work card containing the instructions for the inspection assignment. Next, the subjects were provided with information on defect standards, including images of the defects, descriptions, likely locations for particular defects, and possible indicators. Following this step, the subjects conducted the inspection using representative images of airframe structures wherein they had first search for the defect and later classify it as one necessitating maintenance action or not. The simulator allowed the use of various inspection tools: a mirror, flashlight, scraping knife, and magnifying glass to assist the subject in performing the inspection (Figure 1.13). Following the inspection, subjects completed a non-routine card (Figure 1.17). On completion of the task, subjects were provided with feedback on their overall performance in regard to the subject's search and decision-making performance, for example, the time to complete inspection, the defect detection, and the defect classification performance. The simulator can be operated in various modes (e.g., with or without feedback, paced or unpaced) and it allows the instructor to set various inspection parameters (e.g., the mix of defects, the defect probability and the workcard instructions), thereby facilitating the creation of different inspection scenarios.

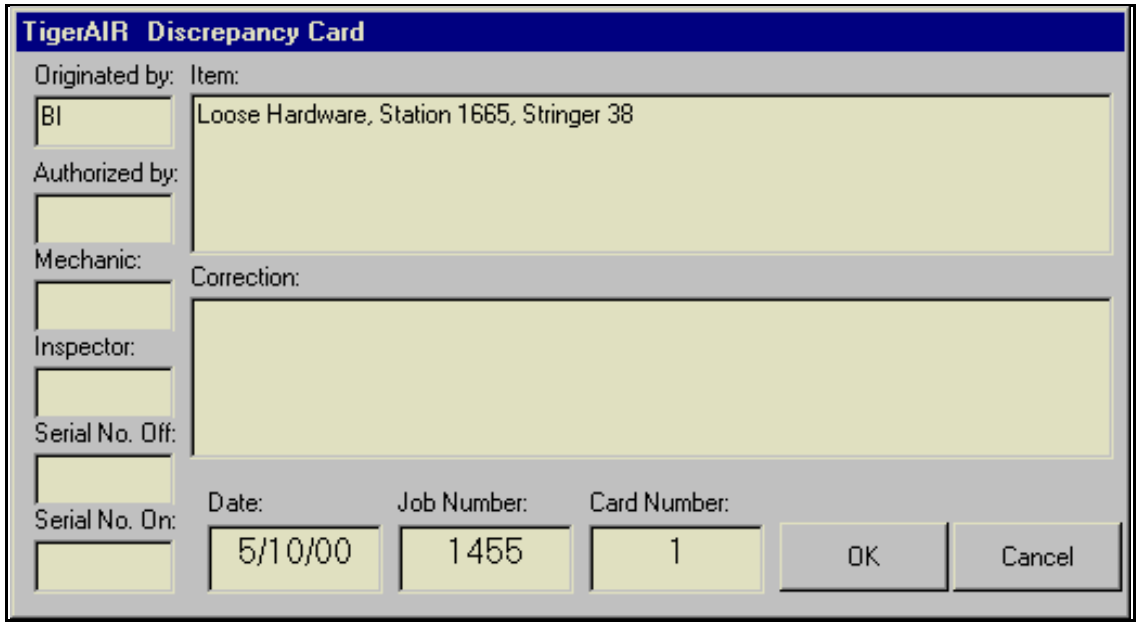

Figure 1.17 Non-routine Card Used to Record an Identified Defect

1.4.3 Conclusions

This section described research in the area of aviation maintenance and inspection pursued at Clemson University. Through the development and systematic application of human factors techniques, the research aimed at improving the effectiveness and efficiency of aircraft visual inspection. The results of the research effort have been made available to the aviation maintenance community as deliverable products in the form of usable CD-ROMs (ASSIST software). The use of these products will lead to improved airworthiness of the U. S. domestic aircraft fleet. Subsequent phase of this research evaluated the utility of ASSIST in an operational setting with aircraft inspectors.

1.5 EVALUATION OF ASSIST - YEAR 2

The development of ASSIST software demonstrates the application and the use of advanced technology for aircraft inspection training. Following the development, a detailed evaluation was conducted to determine the effectiveness of its use as part of Year 2 activities. The objectives of this evaluation were two-fold:

1. To evaluate the effectiveness of using computer-based aircraft inspection training, specifically the ASSIST system, in improving inspection performance, and
2. To conduct a detailed usability evaluation of the ASSIST software.

Accordingly, the study was divided into two parts, with one focusing on performance evaluation and the other on usability evaluation. The methodologies supporting the evaluation are detailed below:

1.5.1 Methodology

Subjects

The subjects for this study consisted of 18 inspectors from the team partner's facilities 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 did not receive any inspection training.
- Trained Group: These subjects received training on both the general aspects of inspection as well as feedback training on a computer-simulated inspection task using the ASSIST software.

Experimental Design

The study used a mixed between and within subjects design. The training condition, training or no training, was the between subject factor whereas the pacing condition, paced or unpaced, was the within subjects factor (Table 1.3).

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 for the study consisted of the general and simulation modules of the ASSIST training program. 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 1.3 Assist Experiment Protocol

			Knowledge Test			ASSIST Training				Knowledge Test		
	Consent form	**Demographic survey**	**Section I: Short** Q & A	Section II: Multiple choice test	Simulation trial & demo	Simulation test	Training general	Training simulator	Simulator Test	Section I: Short Q & A	Section II: Multiple choice test	Hangar floor test
						Unpaced Paced			Unpaced Paced			
Description of Protocol Stage		7 questions on topics such as age, experience, certification, and training	Short answer questions on General aircraft inspection	30 questions total (taken from the ASSIST software)	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	Short answer questions on General aircraft inspection	30 questions total (taken from the ASSIST software)	Demonstration test
9 subjects	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Trained 9 subjects	**X**	**X**	**X**	**X**	**X**	**X**	**N/A**	**N/A**	**X**	**X**	**X**	**X**
Control												

Procedure

At the outset all the subjects completed a consent form (Figure 1.18) and a demographics questionnaire (Figure 1.19) which solicited information on the subjects' backgrounds, ages and experience in inspection. Following this step, all subjects completed a two-section knowledge test with Section 1 consisting of short essay-type questions and Section II of multiple choice questions (Figures 1.20 through 1.22). Both sections of the test collected user information on the subjects' prior knowledge of aircraft inspection.

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 _____

Figure 1.18 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 1.19 Demographic Survey

Knowledge Test Section I: Short Q & A

Scoring:

Correct Answer – all information and terminology given is correct and complete [score = 5]
Partially Correct Answer – information is incomplete or partially wrong [score = 3]
Wrong Answer – information given is wrong [score = 1]

1. What are two types of inspection?
2. What are two types of quality audits? Describe them?
3. What is parts control?
4. With regard to noise, what is masking?
5. What three things can affect the light available for visual inspection?
6. What is the difference between indirect and direct lighting?
7. What are four things you can do as an off-shift worker to combat fatigue?
8. Name two types of search strategies and define them. Which is better?
9. What are seven critical task factors that influence inspection performance?
10. List nine forms that written communication in the aircraft inspection industry may come from?
11. What are five common errors in written communication?
12. Why is feedback important? What are the two forms of feedback?
13. What are two things you could do if you go to the area you are to inspect and you can't see very well do to poor lighting?
14. Why is it sometimes necessary to perform buy-back inspection?

Figure 1.20 Knowledge Test Section I: Short Q & A

ASSIST EVALUATION: MULTIPLE CHOICE TEST (30 QUESTIONS): BEFORE TRAINING

Question 1: Maintenance on an item has been completed, the area has been closed, and maintenance has signed off on it. As a buy-back inspector you should:

Answer A: sign-off on the inspection.
Answer B: ask the mechanic to open up the area and inspect it and then sign off on it (based o inspection)
Answer C: ask another buy-back inspector in the field to sign-off on it.
Answer D: All of the above

Question 2: The common inspection tools include all of the following except:

Answer A: flashlight.
Answer B: steel scale.
Answer C: magnifying glass.
Answer D: screwdriver.

Question 3: When performing an OK to close inspection, always remember to:

Answer A: Take one last look for defects.
Answer B: Sign the work card.
Answer C: Make sure all tools have been picked up.
Answer D: All of the above.

Question 4: Which of the following tasks relate to the scope of the inspector's job:

Answer A: Providing explanation if the mechanic performs an incorrect installation or repair.
Answer B: Inspecting the aircraft and not performing the mechanic's work.
Answer C: Answering any questions about the Non-Routine card.
Answer D: All of the above.

Question 5: Your actions while inspecting an aircraft can affect which of the following:

Answer A: You
Answer B: Your fellow employees
Answer C: The airworthiness of the aircraft
Answer D: All of the above

Question 6: When attempting to inspect inside a poorly lighted bag bin:

Answer A: Do not be concerned, there is probably enough light to see your way.
Answer B: Keep all the doors open so light from the hangar can enter.
Answer C: Bring more fixed lighting equipment inside the bag bin.
Answer D: Just use your flashlight to see.

Figure 1.21 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 7: Being very familiar with emergency equipment in your area will:

Answer A: help you quickly resolve an emergency situation.
Answer B: let you escape a dangerous area.
Answer C: provide a safe place during emergencies.
Answer D: All of the above

Question 8: What is the biggest danger of foreign object damage (FOD)?

Answer A: Danger to the hangar.
Answer B: Loss of a tool.
Answer C: Damage to the aircraft.
Answer D: None of the above.

Question 9: Which is a long-range 4 engine aircraft?

Answer A: 737
Answer B: 747
Answer C: 757/767
Answer D: 777

Question 10: Which aircraft would be least likely to have a large number of defects based on years in service?

Answer A: MD-90
Answer B: L-1011
Answer C: 747
Answer D: A300

Question 11: _____ is the ability to see detail at various distances from the object of regard.

Answer A. Color vision
Answer B. Visual acuity
Answer C. Peripheral vision

Answer B. Visual acuity
Answer C. Peripheral vision
Answer D. Conspicuity

Question 12: Factor(s) that make up an inspector's physical environment is (are):

Answer A. Amount of lighting
Answer B. Work design
Answer C. Ambient temperature and humidity level.
Answer D. Both A and C

Question 13: Experience can be categorized based on:

Answer A. Number of years of work
Answer B. Variety of work conducted
Answer C. Both A and B
Answer D. None of the above

Figure 1.21 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 14: Given a fixed time period, strategies to maintain accuracy when time is limited are:

Answer A. Add more inspectors
Answer B. Incorporate a systematic search strategy
Answer C. Both A and B
Answer D. None of the above

Question 15: In order for an inspector to properly perform an inspection, the inspector:

Answer A. Must have the correct equipment and tools available.
Answer B. Must have access to the required documentation and manuals.
Answer C. Must be trained on the proper use of the equipment and tools.
Answer D. All of the above

Question 16: Process factors refer to:

Answer A. Elements of the inspection process that may either help or hinder an inspector from doing his/her job.
Answer B. Organizational requirements by an inspector's employer.
Answer C. Factors regarding the communication of information.
Answer D. Factors that make up an inspector's physical environment.

Question 17: Where is the Aircraft Logbook kept?

Answer A: At the service facility that would use it the most
Answer B: Each service facility has a copy
Answer C: With the aircraft both in-flight and during service
Answer D: At FAA Headquarters

Question 18: Where does an inspector go to pick up the work cards for an inspection assignment?

Answer A: The work dock or the inspection supervisor
Answer B: They are already on the aircraft
Answer C: The quality assurance department
Answer D: FAA Headquarters

Question 19: Which type of inspection would be best suited for viewing the inside of an engine during an engine check?

Answer A: Visual
Answer B: Borescope
Answer C: X-Ray
Answer D: Coin Tap

Figure 1.21 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 20: A check to see whether a unit or system performs within specified limits is called what?

Answer A: Final Inspection
Answer B: Functional Check
Answer C: Missed Item
Answer D: Required Inspection Item (RII)

Question 21: In addition to being familiar with all inspection methods, techniques, and equipment in their specialty, aircraft inspectors must:

Answer A: maintain proficiency in using various inspection aids intended for that purpose.
Answer B: have available and understand current specifications involving inspection tolerances, limitations, and procedures established by the manufacturer of the product being inspected and with other information such as FAR's.
Answer C: in cases where mechanical inspection devices are to be used, be skilled in operating

Answer C: in cases where mechanical inspection devices are to be used, be skilled in operating that equipment and be able to properly interpret indications.
Answer D: All of the above.

Question 22: Buy-back inspection steps include all of the following except:

Answer A: Signing off on a workcard if satisfied.
Answer B: Helping the mechanic complete his or her work.
Answer C: A mechanic requesting an inspection.
Answer D: Inspecting the work done by the mechanic.

Question 23: When in doubt about a procedure for safety reasons, you should:

Answer A: Use your own judgement.
Answer B: Consult the company safety manual.
Answer C: Consult Airworthiness Directives.
Answer D: Consult other inspectors in the area.

Question 24: For effective hearing protection, you should:

Answer A: Know the blast and suction zones around a particular aircraft.
Answer B: Wear earplugs or "earmuffs."
Answer C: Work frequently near the use of a pneumatic rivet gun.
Answer D: All of the above

Question 25: Which Airbus aircraft is an ultra-long range 4-engine model?

Answer A: A300
Answer B: A320
Answer C: A330
Answer D: A340

Figure 1.21 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 26: Written communication in the aircraft inspection industry may come in the form of:

Answer A. Workcards, non-routine cards, and bulletins.
Answer B. Manufacturer's manuals, OSHA guidelines, and advisory circulars.
Answer C. FAR's, AD's, and company procedures.
Answer D. All of the above

Question 27: _____ may lead to lowering of quality and performance, loss of time and money, and frustration.

Answer A. Work design
Answer B. Improper communication
Answer C. Teamwork
Answer D. Lighting

Question 28: Because of the depth of knowledge and skills required for aviation inspection and maintenance tasks, a heavy emphasis must be placed upon _____.

Answer A. Job design
Answer B. Work design
Answer C. Workplace design
Answer D. Training

Question 29: Which of the following is NOT considered to be a type of Non-Destructive Inspection (NDT)?

Answer A: Eddy Current
Answer B: Dye-Penetrant
Answer C: Visual Inspection
Answer D: Coin Tap

Question 30: Which of these documents would you expect to have information about a widely known problem on an aircraft?

Answer A: Significant Structural Item (SSI)
Answer B: Federal Aviation Regulations (FAR)
Answer C: Inspection work dock
Answer D: Discrepancy Report

Figure 1.21 Knowledge Test Section II: Multiple Choice Test

ASSIST EVALUATION: MULTIPLE CHOICE TEST (30 QUESTIONS): AFTER TRAINING

Question 1: Maintenance on an item has been completed, the area has been closed, and maintenance has signed off on it. As a buy-back inspector you should:

Answer A: sign-off on the inspection.
Answer B: ask the mechanic to open up the area and inspect it and then sign off on it (based on inspection)
Answer C: ask another buy-back inspector in the field to sign-off on it.
Answer D: All of the above

Question 2: The common inspection tools include all of the following except:

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Answer B: steel scale.
Answer C: magnifying glass.
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Question 4: Which of the following tasks relate to the scope of the inspector's job:

Answer A: Providing explanation if the mechanic performs an incorrect installation or repair.
Answer B: Inspecting the aircraft and not performing the mechanic's work.
Answer C: Answering any questions about the Non-Routine card.
Answer D: All of the above.

Question 5: Your actions while inspecting an aircraft can affect which of the following:

Question 5: Your actions while inspecting an aircraft can affect which of the following:

Answer A: You
Answer B: Your fellow employees
Answer C: The airworthiness of the aircraft
Answer D: All of the above

Question 6: When attempting to inspect inside a poorly lighted bag bin:

Answer A: Do not be concerned, there is probably enough light to see your way.
Answer B: Keep all the doors open so light from the hangar can enter.
Answer C: Bring more fixed lighting equipment inside the bag bin.
Answer D: Just use your flashlight to see.

Figure 1.22 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 7: Being very familiar with emergency equipment in your area will:

Answer A: help you quickly resolve an emergency situation.
Answer B: let you escape a dangerous area.
Answer C: provide a safe place during emergencies.
Answer D: All of the above

Question 8: What is the biggest danger of foreign object damage (FOD)?

Answer A: Danger to the hangar.
Answer B: Loss of a tool.
Answer C: Damage to the aircraft.
Answer D: None of the above.

Question 9: Which is a long-range 4 engine aircraft?

Answer A: 737
Answer B: 747
Answer C: 757/767
Answer D: 777

Question 10: Which aircraft would be least likely to have a large number of defects based on years in service?

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Question 11: _____ is the ability to see detail at various distances from the object of regard.

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Question 13: Experience can be categorized based on:

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Figure 1.22 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 14: Given a fixed time period, strategies to maintain accuracy when time is limited are:

Answer A. Add more inspectors
Answer B. Incorporate a systematic search strategy
Answer C. Both A and B
Answer D. None of the above

Question 15: In order for an inspector to properly perform an inspection, the inspector:

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Answer B. Must have access to the required documentation and manuals.
Answer C. Must be trained on the proper use of the equipment and tools.
Answer D. All of the above

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Answer A. Elements of the inspection process that may either help or hinder an inspector from doing his/her job.
Answer B. Organizational requirements by an inspector's employer.
Answer C. Factors regarding the communication of information.
Answer D. Factors that make up an inspector's physical environment.

Question 17: Where is the Aircraft Logbook kept?

Answer A: At the service facility that would use it the most
Answer B: Each service facility has a copy
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Answer D: At FAA Headquarters

Question 18: Where does an inspector go to pick up the work cards for an inspection assignment?

Answer A: The work dock or the inspection supervisor
Answer B: They are already on the aircraft
Answer C: The quality assurance department
Answer D: FAA Headquarters

Question 19: Which type of inspection would be best suited for viewing the inside of an engine during an engine check?

Answer A: Visual
Answer B: Borescope
Answer C: x-ray
Answer D: Coin Tap

Figure 1.22 Knowledge Test Section II: Multiple Choice Test (Continued)

Question 20: A check to see whether a unit or system performs within specified limits is called what?

Answer A: Final Inspection
Answer B: Functional Check
Answer C: Missed Item
Answer D: Required Inspection Item (RII)

Question 21: Initial inspection

Answer A: is performed in order to find any damage after normal use of the aircraft.
Answer B: includes receipt of a work card, locating the designated area on the aircraft, searching for defects, showing the defects to mechanics.
Answer C: Both A and B.
Answer D: None of the above

Question 22: During an engine run, you should be most concerned about:

Answer A: Personnel and equipment near the aircraft.
Answer B: Taxiing the aircraft to the test area.
Answer C: Running the engines at test speeds.
Answer D: None of the above

Question 23: When attempting to access an aircraft for inspection, remember to:

Answer A: Not worry about how old or unstable a ladder looks, just use it.
Answer B: Find a stable platform to climb and enter the aircraft.
Answer C: Drive the mobile lifts as close as possible to the aircraft.
Answer D: None of these.

Question 24: Which aircraft are tri-jets?

Answer A: L-1011
Answer B: MD-11
Answer C: 777
Answer D: A and B

Question 25: The two types of lighting are:

Answer A. Stroboscopic and black.
Answer B. Black and white.
Answer C. Direct and indirect.
Answer D. Direct and stroboscopic.

Answer C. Direct and indirect.
Answer D. Direct and stroboscopic.

Figure 1.22 Knowledge Test Section II : Multiple Choice Test (Continued)

Question 26: Which statement(s) is(are) true about masking.

Answer A. Masking can result in hearing loss.
Answer B. Masking is a condition in which one component of the sound environment reduces sensitivity of the ear to another component.
Answer C. An example of masking is the sound of a rivet gun going off which drowns the sound of the back up alarm on a truck or cherry picker.
Answer D. Both B and C

Question 27: Teams in the aircraft inspection and maintenance environment:

Answer A. Share common goals.
Answer B. Require cooperation and communication.
Answer C. Have more pride in their work.
Answer D. All of the above

Question 28: On average, how often does a plane come in for a layover check?

Answer A: Every 4 years
Answer B: Every 12-13 months
Answer C: Every 3 months
Answer D: Every 3-5 days

Question 29: With variation by fleet, on average, how often does a plane come in for a service check?

Answer A: Every 4 years
Answer B: About 12-13 months
Answer C: About every month
Answer D: Every night

Question 30: What document is used to record defects found during inspection in the hangar?

Answer A: A work card
Answer B: A discrepancy report (non-routine card)
Answer C: A significant structural item (SSI)
Answer D: The aircraft logbook

Answer C: A significant structural item (SSI)
Answer D: The aircraft logbook

Figure 1.22 Knowledge Test Section II: Multiple Choice Test

Following this step, subjects in the both the Control and Training Groups were provided with an orientation on the ASSIST software. Upon completion of the orientation, only the subjects in the training group received inspection training through the general and simulation training modules of the ASSIST software. The general training module consisting of various sub-modules focused on the following topics: Role of Inspector, Safety, Aircraft Review, Factors Affecting Inspection and Inspection Procedure (Figure 1.23). After completion of each sub-module, the subjects' knowledge of the material was tested through a short Q and A session with subjects being provided with immediate feedback on their performance and correct answers being supplied to incorrect responses (Figure 1.24).

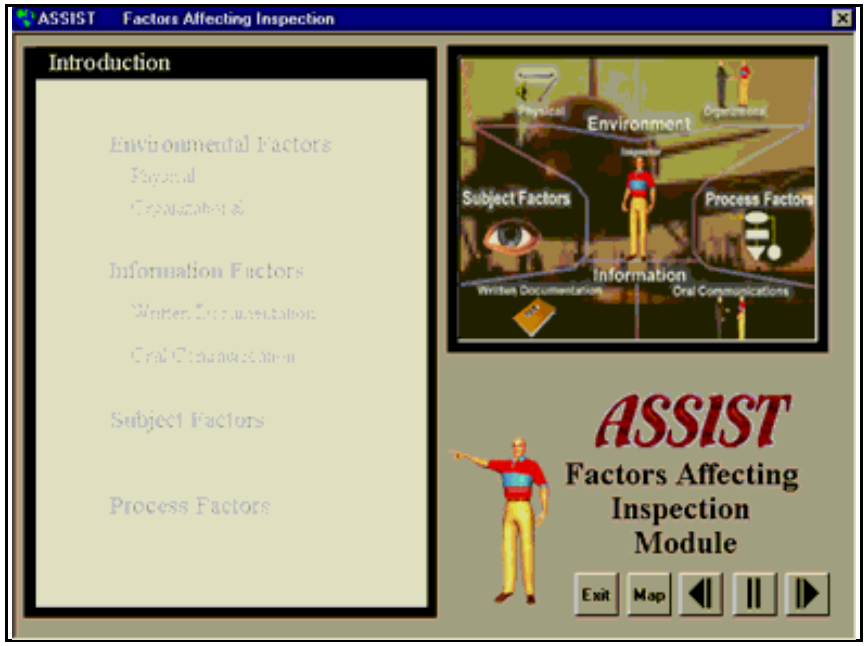


Figure 1.23 Screen Shot from Factors Affecting Inspection in ASSIST

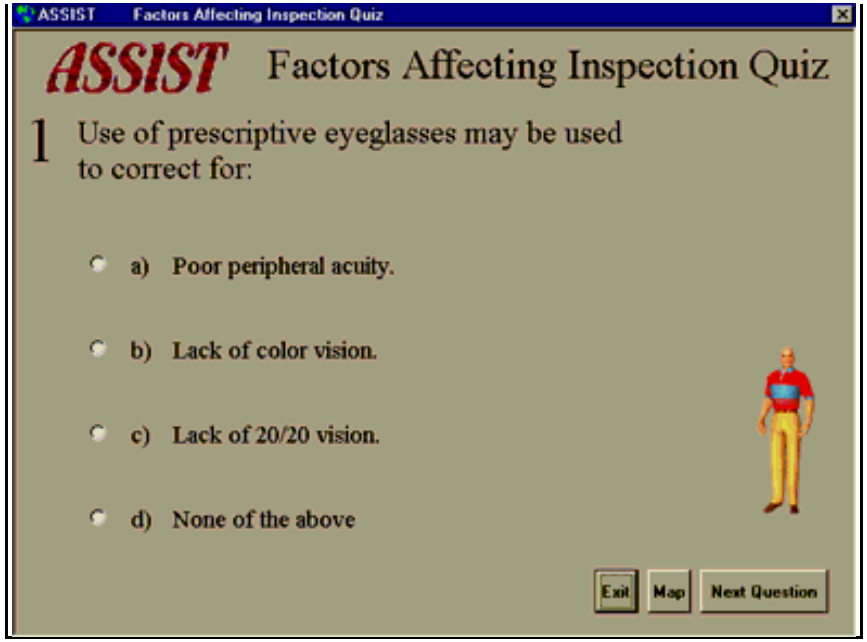


Figure 1.24 Sample Question from a Final Test

In the simulation training portion, subjects were provided inspection training on the computer-simulated aircraft inspection task (Figures 1.25 through 1.31). 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 1.32). Following this step 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 1.33). 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 1.34). 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 1.35).

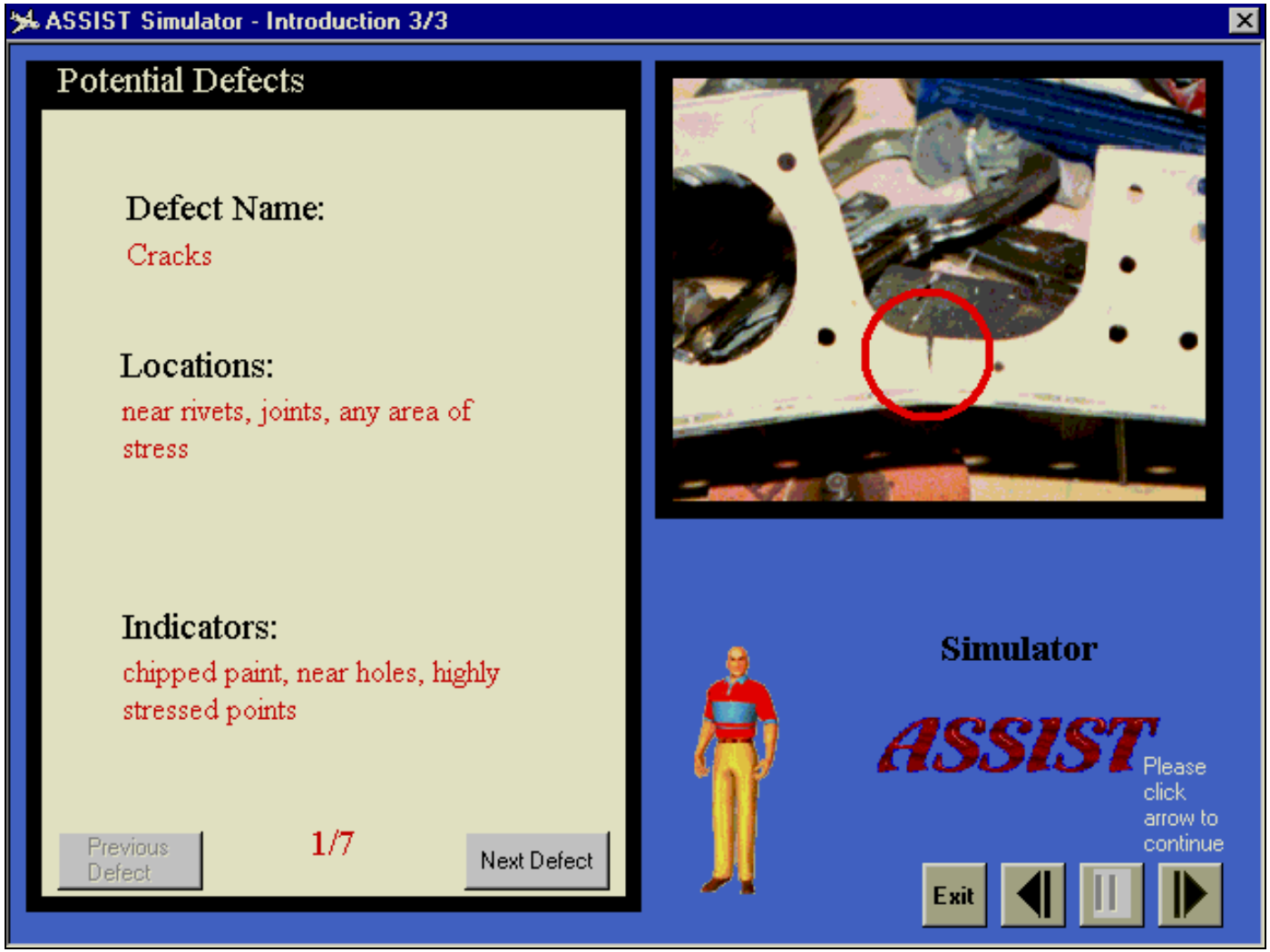


Figure 1.25 The Crack Defect Simulated in ASSIST

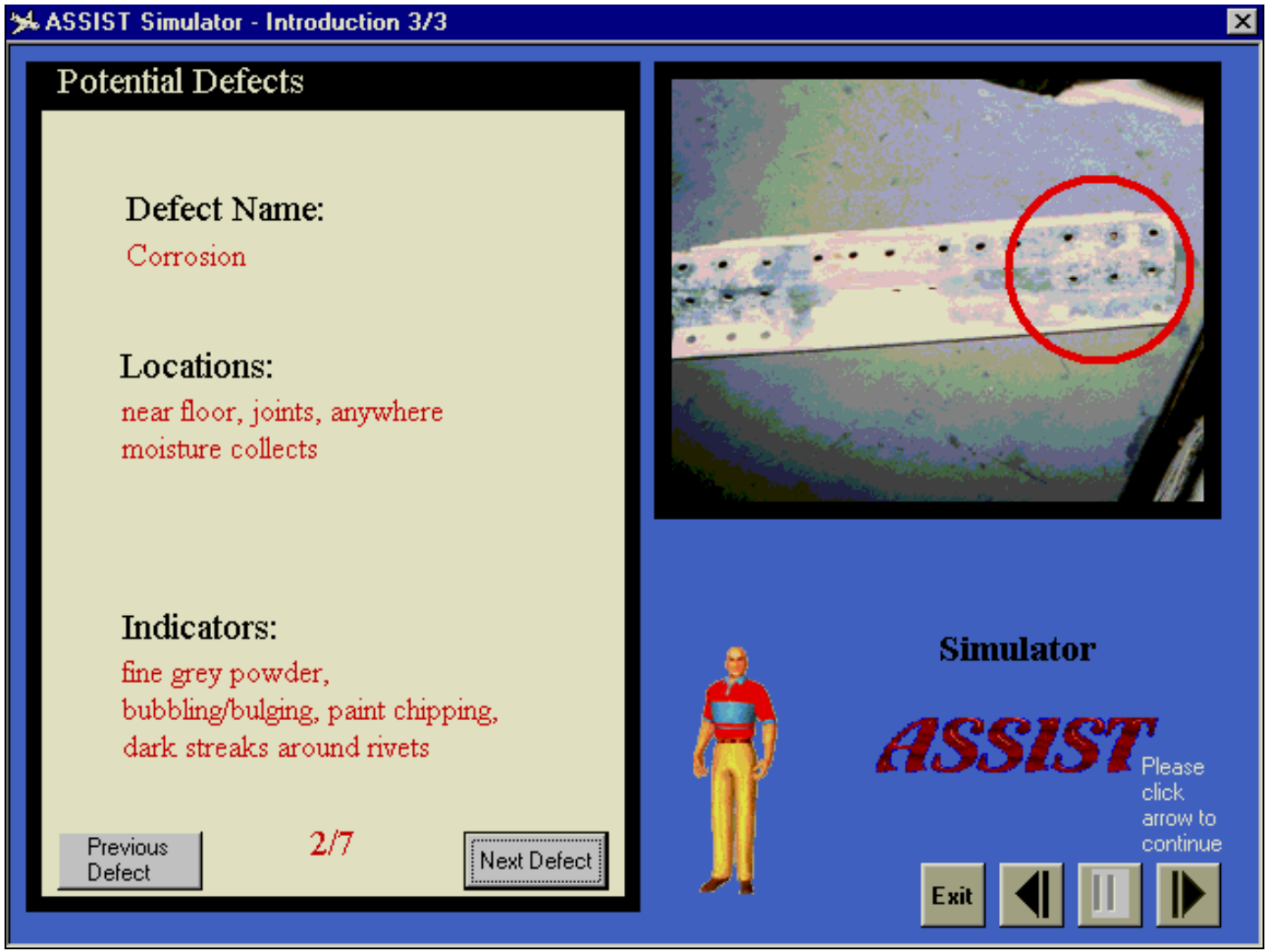


Figure 1.26 The Corrosion Defect Simulated in ASSIST

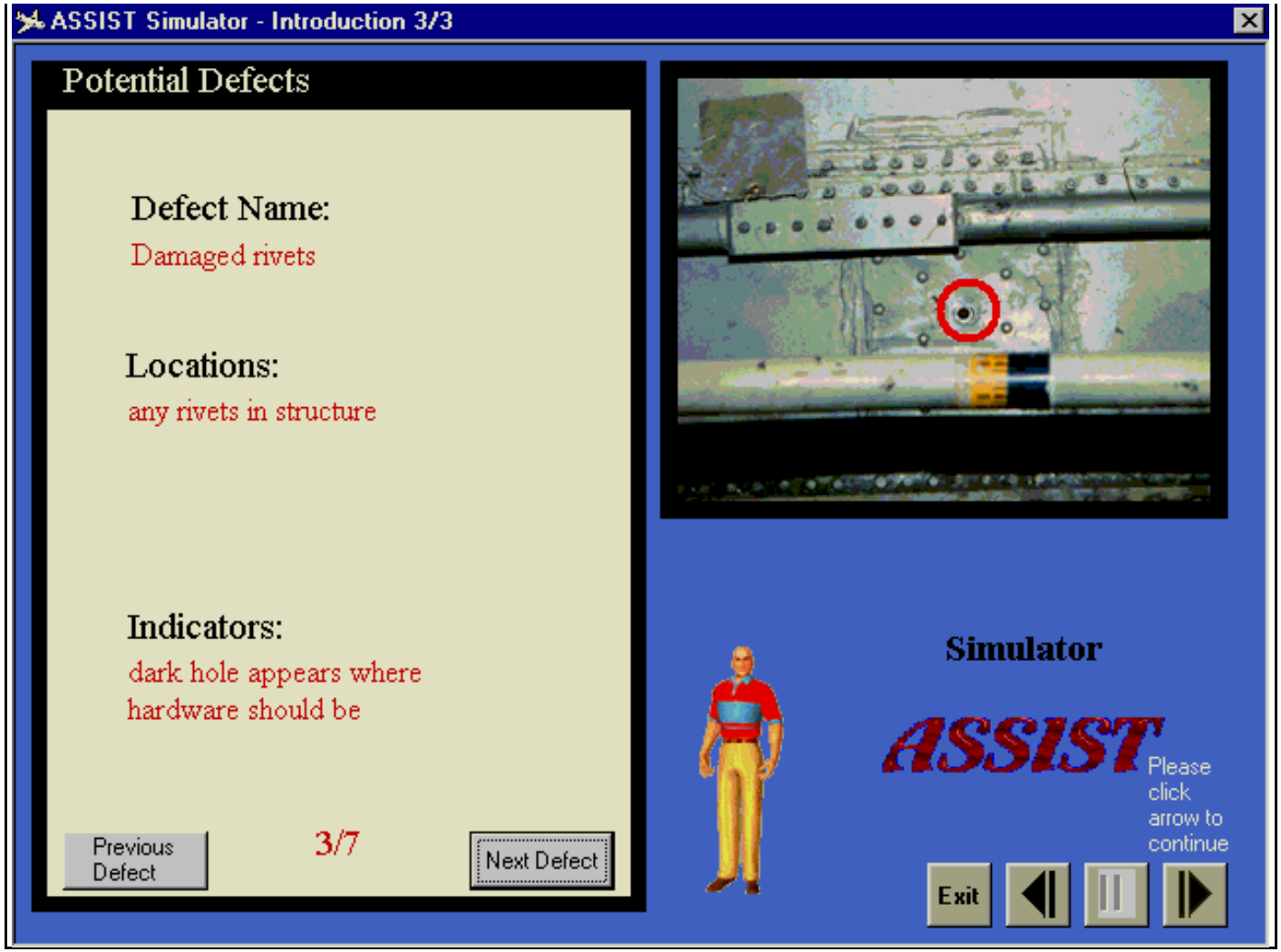


Figure 1.27 The Damaged Rivet Defect Simulated in ASSIST

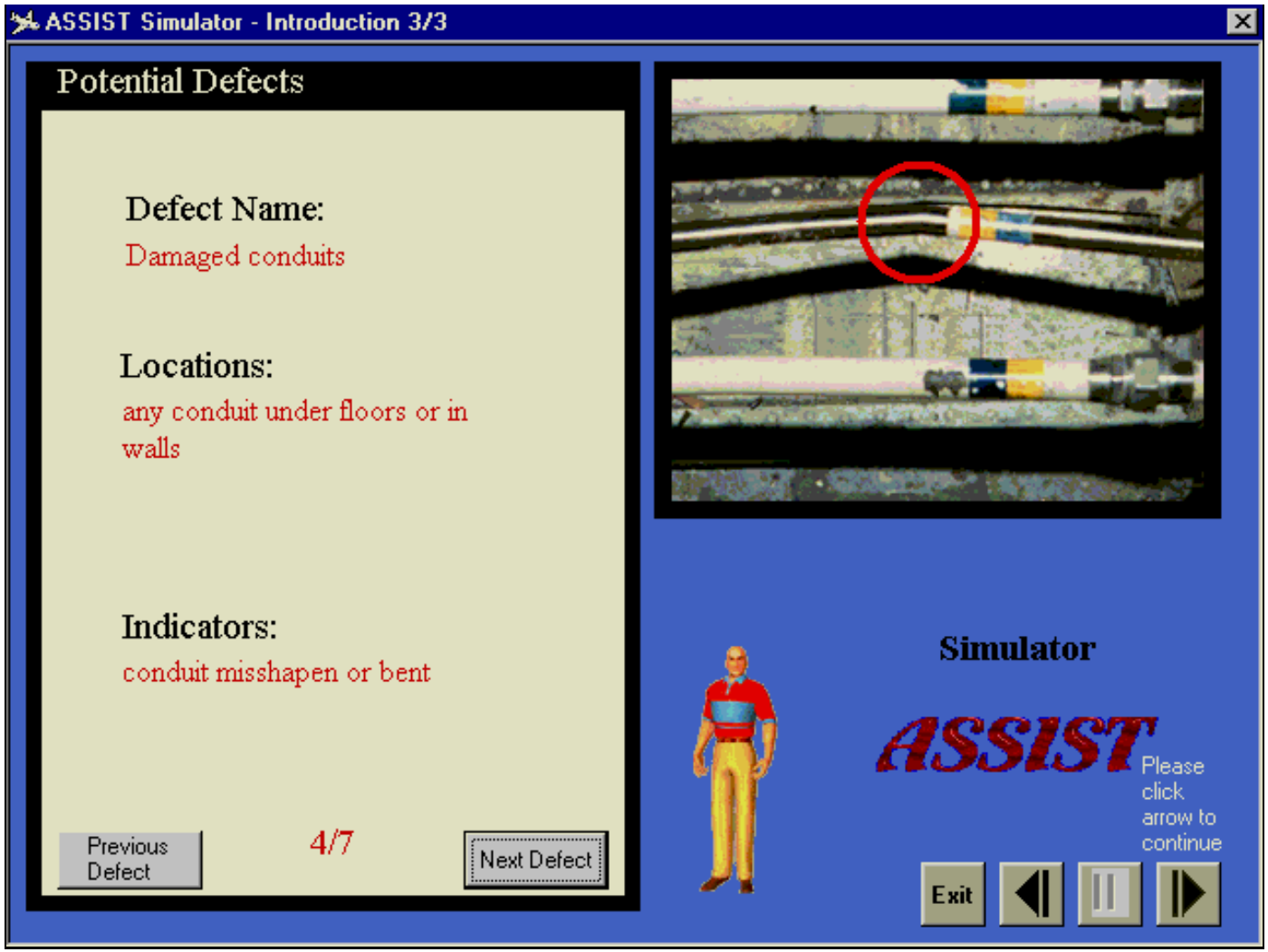


Figure 1.28 The Damaged Conduit Defect Simulated in ASSIST

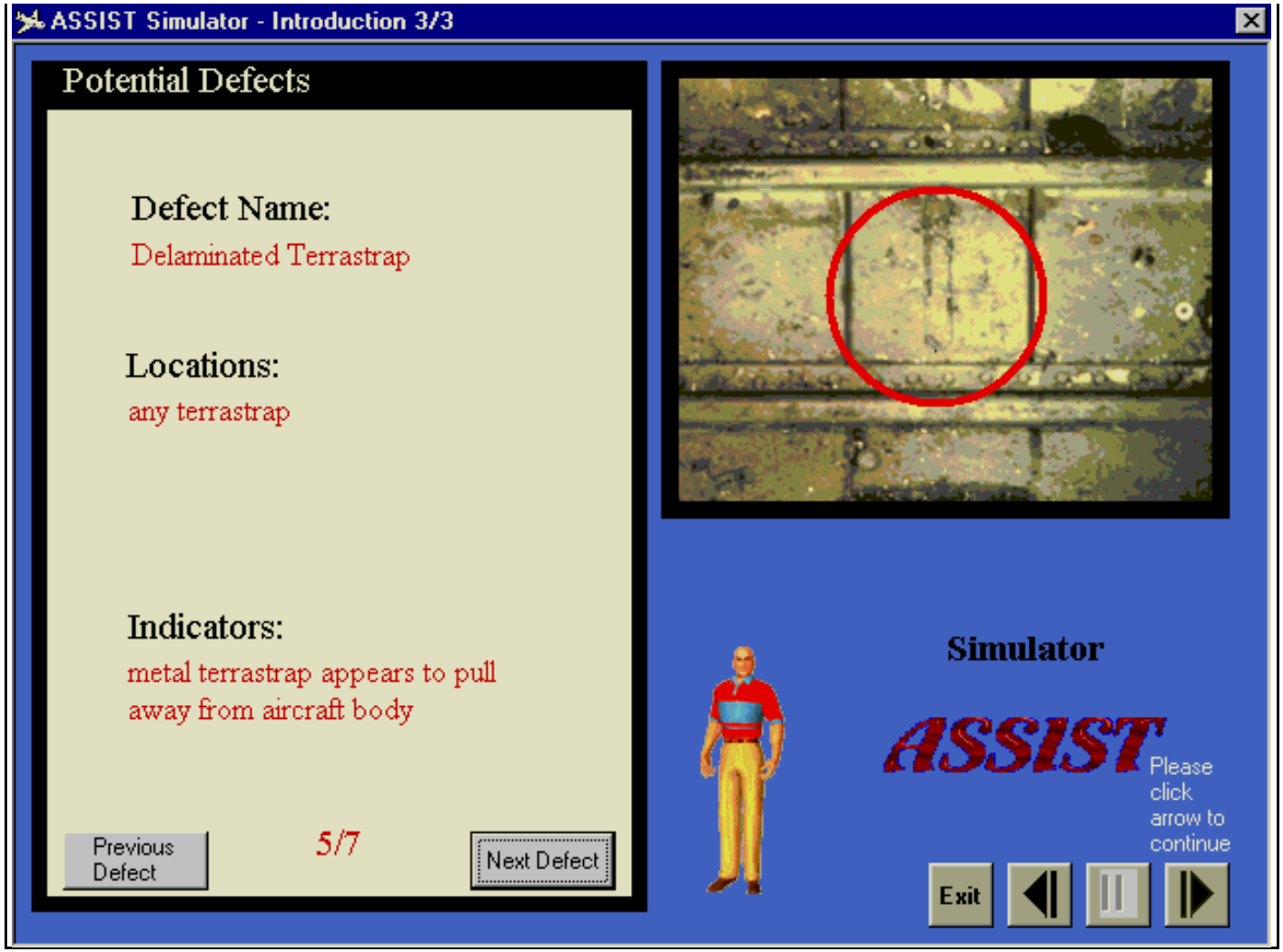


Figure 1.29 The Delaminated Terrastrap Defect Simulated in ASSIST

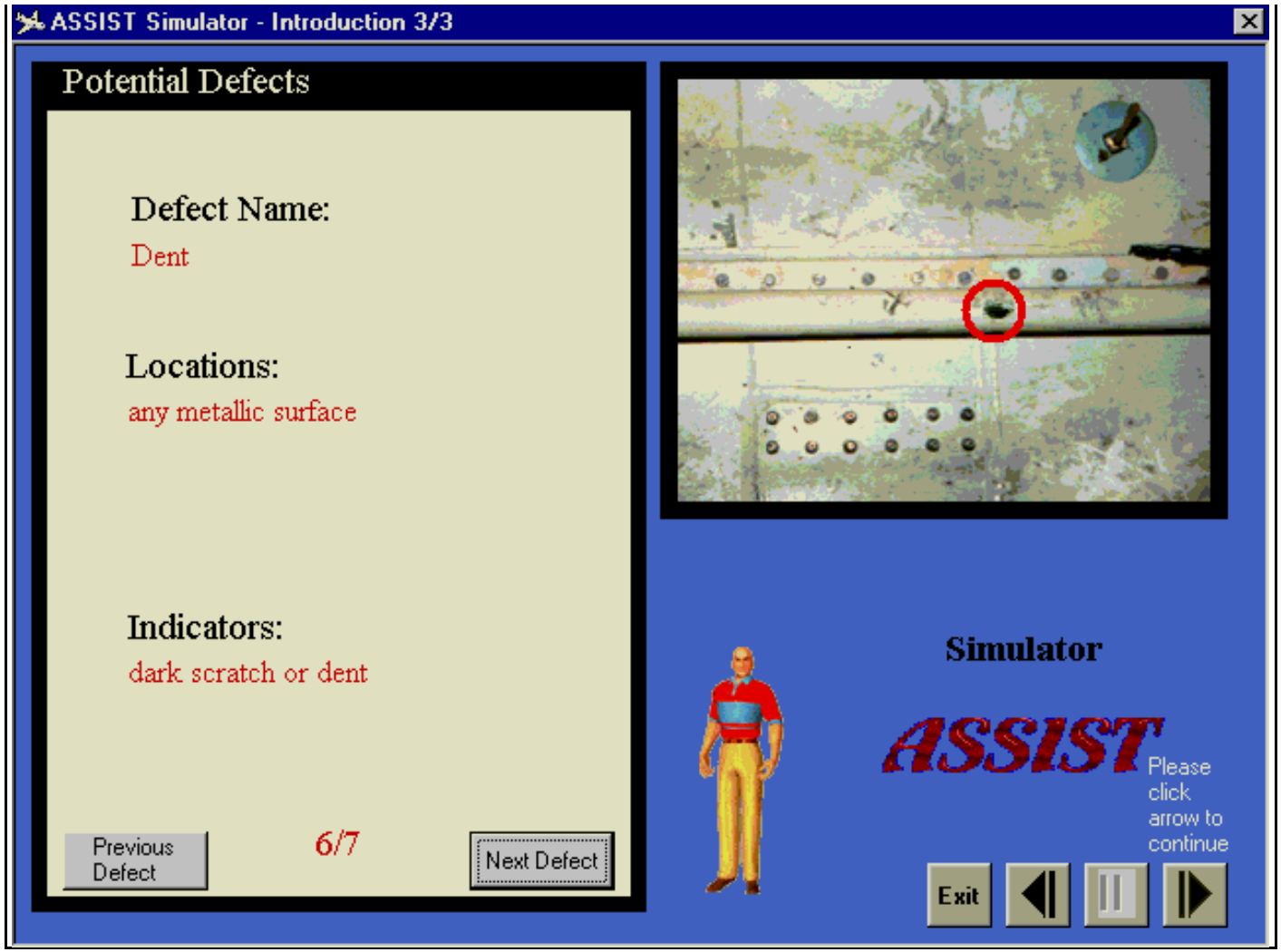


Figure 1.30 The Dent Defect Simulated in ASSIST

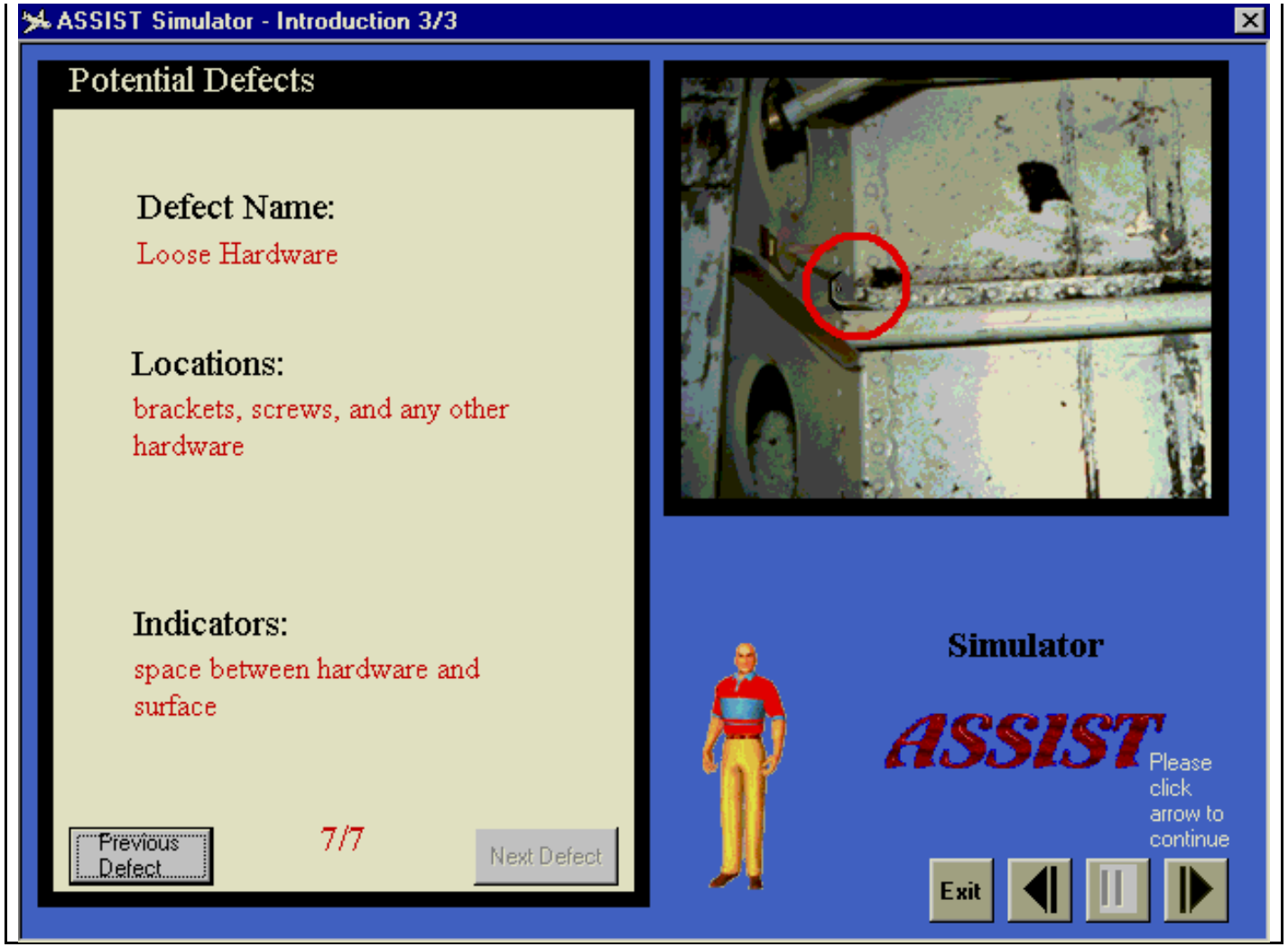


Figure 1.31 The Loose Hardware Defect Simulated in ASSIST

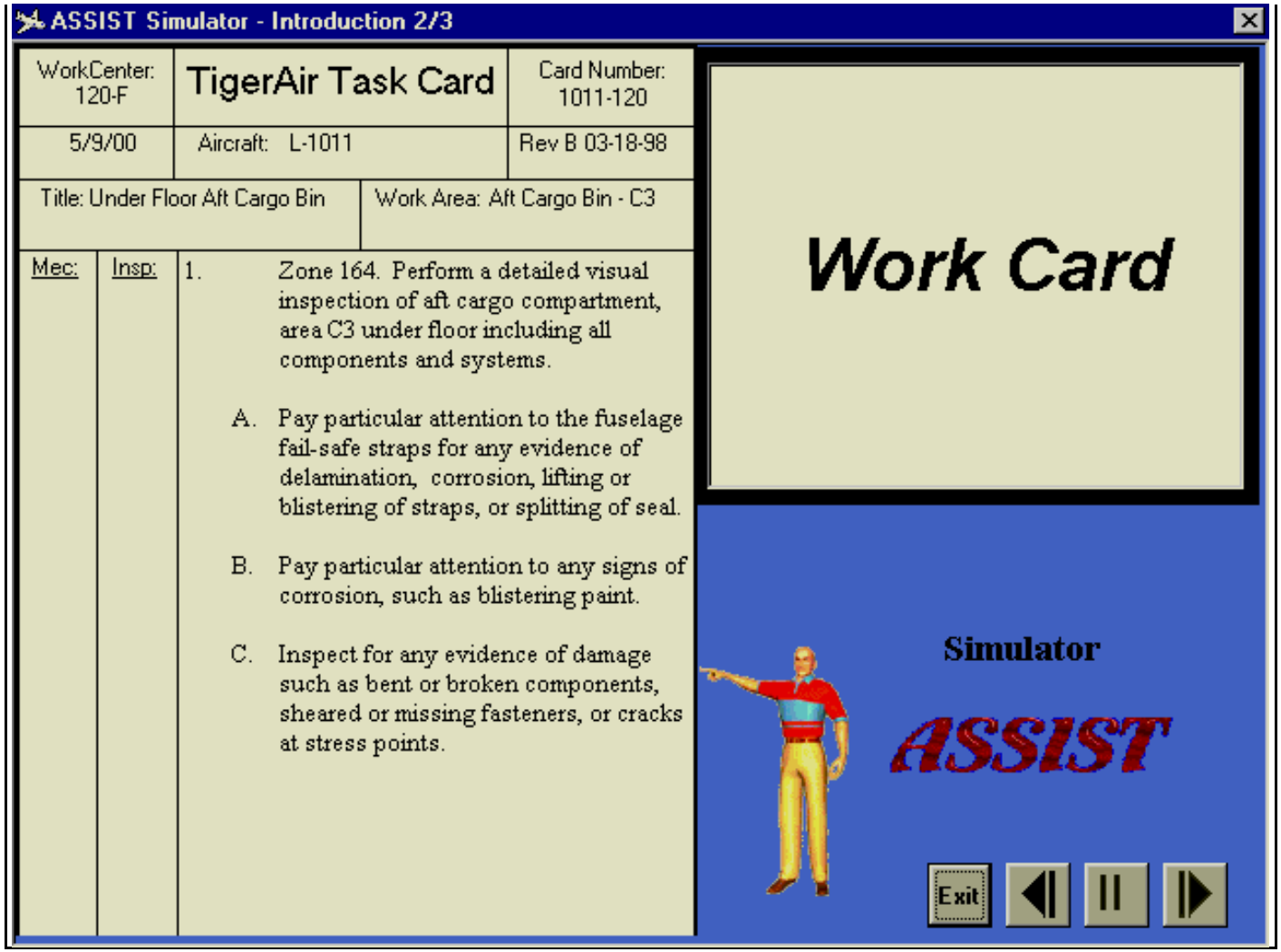


Figure 1.32 Work Card Used to for the Simulation in ASSIST

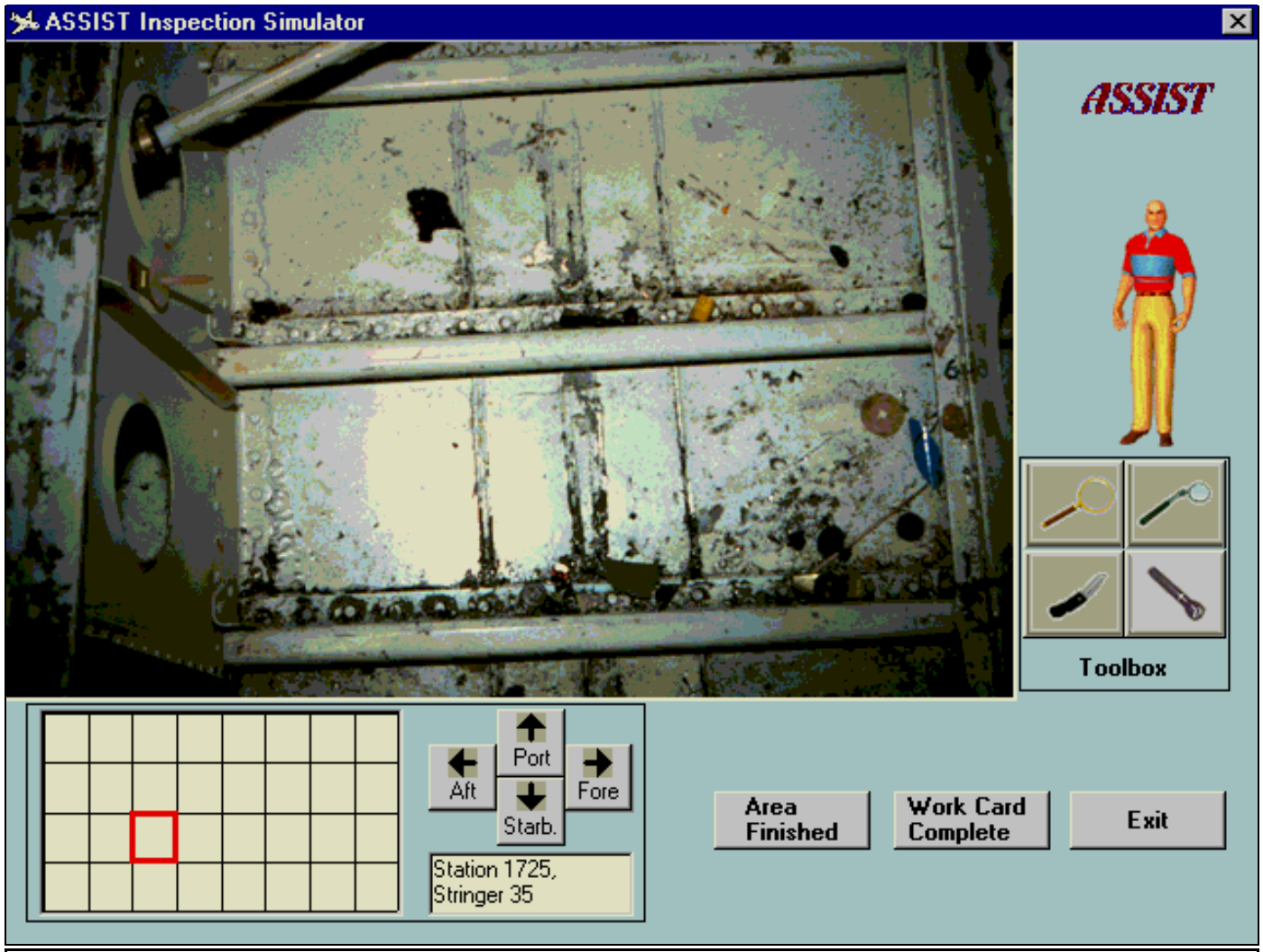


Figure 1.33 Simulation Module Containing a Picture of the Aft-Cargo Bin

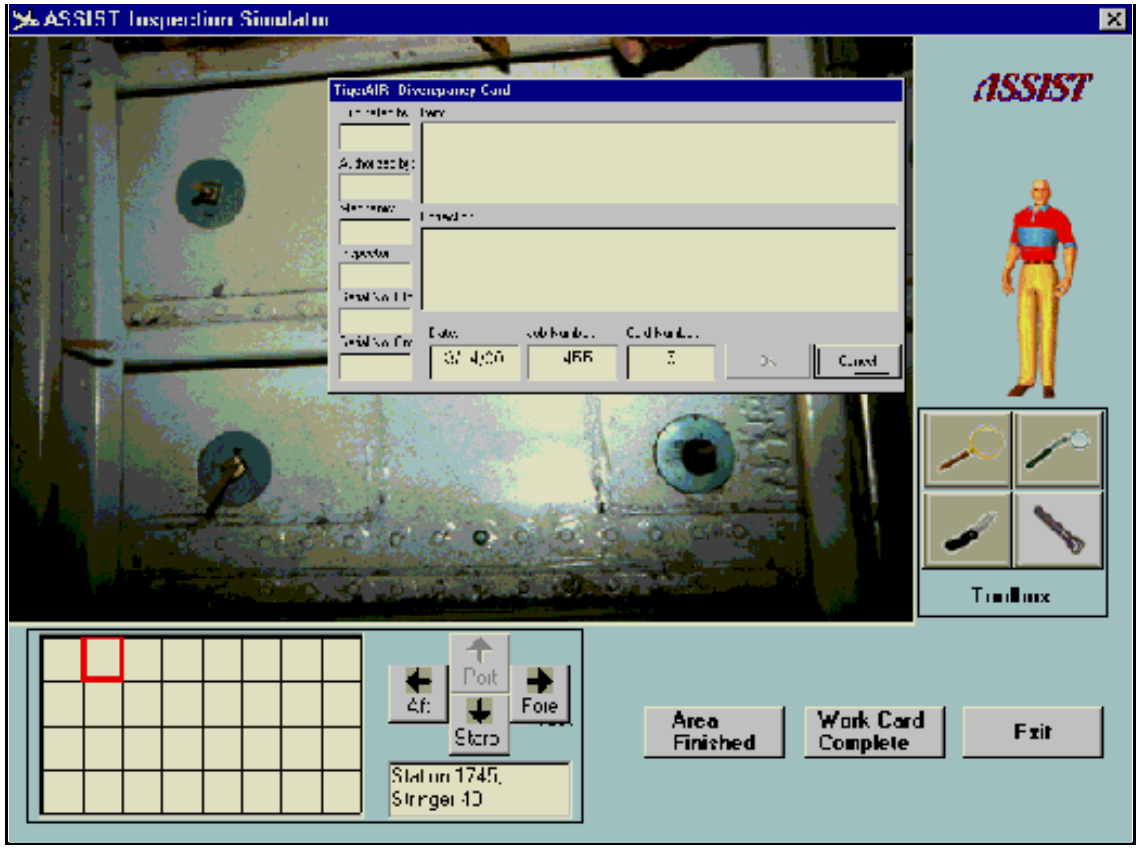


Figure 1.34 Non-routine card used to Write-up Defects Found in the Simulator

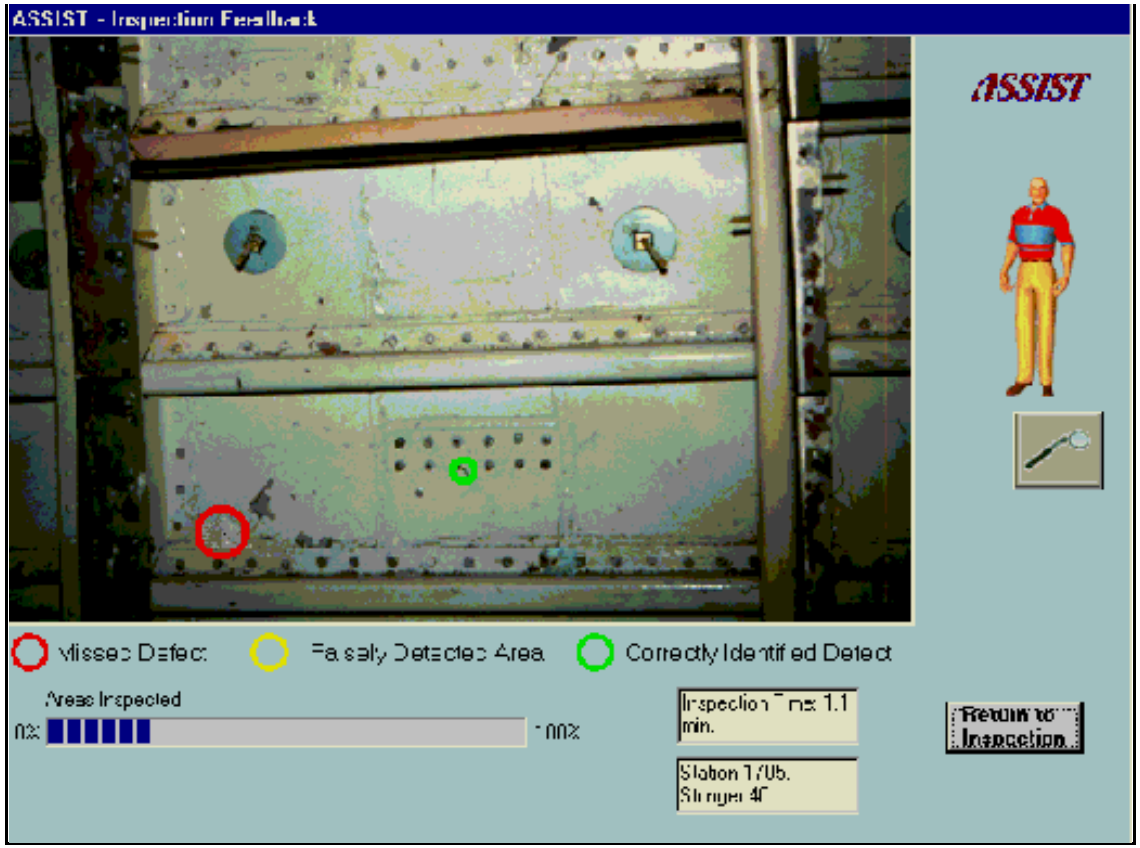


Figure 1.35 Feedback Provided in the Simulation Module

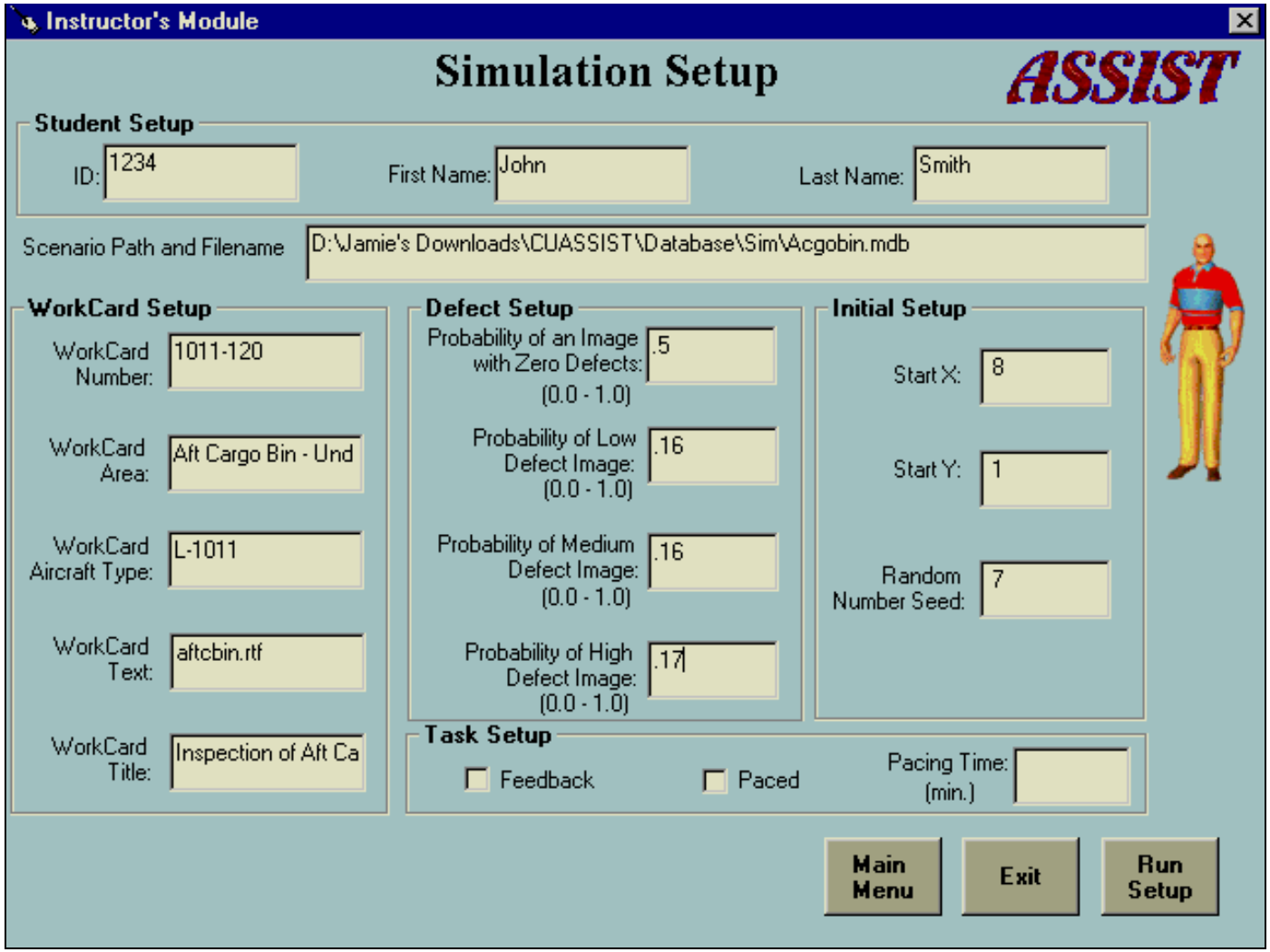


Figure 1.36 Simulator Setup Utility Shown for Unpaced Scenario

After completing the training, subjects in the training group and those in the control group performed the criterion inspection tasks: a visual inspection of 32 distinct search areas constituting one distinct and logical portion of the Aft-Cargo bin of an L-1011 wherein subjects searched for seven different types of defects. The probability, location and defect mix were all pre-specified using the parameter file. Initially, subjects performed the inspection task in the unpaced mode and then in the paced-mode so that the results of the unpaced trial could be used to determine the actual pacing conditions for the paced per-lot trial (Figures 1.36 through 1.37). In the paced mode subjects had a time limit for completion of the entire inspection task. Subjects were paced based on their individual unpaced times. To gauge their knowledge of inspection following training, subjects in both the groups completed the same Sections I and II of the knowledge test. Then, to test whether computer-based training transferred to performance on the job, all subjects completed a hangar floor test (Figure 1.38) wherein they were tasked to conduct a detailed inspection of the cargo compartment door (Figures 1.39 and 1.40). After completing this final test, the subjects were debriefed and thanked for their participation.

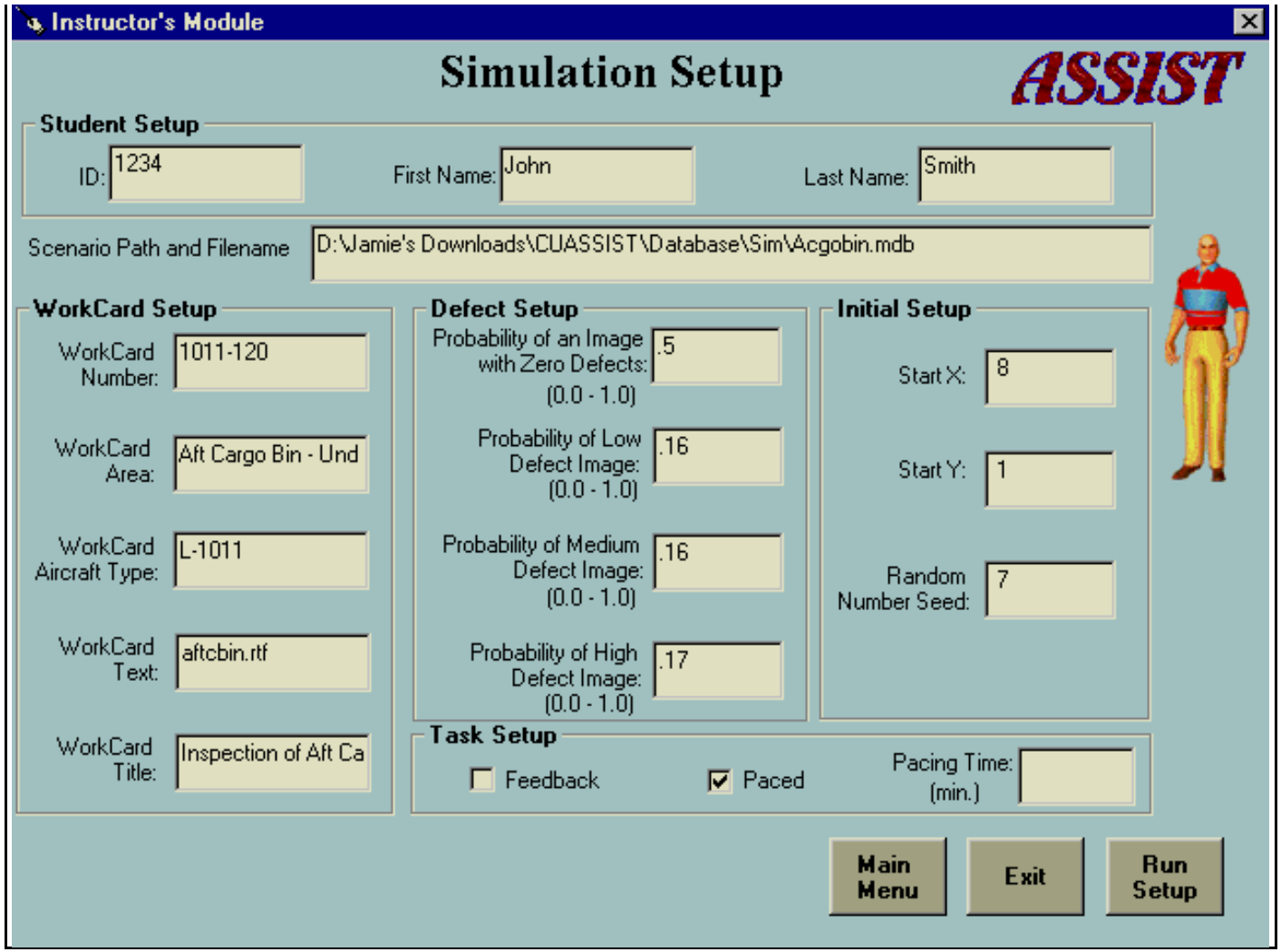


Figure 1.37 Simulator Setup Utility Shown for Paced Scenario

Hangar Floor Test

Scoring:

Correct Answer – all steps are correct and in the correct order [score = 5]
Partially Correct Answer – some steps are omitted or out of order; otherwise are correct [score = 3]
Wrong Answer – some information provided is incorrect [score = 1]

1. What are the major steps in initial inspection from beginning to end?

2. Task: Ask the inspector to follow the procedures from time of assignment by foreman.

   Task: Search for defects on the door and have inspector fill out non-routine work cards.

- Did you follow a pattern when visually inspecting? Describe the pattern.

- (for defects located) (for defects located) Did you look in certain areas for certain defects, if so why?

3. Presents improperly worded non-routines card and have the inspector find the errors. [SEE NON-ROUTINE CARD]

4. What steps do you take after you finish the inspection of an area?

5. What are three steps in buy-back inspection?

Figure 1.38 Hangar Floor Test

B-767	PRODUCTION COUNT	REV.DATE 10-09-98	OPN.NO. 57116

TIME DAY ON/OFF	SUB. TOTALS	DETAILED INSPECTION OF CARGO COMPARTMENT DOORS	KEYWORD INSPECT
		1. Inspect FWD. Cargo Door. 2. Inspect AFT. Cargo Door. 3. Inspect Bulk Cargo Door.	

PWR REQ: N___ Y___ HYD___ PNEU___ ELEC___

ACTUAL HOURS											
SHIP	CR/BLK	DATE	JOB NO.	MRS WO	WK.CTR.	OPN.NO.	EST STD	CARD NO.	SKILL	NO.MEN	AREA
					242-01	57116	1.5		12	1	7-0

B-767	JOB DESCRIPTION	REV.DATE 10-09-98	OPN.NO. 57116

MECH.	INSPECTED BY	DETAILED INSPECTION OF CARGO COMPARTMENT DOORS	KEYWORD INSPECT
	1	1. Inspect FWD. Cargo Door.	
	2	2. Inspect AFT. Cargo Door.	
	3	3. Inspect Bulk Cargo Door.	

PWR REQ: N___ Y___ HYD___ PNEU___ ELEC___

SHIP	CR/BLK	DATE	JOB NO.	MRS WO	WK.CTR.	OPN.NO.	ATA CODE	CARD NO.	SKILL	NO.MEN	AREA
					242-01	57116	52-00-00		12	1	7-0

B-767 **OPN. NO. 57116** **KEYWORD: INSPECT** **OPN. ID: 100193541**

1. Inspect FWD. Cargo Door as follows:

   A. Inspect Door Stops and visible adjacent cut-out structure within aircraft contour.

      (1) Pay particular attention to Door Sills and Frame Chords. (Ref. MPD 5302-100-07E) (Ref. Figure 2)

2. Inspect AFT. Cargo Door as follows:

   A. Inspect Door Stops and visible adjacent cut-out structure within aircraft contour.

      (1) Pay particular attention to Door Sills and Frame Chords. (Ref. MPD 5302-100-07E) (Ref. Figure 1)

(Ref. Figure 1)

3. Inspect Bulk Cargo Door as follows:

   A. Inspect Door Stops and visible adjacent cut-out structure within aircraft contour.

      (1) Pay particular attention to Door Sills and Frame Chords (Ref. MPD 5302-100-07E) (Ref. Figure 3)

Figure 1.39 Hangar Floor Test: Workcard

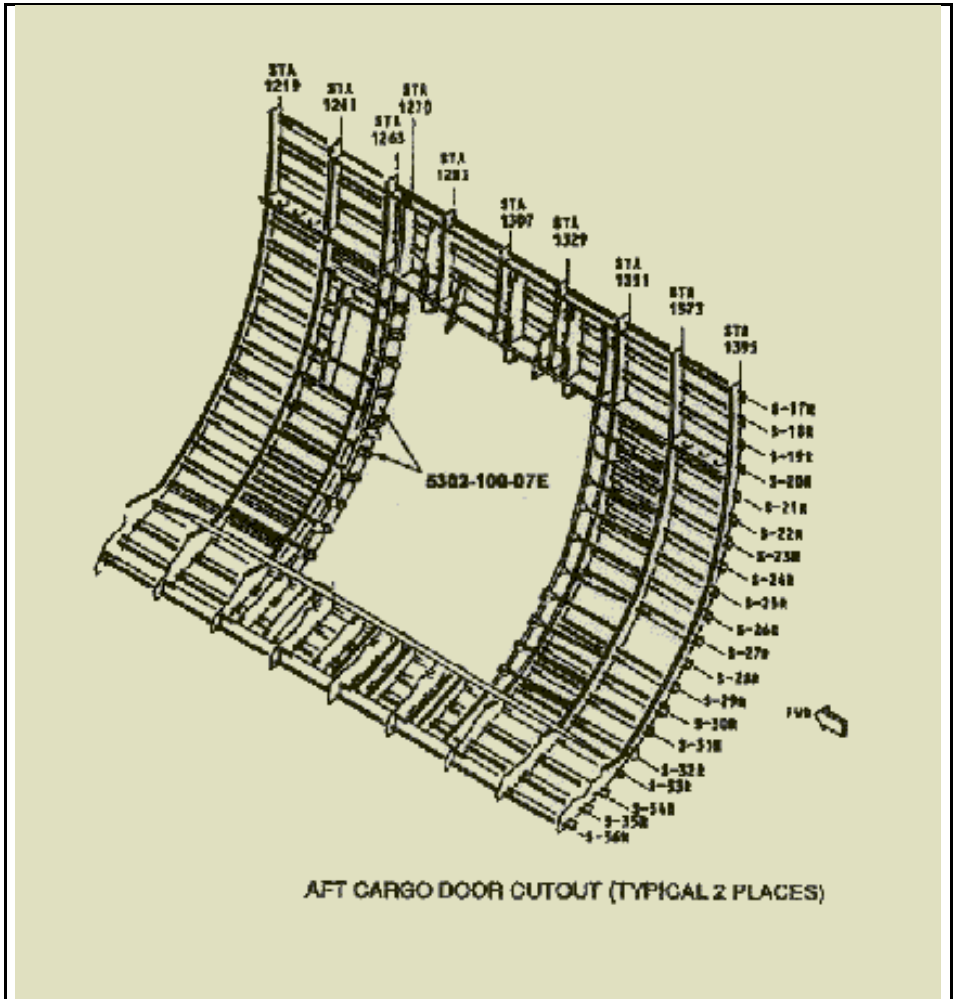


Figure 1.40 Hangar Floor Test : Workcard

Data Collection

Data was collected on the following measures:

- Knowledge Tests (Sections I and II): number of correct responses.
- Criterion Inspection task: Inspection time, misses, false alarms, percentage of defects correctly detected, non-routine card entries.
- Hangar Floor Test: performance test focused on inspection conducted in the hangar floor.

1.5.2 Usability and Performance Analyses

Usability Analysis

To test whether the ASSIST software met usability goals, inspectors, supervisors, and training personnel at aircraft maintenance facilities evaluated the software on specific usability dimensions, e.g., content, presentation, usefulness and format. Separate usability questionnaires were administered for the general and the simulation modules (Figures 1.41 and 1.42). The responses were recorded using a seven-point Likert scale, with one being very strongly agree and seven being very strongly disagree. The mean scores and standard deviations for each group were recorded (Table 1.4).

ASSIST: GENERAL INSPECTION MODULE – USABILITY QUESTIONNARIE

Content

1. The amount of information presented was adequate.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

2. The information presented is extremely relevant to my job as an inspector.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The subjects were well covered.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. The information presented was understandable.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Presentation

1. The language used by the speaker was understandable.

1. The language used by the speaker was understandable.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

2. The screens were understandable.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The information presented flowed smoothly.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.41 Usability Questionnaire -ASSIST: General Module (Continued)

4. The presentation was interesting.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

5. The narration in the modules helped in understanding the material.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

6. It was easy to navigate through the modules.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Usefulness

Usefulness

1. The knowledge gained from each of the following sub-modules was useful:

"Role of Inspection" Sub-module

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

"Safety" Sub-module

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

"Aircraft Review" Sub-module

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

"Factors Affecting Inspection" Sub-module

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

"Inspection Procedure" Sub-module

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.41 Usability Questionnaire -ASSIST: General Module (Continued)

1. The short questions presented during the final test were helpful in reinforcing what you learned.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

2. The information provided by the general module will help me in my job on the hangar floor.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The information provided should be part of any inspection training.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. In addition to your OTJ and classroom training, all inspectors should be trained on the general module.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

5. The information is useful for anyone aspiring to be an inspector.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Format

1. The colors used on the screen did not distract from the task or cause eye discomfort.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

1. The buttons on the screen were easy to understand.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.41 Usability Questionnaire -ASSIST: General Module (Continued)

1. The time for the computer to process information did not frustrate you.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

2. You were satisfied with the interaction with the computer.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The tutorial was effective in providing instruction.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. The colors used were pleasing.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.41 Usability Questionnaire -ASSIST: General Module (Continued)

ASSIST: SIMULATION INSPECTION MODULE

Content

1. The amount of information presented was adequate.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

2. The subjects were thoroughly covered.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The information presented was understandable.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Presentation

1. The language used by the speaker was understandable.

1	2	3	4	5	6	7

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

2. The screens were understandable.

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

3. The information presented flowed smoothly.

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

4. The narration in the modules helped in understanding the material.

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

Figure 1.42 Usability Questionnaire - ASSIST: Simulation Module (Continued)

5. It was easy to navigate through the screens.

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

Usefulness

1. The knowledge gained from the "Introduction" sub-module was useful.

1 2 3 4 5 6 7

Very Strongly Disagree — Neutral — Very Strongly Agree

2. The inspection tools (scraping knife, magnifying glass, mirror, and flashlight) used during

2. The inspection tools (scraping knife, magnifying glass, mirror, and flashlight) used during the "Testing" sub-module was realistic and helpful in looking for defects.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The feedback provided at the end of each screen was useful.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. The feedback provided at the end-of-session was useful.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

5. The defect write-up provided on the discrepancy card was useful.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

6. This computer program will make a good component of your overall training.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.42 Usability Questionnaire - ASSIST: Simulation Module (Continued)

3. The information provided by the Simulation module will help me in my job on the hangar floor.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. The information provided should be part of any inspection training.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

5. In addition to your OTJ and classroom training, all inspectors should be trained on the simulation module.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

6. The information is useful for anyone aspiring to be an inspector.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

7. This training would be useful for periodic re-training of inspectors.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

8. This training was very realistic to the real-world of inspecting.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Format

1. The colors used on the screen did not distract from the task or cause eye discomfort.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.42 Usability Questionnaire - ASSIST: Simulation Module (Continued)

2. The buttons on the screen were easy to understand.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

3. The time for the computer to process information did not frustrate you.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

4. You were satisfied with the interaction with the computer.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

5. The tutorial was effective in providing instruction.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

6. The picture quality used for the aircraft was realistic.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

7. The picture quality of the defects was realistic.

1	2	3	4	5	6	7
Very Strongly Disagree			Neutral			Very Strongly Agree

Figure 1.42 Usability Questionnaire - ASSIST: Simulation Module (Continued)

Table 1.4 Results from the Usability Questionnaire

Category	7 Point Scale		Mean Scores (S.D.)		Wicoxon Test
	1	7	General Module	Simulation Module	
Content	Very Strongly Agree	Very Strongly Disagree	5.66 (1.88)	5.27 (1.91)	$p<0.05$
Presentation	Very Strongly Agree	Very Strongly Disagree	5.72 (1.23)	5.48 (1.32)	$p<0.05$
Usefulness	Very Strongly Agree	Very Strongly Disagree	5.47 (1.52)	4.81 (3.07)	$p<0.05$
Format	Very Strongly Agree	Very Strongly Disagree	5.55(1.45)	5.14 (2.39)	$p<0.05$

A Cronbach's Coefficient Alpha (Cronbach, 1951), was calculated for the group of questions to ensure that it was appropriate to place them into a particular usability dimension (Tables 1.5, 1.6). The Alpha Coefficient can be expressed mathematically as

Alpha
=

where

k = the number of questions combined,

Vt = the variance of the participants' total scores, and

Vi = the sum of the variances of the responses for each individual question.

Table 1.5 Cronbach's Alpha Coefficient: General Module

Category	Var_s	Var_T	k	Alpha
Content	9.54	32.26	4	0.94
Presentation	5.48	17.35	6	0.82
Usefulness	12.27	61.76	10	0.89
Format	9.08	21.09	6	0.68

Table 1.6 Cronbach's Alpha Coefficient: Simulation Module

Category	Var_s	Var_T	k	Alpha
Content	7.07	15.71	3	0.82
Presentation	7.02	14.25	5	0.63
Usefulness	32.95	364.50	12	0.96
Format	13.89	37.14	7	0.73

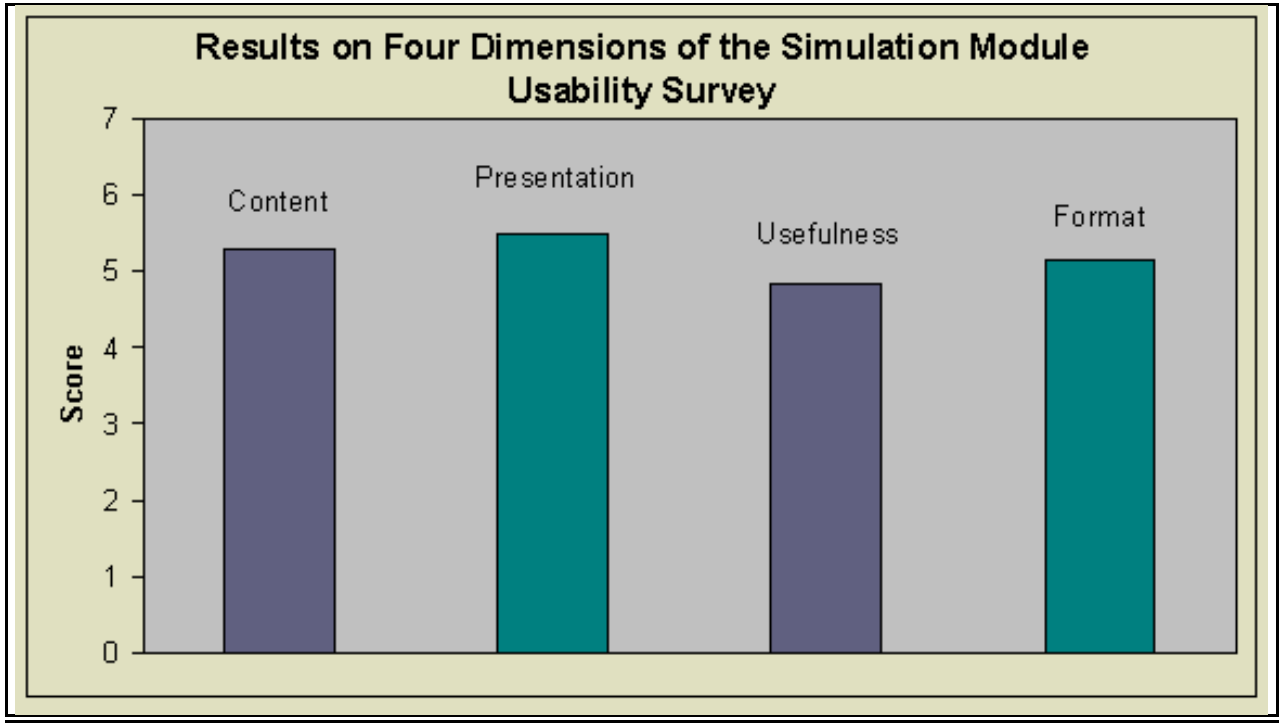


Figure 1.43 Results on Four Dimensions of the Simulation Module Usability Survey

To ensure that the questions would yield interpretable results about usability, the Cronbach's Coefficient Alpha should be greater than 0.5 and less than or equal to 1.0 (Cronbach, 1951). The alpha coefficients for all four dimensions were within the prescribed limits; thus, the questions were grouped into their respective categories. The results of the usability survey are summarized in Table 1.5, listing the mean and standard deviation for each usability dimension. Then, a Wilcoxon Signed Rank Test was used to determine whether the subjects preferred the system of each of the four different usability dimensions by comparing the actual mean scores versus the expected mean score of 4.0. The results revealed that the subjects favored the computer system (Figure 1.43) on all the four dimensions investigated (Tables 1.7 and 1.8).

Table 1.7 Usability Analysis: General Module (Continued)

Category	Question	Likert Scale		Compared Mean	Mean (S.D.)	Wilcoxon test
		1	7			
Content	1. The amount of information presented was adequate.	Very Strongly Disagree	Very Strongly Agree	4	5.45 (2.11)	(p<0.05)
	2. The information presented is extremely relevant to my job as an inspector.	Very Strongly Disagree	Very Strongly Agree	4	5.48 (1.97)	(p<0.05)
	3. The subjects were well covered.	Very Strongly Disagree	Very Strongly Agree	4	5.76 (1.98)	(p<0.05)
	4. The information presented was understandable.	Very Strongly Disagree	Very Strongly Agree	4	5.93 (1.50)	(p<0.05)
Presentation	5. The language used by the speaker was understandable.	Very Strongly Disagree	Very Strongly Agree	4	6.02 (0.82)	(p<0.05)
	6. The screens were understandable.	Very Strongly Disagree	Very Strongly Agree	4	5.79 (0.88)	(p<0.05)
	7. The information presented flowed smoothly.	Very Strongly Disagree	Very Strongly Agree	4	5.66 (1.31)	(p<0.05)
	8. The presentation was interesting.	Very Strongly Disagree	Very Strongly Agree	4	5.59 (1.61)	(p<0.05)
	9. The narration in the modules helped in understanding the material.	Very Strongly Disagree	Very Strongly Agree	4	5.41 (1.18)	(p<0.05)
	10. It was easy to navigate through the modules.	Very Strongly Disagree	Very Strongly Agree	4	5.86 (1.12)	(p<0.05)

Usefulness	11. The knowledge gained from each of the following sub-modules was useful:“Role of Inspection” Sub-module	Very Strongly Disagree	Very Strongly Agree	4	5.41 (0.75)	(p<0.05)
	12. The knowledge gained from each of the following sub-modules was useful:“Safety” Sub-module	Very Strongly Disagree	Very Strongly Agree	4	5.33 (1.03)	(p<0.05)
	13. The knowledge gained from each of the following sub-modules was useful:“Aircraft Review” Sub-module	Very Strongly Disagree	Very Strongly Agree	4	4.88 (1.24)	(p<0.05)
	14. The knowledge gained from each of the following sub-modules was useful:“Factors Affecting Inspection” Sub-module	Very Strongly Disagree	Very Strongly Agree	4	5.47 (1.06)	(p<0.05)
	15. The knowledge gained from each of the following sub-modules was useful:“Inspection Procedure” Sub-module	Very Strongly Disagree	Very Strongly Agree	4	5.40 (1.48)	(p<0.05)

Table 1.7 Usability Analysis: General Module (Continued)

Category	Question	Likert Scale		Compared Mean	Mean (S.D.)	Wilcoxon test
		1	7			
Usefulness	16. The short questions presented during the final test were helpful in reinforcing what you learned.	Very Strongly Disagree	Very Strongly Agree	4	5.68 (1.22)	(p<0.05)
	17. The information provided by the general module will help me in my job on the hanger floor.	Very Strongly Disagree	Very Strongly Agree	4	5.31 (2.36)	(p<0.05)
	18. The information provided should be part of any inspection training.	Very Strongly Disagree	Very Strongly Agree	4	5.90 (1.95)	(p<0.05)
	19. In addition to your OTJ and classroom training, all inspectors should be trained on the general module.	Very Strongly Disagree	Very Strongly Agree	4	5.55 (2.18)	(p<0.05)
	20. The information is useful for anyone aspiring to be an inspector.	Very Strongly Disagree	Very Strongly Agree	4	5.75 (1.76)	(p<0.05)
Format	21. The colors used on the screen did not distract from the task or cause eye discomfort.	Very Strongly Disagree	Very Strongly Agree	4	5.41 (2.54)	(p<0.05)
	22. The buttons on the screen were easy to understand.	Very Strongly Disagree	Very Strongly Agree	4	5.76 (0.76)	(p<0.05)

	23. The time for the computer to process information did not frustrate you.	Very Strongly Disagree	Very Strongly Agree	4	5.69 (0.86)	(p<0.05)
	24. You were satisfied with the interaction with the computer.	Very Strongly Disagree	Very Strongly Agree	4	5.61 (0.74)	(p<0.05)
	25. The tutorial was effective in providing instruction.	Very Strongly Disagree	Very Strongly Agree	4	5.62 (1.82)	(p<0.05)
	26. The colors used were pleasing.	Very Strongly Disagree	Very Strongly Agree	4	5.24 (2.05)	(p<0.05)

Table 1.8 Usability Analysis: Simulation Module

Category	Question	Likert Scale		Compared Mean	Mean(S.D.)	Wilcoxon test
		1	7			
Content	1. The amount of information presented was adequate.	Very Strongly Disagree	Very Strongly Agree	4	5.31 (1.95)	(p<0.05)
	2. The subjects were thoroughly covered.	Very Strongly Disagree	Very Strongly Agree	4	5.08 (1.97)	(p<0.05)
	3. The information presented was understandable.	Very Strongly Disagree	Very Strongly Agree	4	5.46 (1.03)	(p<0.05)
Presentation	1. The language used by the speaker was understandable.	Very Strongly Disagree	Very Strongly Agree	4	5.71 (2.33)	(p<0.05)
	2. The screens were understandable.	Very Strongly Disagree	Very Strongly Agree	4	5.08 (0.93)	(p<0.05)
	3. The information presented flowed smoothly.	Very Strongly Disagree	Very Strongly Agree	4	5.41 (1.01)	(p<0.05)
	4. The narration in the modules helped in understanding the material.	Very Strongly Disagree	Very Strongly Agree	4	5.31 (1.13)	(p<0.05)
	5. It was easy to navigate through the screens.	Very Strongly Disagree	Very Strongly Agree	4	5.77 (2.23)	(p<0.05)
Usefulness	1. The knowledge gained from the “Introduction” sub-module was useful.	Very Strongly Disagree	Very Strongly Agree	4	5.13 (3.70)	(p<0.05)

2. The inspection tools (scraping knife, magnifying glass, mirror, and flashlight) used during the "Testing" sub-module were realistic and helpful in looking for defects.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**4.69 (2.42)**	**(p<0.05)**
3. The feedback provided at the end of each screen was useful.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**5 (2.60)**	**(p<0.05)**
4. The feedback provided at the end-of-session was useful.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**5.03 (1.69)**	**(p<0.05)**
5. The defect write-up provided on the discrepancy card was useful.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**5.12 (3.02)**	**(p<0.05)**
6. This computer program will make a good component of your overall training.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**4.97 (3.76)**	**(p<0.05)**
7. The information provided by the Simulation module will help me in my job on the hanger floor.	**Very Strongly Disagree**	**Very Strongly Agree**	**4**	**4.23 (2.73)**	**(p<0.05)**

Performance Analysis

The data was analyzed using a mixed between and within subjects design. Separate analyses of variance were conducted on the following performance measures: inspection time, percentage defects correctly detected, number of false alarms, number of misses, total score on non-routine cards, score on the knowledge test (sections I and II) and the score on the hangar floor test. The mean score for the different experimental conditions along with the ANOVAs are shown in Tables 9 through 22. Analyses of variance showed training was significant for the following performance measures: percentage correctly detected (Figure 1.44), number of false alarms (Figure 1.45), misses (Figure 1.46), total score on non-routine cards (Figure 1.47). Although, the effect of training for the post training trail for the knowledge test (sections I and II) was not statistically significant, looking at Figure 1.48, it can be seen that the training group reported higher scores on the post training trail for the knowledge test on both sections I and II. The effect of pacing was significant for the following performance measures: inspection time, percentage correctly detected, number of false alarms, misses, and total score on non-routine cards. Interestingly, analyses of variance did not reveal any significant differences between groups for the hangar-floor test (Figure 1.49).

Table 1.9 Performance Measures Table

Group	Inspector Number	Inspection time (min)		Percentage correctly detected		Number of false alarms		Number of misses		Total score on non-routine work cards	
		Unpaced	Paced	Unpaced	Paced	Unpaced	Paced	Unpaced	Paced	Unpaced	Paced
	S1	26.60	27.02	45	40	13	40	11	12	7.50	6.50
Trained Group											
	S2	33.23	16.45	45	45	6	2	11	11	9.00	9.00
	S3	49.67	32.73	60	60	35	32	8	8	11.00	11.00
	S4	57.38	13.50	60	65	29	27	8	7	11.50	11.50
	S5	38.98	39.22	45	65	23	73	11	7	9.00	11.00
	S6	35.50	30.70	60	70	30	43	8	6	12.00	12.50
	S7	57.83	35.70	50	55	36	46	10	9	9.00	9.50
	S8	37.73	29.75	50	55	35	42	10	9	10.50	11.00
	S9	39.52	30.28	50	70	29	39	10	6	9.50	14.00
	Mean	41.83	28.37	51.67	58.33	26.22	38.22	10.00	8.00	9.89	10.67
	Std. Dev.	10.81	8.41	6.61	10.61	10.45	18.67	1.32	2.12	1.45	2.15
	S10	48.35	46.50	30	60	15	34	14	8	4.50	10.50
Control Group											
	S11	40.50	29.17	20	45	14	22	16	11	4.00	8.00
	S12	69.37	33.70	35	40	24	12	13	12	7.00	7.00

S13	9.30	6.27	15	15	13	29	17	17	3.00	3.00
S14	18.12	11.29	15	20	7	11	17	16	2.50	3.50
S15	21.58	19.24	35	35	2	5	13	13	7.00	6.50
S16	63.49	40.28	45	70	12	6	11	6	9.00	13.50
S17	55.46	31.52	40	50	20	20	12	10	7.00	10.00
S18	63.14	30.47	30	65	27	32	14	7	5.50	13.00
Mean	43.26	27.60	29.44	44.44	14.89	19.00	14.00	11.00	5.50	8.33
Std. Dev.	22.14	13.09	10.74	19.11	7.88	11.08	2.14	3.82	2.17	3.76

Score on non-routine work cards

$$\text{Score} = \sum_{i=1}^{20} S_i \qquad S_i = 0, 0.5, 1$$

0 = Incorrect
0.5 = Partially correct
1 = Correct

i = Number of questions

Table 1.10 Inspection Time

Source	df	SS	MS	F
Group	**1**	**.98**	**.98**	**0.001**
Pacing	**1**	**1906.20**	**1906.20**	**20.56***
Group * Pacing	**1**	**10.87**	**10.87**	**0.12**

*p<0.05

Table 1.11 Percentage Correctly Detected

Source	df	SS	MS	F
Group	**1**	**2934.03**	**2934.03**	**11.61***
Pacing	**1**	**1056.25**	**1056.25**	**16.10***
Group * Pacing	**1**	**156.25**	**156.25**	**2.38**

*p<0.05

Table 1. 12 Number of False Alarms				
Source	**df**	**SS**	**MS**	**F**
Group	**1**	**2100.69**	**2100.69**	**9.41***
Pacing	**1**	**584.03**	**584.03**	**5.95***
Group * Pacing	**1**	**140.03**	**140.03**	**1.43**

*$p<0.05$

Table 1.13 Number of Misses				
Source	**df**	**SS**	**MS**	**F**
Group	**1**	**117.36**	**117.36**	**11.61***
Pacing	**1**	**42.25**	**42.25**	**16.10***
Group * Pacing	**1**	**6.25**	**6.25**	**2.38**

*$p<0.05$

Table 1.14 Total Score on Non-routine Workcards				
Source	**df**	**SS**	**MS**	**F**
Group	**1**	**101.67**	**101.67**	**10.11***
Pacing	**1**	**29.34**	**29.34**	**10.78***
Group * Pacing	**1**	**9.51**	**9.51**	**3.49**

*$p<0.05$

Table 1.15 Knowledge Test Section I : Scores Obtained from set of 14 Questions			
	Subject	Before Training	After Training
Trained Group	T1	55	59
	T2	65	63
	T3	23	29
	T4	43	43
	T5	44	49
	T6	49	59
	T7	49	62
	T8	43	35
	T9	45	51
	Mean (Std. Dev.)	46.22 (11.24)	50.00 (12.20)
Control Group	C1	41	43
	C2	43	47
	C3	41	39
	C4	33	35
	C5	51	33
	C6	57	57
	C7	39	49
	C8	35	53
	C9	33	37
	Mean (Std. Dev.)	41.44 (8.11)	43.67(8.37)

Table 1.16 Knowledge Test Section I : Short Q & A (analysis)				
Source	df	SS	MS	F
Group	1	277.77	277.77	1.61
Condition	1	81.00	81.00	2.42

Group * Condition	**1**	**5.444**	**5.44**	**0.16**

*p<0.05

Table 1.17 Knowledge Test Section II : Scores Obtained from set of 30 Questions

	Subject	Before Training	After Training
Trained Group	T1	25	28
	T2	29	29
	T3	28	28
	T4	28	29
	T5	25	28
	T6	29	30
	T7	28	27
	T8	29	29
	T9	28	29
	Mean (Std. Dev.)	27.67 (1.58)	28.56 (0.88)
Control Group	C1	27	28
	C2	28	30
	C3	25	25
	C4	25	26
	C5	26	25
	C6	24	28
	C7	27	27
	C8	28	23
	C9	25	28
	Mean (Std. Dev.)	26.11 (1.45)	26.67 (2.12)

Table 1.18 Knowledge Test Section II : Multiple Choice (analysis)

Source	df	SS	MS	F
Group	1	26.69	26.69	9.59*
Condition	1	4.69	4.69	2.17
Group * Condition	1	0.25	0.25	0.12

*p<0.05

Table 1.19 Summary of F values from ANOVA (Tables 8-12)

Source	Inspection Time (min)	Percentage Correctly Detected	Number of False Alarms	Number of Misses	Total Score non-routine work cards
Group	0.00	11.61*	9.41*	11.61*	10.11*
Pacing	20.56*	16.10*	5.95*	16.10*	10.78*
Group * Pacing	0.12	2.38	1.43	2.38	3.49

*p<0.05

Table 1.20 Summary of F values from ANOVA (Tables 14 & 16)

Source	Short Q & A	Multiple Choice test
Group	1.61	9.59*
Trial	2.42	2.17
Group * Trial	0.16	0.12

*p<0.05

Table 1.21: Mean scores of Hangar Floor Test		
	Subject	After Training
Trained Group	T1	25
	T2	21
	T3	21
	T4	19
	T5	23
	T6	23
	T7	21
	T8	21
	T9	21
	Mean (Std. Dev.)	21.67 (1.73)
Control Group	C1	23
	C2	23
	C3	23
	C4	23
	C5	19
	C6	17
	C7	19
	C8	14
	C9	23
	Mean (Std. Dev.)	20.44 (3.36)

Table 1.22: Hangar Floor Test (analysis)				
Source	df	SS	MS	F
Group	1	6.72	6.72	0.94
*p<0.05				

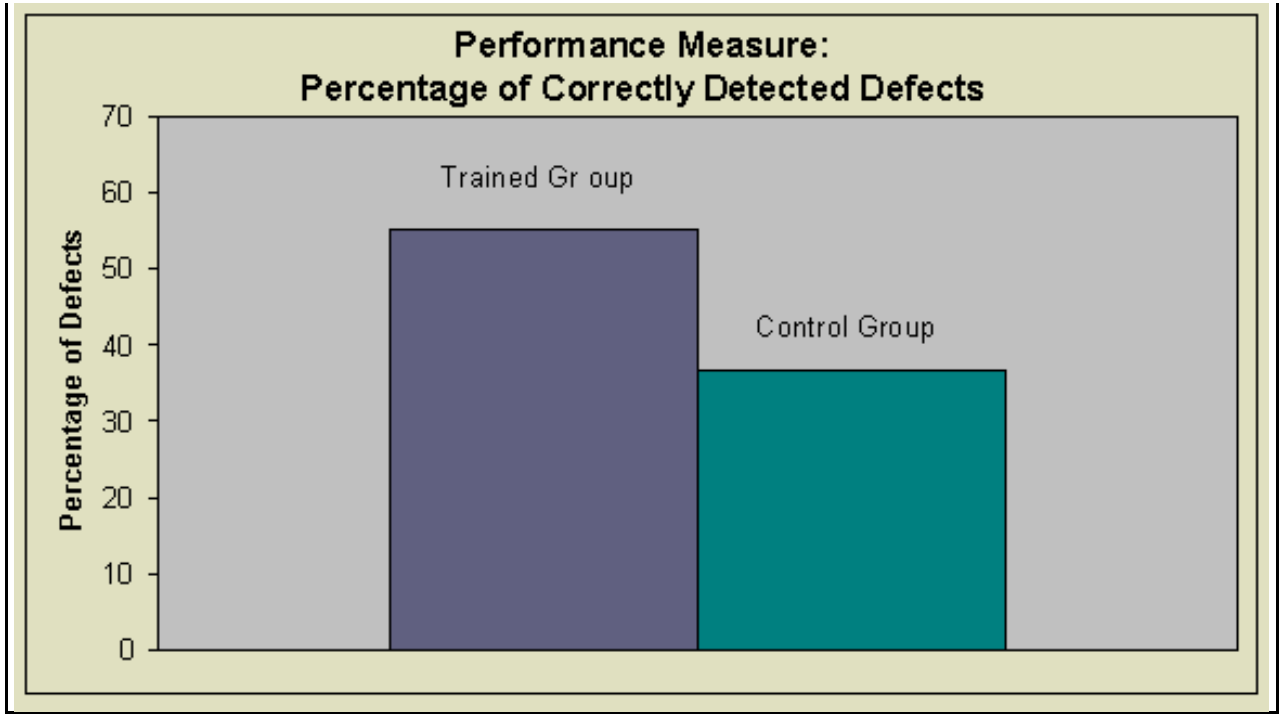


Figure 1.44 Performance Measure: Percentage of Correctly Detected Defects

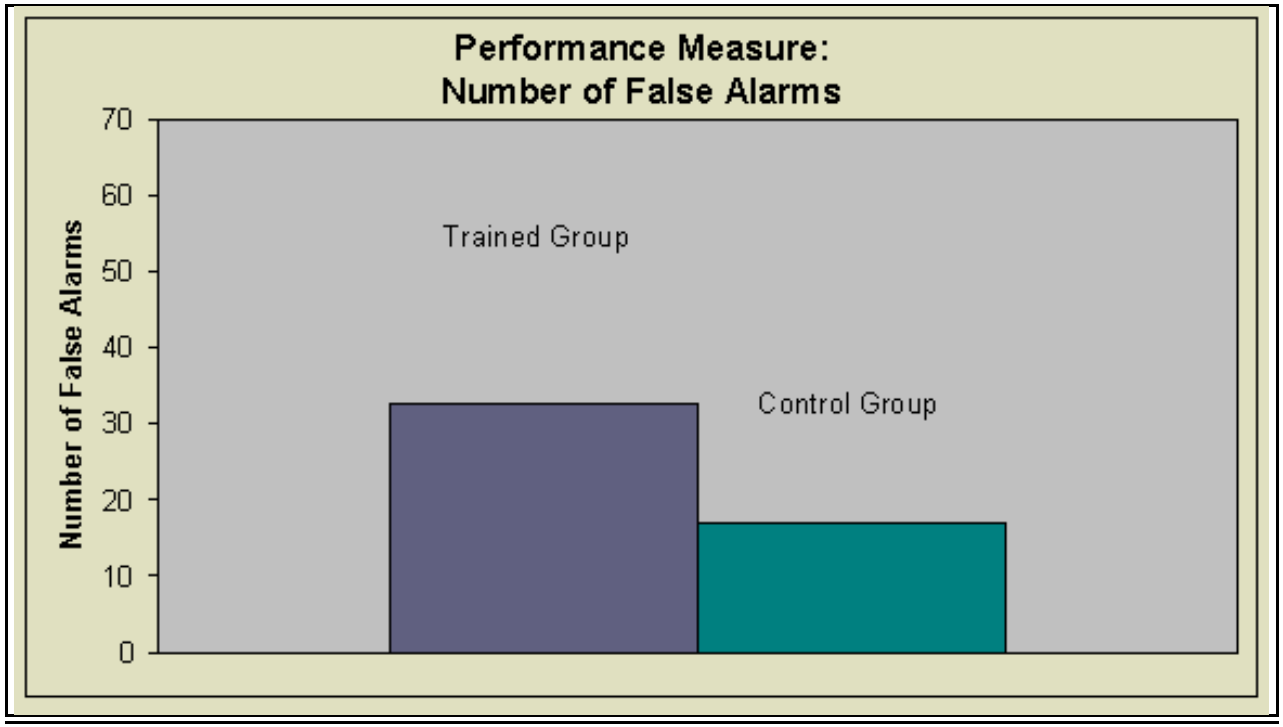


Figure 1.45 Performance Measure: Number of False Alarms

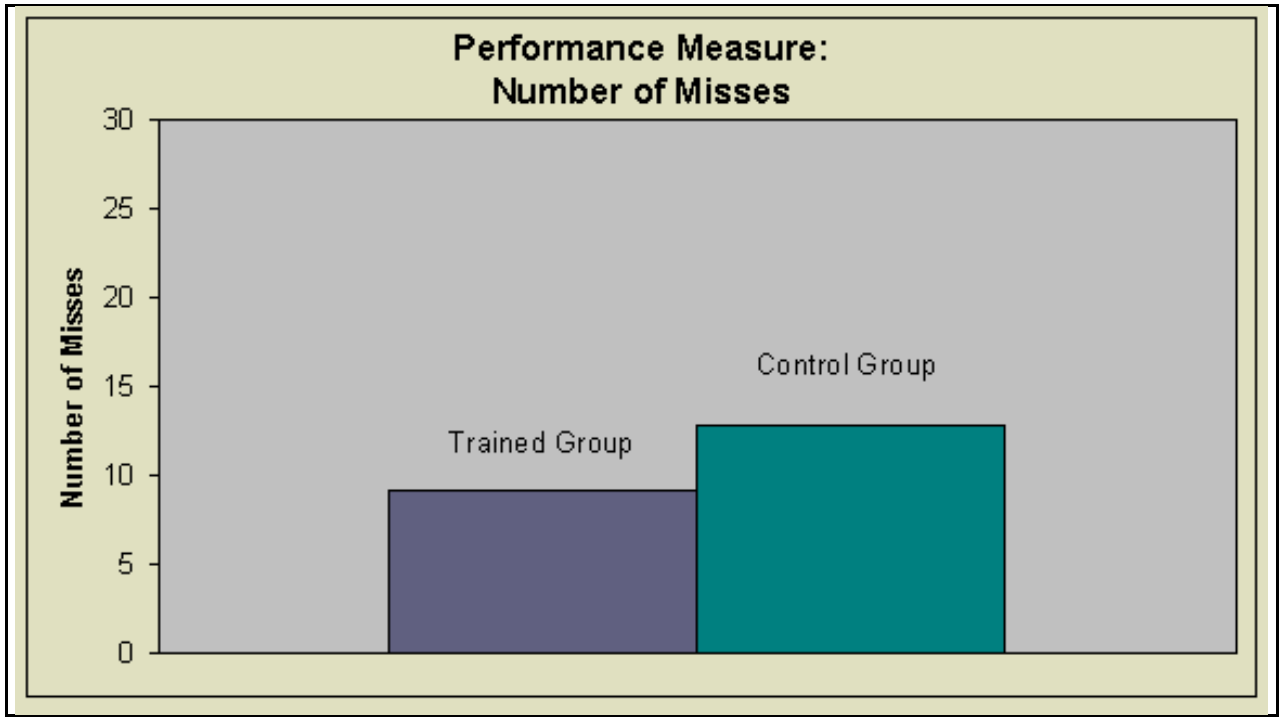


Figure 1.46 Performance Measure: Number of Misses

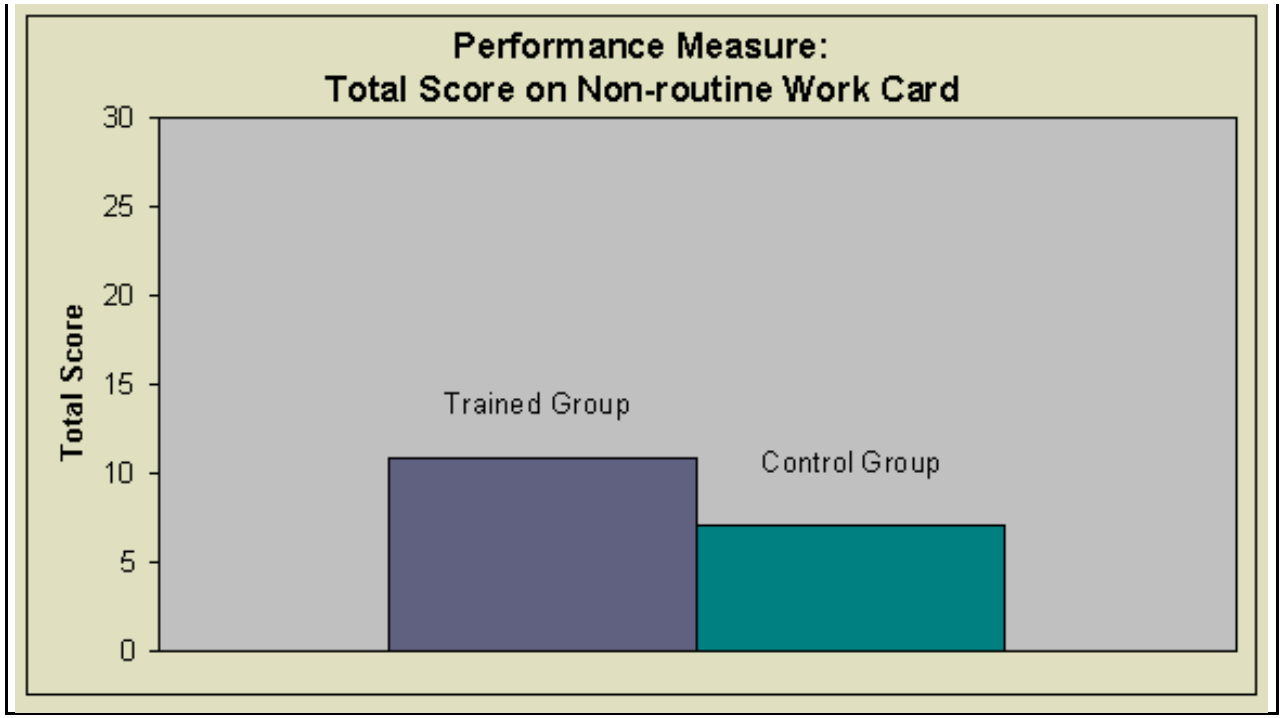


Figure 1.47 Performance Measure: Total Score on Non-routine Work Card

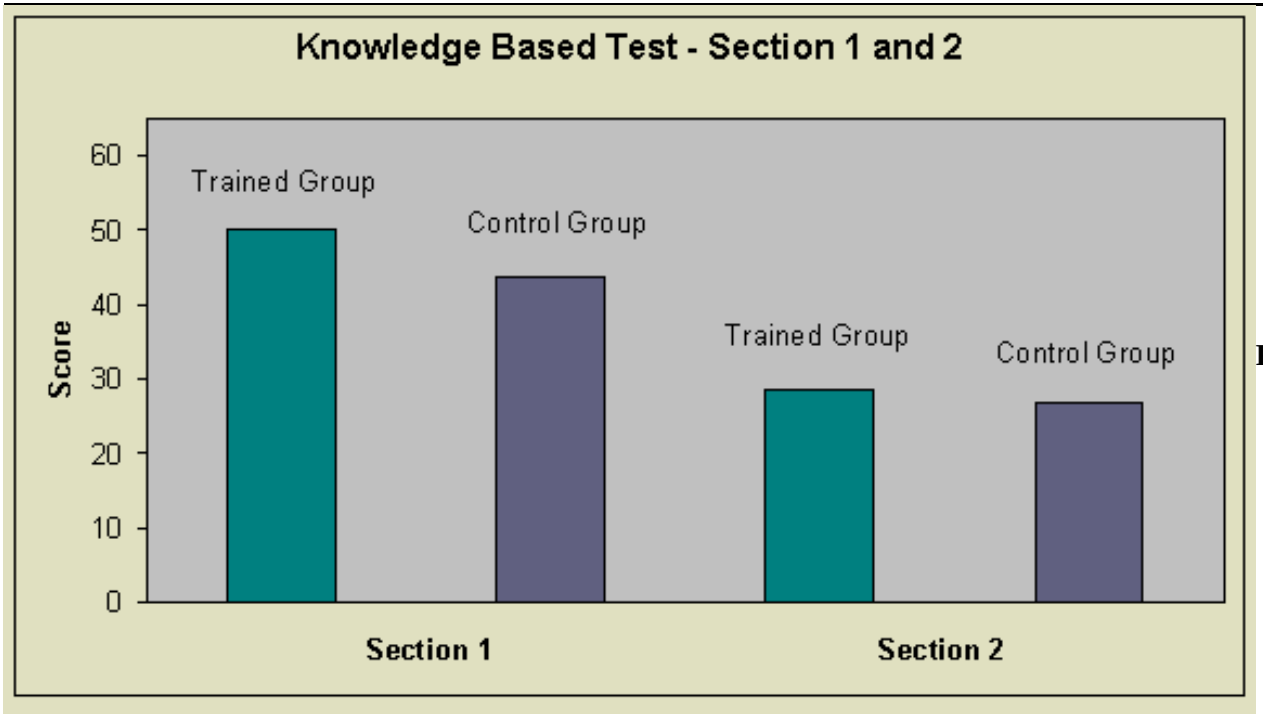


Figure 1.48 Performance Measure: Knowledge Based Test–Section 1 and Section 2

The results are unequivocal as to the usefulness of the system as perceived by the inspectors and supervisors. The usability analysis clearly demonstrates that the system was well-liked and easy to use. This is a testament to the task analytic and the iterative development methodology used in developing ASSIST. The system developers worked closely with aircraft maintenance personnel--inspectors, supervisors, training departments and quality assurance staff--in developing the system to ensured it was not only appropriate in its content and addressed the inspection training needs of aircraft maintenance organization but also user-friendly.

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.

Moreover, 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. Significantly improved performance for the training group in completing the non-routine card has information has obvious implications for incorporating ASSIST training as part of regular inspection training. The training program also resulted in improved inspection knowledge about the job. The content of ASSIST helped the inspectors in the training group develop a better understanding of the “inspection job” as indicated by the higher scores on the post-training knowledge test, a response supported by the subjects’ feelings regarding the appropriateness of the content as shown by the high scores assigned to content related questions on the usability questionnaire for both the general and simulation modules, specifically questions 1, 2 and 3 for the general modules and questions 2 and 3 for the simulation module.

Inspectors reported that the information provided by the general and simulation modules should be part of any inspection training. Moreover, they also stated that ASSIST training should be incorporated into the existing training for inspectors. Although the hangar floor test did not show significant differences between the two groups, these results were expected. Unlike the simulation tests in which there was greater experimental control, the hangar floor test was conducted in an uncontrolled hangar environment. Moreover, the hangar floor tests were conducted following the knowledge test, suggested that performance on the latter may have resulted in all subjects spending extra time reviewing material on their own, thus explaining the lack in sensitivity to inspection training.

1.5.3 Conclusions

In summary, the results have demonstrated the benefits of a well-designed computer based inspection training program. ASSIST not only improved performance but also was well accepted by inspectors. The following specific conclusions can be drawn from this study.

1. Improved Inspection Performance: Training using ASSIST translated into improved knowledge of the inspection task, resulting in reduced errors in the form of a significantly higher percentage detected, fewer misses and more correct write-ups for non-routine cards.

2. High Level of User Satisfaction: Usability evaluation clearly revealed that inspectors with different levels of computer experience could easily use a computer-based training tool. The high scores obtained for the various usability dimensions is a testament to the task analytic and iterative and customer focused methodology employed in development of ASSIST.

3. Standardized Method for Inspection Training: ASSIST can help standardize the aircraft inspection training process by ensuring similar content across inspection training curriculums.

4. Completeness: Inspectors can be exposed to a wide variety of defects with varying degrees of severity at different locations through the use of a library of defect images. Inspectors can also be trained on less frequently occurring critical defects.

5. Adaptability: ASSIST can be modified to meet the needs of individual inspectors. Batch files of images can be created to train inspectors on particular aspects of the inspection task with which they have the greatest difficulty. Thus, the program can be tailored to accommodate individual differences in inspection abilities.

6. Efficiency: Since the training will be more intensive, the trainees will be able to become more skilled in a shorter period of time.

7. Integration: The training system will integrate different training methods, for example, feedback training, feed-forward training, and active training into a single comprehensive training program.

8. Certification: ASSIST can be used as part of the certification process. Since the record keeping process can be automated, instructors can more easily monitor and track an individual's performance, initially for training and later for retraining.

9. Instruction: ASSIST could be used by instructors in FAA certified A&P schools for training. Under these conditions, for example, aircraft maintenance technicians could gain exposure to defects on wide-bodied aircraft that they might not have otherwise.

Although, the training group showed significant improvements in performance, we still do not know whether the training was effective for all inspectors because as literature has shown, large differences exist in inspection abilities. Unless we answer this very important question, developers of training program will tend to design strategies insensitive to individual differences in aircraft inspection abilities. In light of this situation, it is clear that we must identify training strategies to compensate for individual differences in inspection abilities to raise performance to a higher level. The individual differences issue was addressed as part of year 3 activities.

1.6 IMPROVING INSPECTION PERFORMANCE: STUDY OF INDIVIDUAL DIFFERENCES - YEAR 3

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.[20] 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.

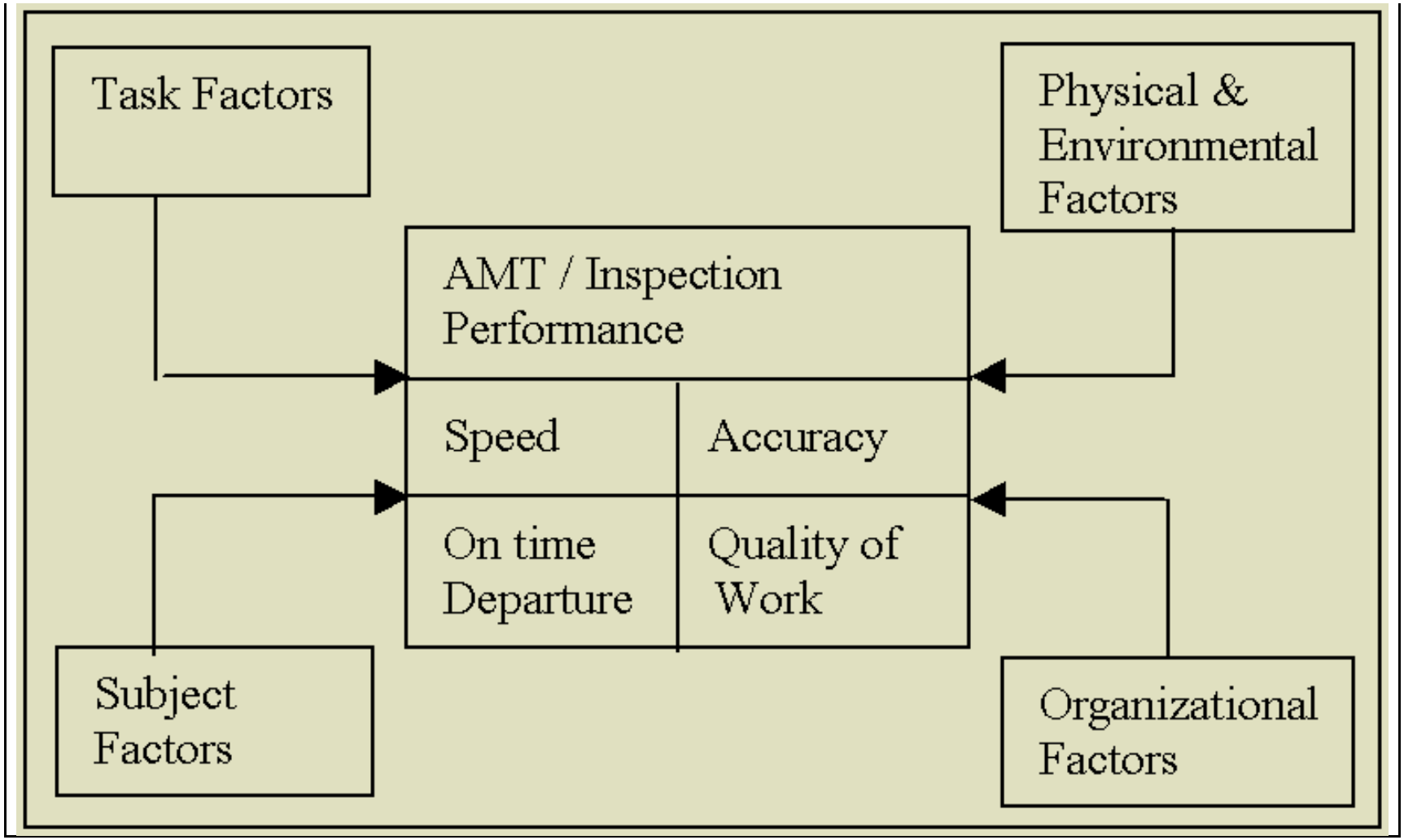


Figure 1.49 Factors Impacting Aircraft Inspection Performance

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 1.49).[17,66]

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.[20,21,32] 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 1.23 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 1.23 Tests used as predictors of Individual Differences

Individual Difference	Test	Measures	Significance
Student subjects vs. inspectors	---	Student or industrial inspectors	None[26]
Age	Demographics survey	Age	Good[37,46]
Experience	Demographics survey	Years of work experience	Good[3,46]
Gender	Demographics survey	Gender	Good[46,64]
Visual Acuity	---	20/20 vision	High[48,69]
Lobe Size	Measure of fixation point	Area around fixation point	Good[25]
Aptitude Skills	Harris Inspection Test	Identify unmatching objects	High(electronics) [35]
	WAIS	IQ test	Good[25]
	Short Term Memory	Memory – short-term	Weak[25]
	Gordon Test	Photographic memory	Good[25]
Cognitive	*EFT	Identify embedded context	High[25]
Behavior	Eysenck	Introversion/extroversion	Mixed[25,68]
	Guilford-Zimmerman	Sociability,stability restraint	Low[69]
	MMPI	Guardedness, anxiety	Low[69]
	MFFT	Impulsives/reflectives	High[59]
	*Locus of Control	Introversion/extroversion	High[19,57]
	*Certainty Equivalence	Risk seekers, risk aversion	N/A[54]
	*Myers-Briggs	Introversion,sensing,thinking	N/A[49]

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.[25,49,55,63]

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.[2,7,44] 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.[16,34,69] 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 FAA[20,28]). 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.[69] 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.[16,69] 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.[69] Using realistic photographic images as a training aid in controlled practice with feedback has also been shown to be superior to only OJT.[41,69]

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.[8] 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.[29,41] Similarly, Drury and Chi studied human performance using a high fidelity computer simulation of a printed circuit board inspection.[11] 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.30

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.

1.6.1 METHODOLOGY

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.

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 1.24).

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.30 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 1.24 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 Section II: 30 multiple choice questions total (taken from the ASSIST software)	Demonstration test
9 subjects Trained	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
9 subjects Control	**X**	**X**	X	X	X	**X**	**X**	**X**	**N/A**	**N/A**	**X**	**X**	**X**

Procedure

At the outset all the subjects completed a consent form (Figure 1.50) and a demographics questionnaire (Figure 1.51) 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 1.52), the Myers-Briggs Test (Figure 1.53), the Locus of Control Test (Figure 1.54), and the Responsible Risk Taking Inventory Test (Figure 1.55).25,49,55,63

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 _____

Figure 1.50 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 1.51 Demographics questionnaire

GROUP EMBEDDED FIGURES TEST

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

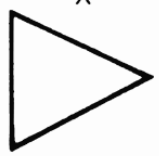
Name _____ Sex _____

Today's date _____ Birth date _____

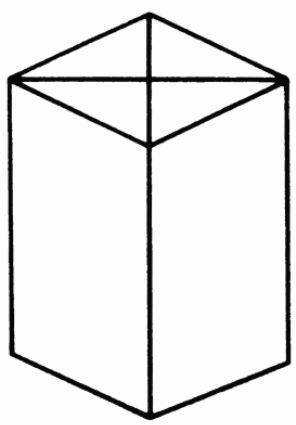
INSTRUCTIONS: This is a test of your ability to find a simple form when it is hidden within a complex pattern.

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.

complex figure as when it appeared alone.

Figure 1.52 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 1.53 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 1.54 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 1.55 Responsible Risk Taking Inventory Test

In the simulation training portion, subjects were provided inspection training on the computer-simulated aircraft inspection task (Figures 1.56 through 1.59). 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 1.60). 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 1.61). 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 1.62).

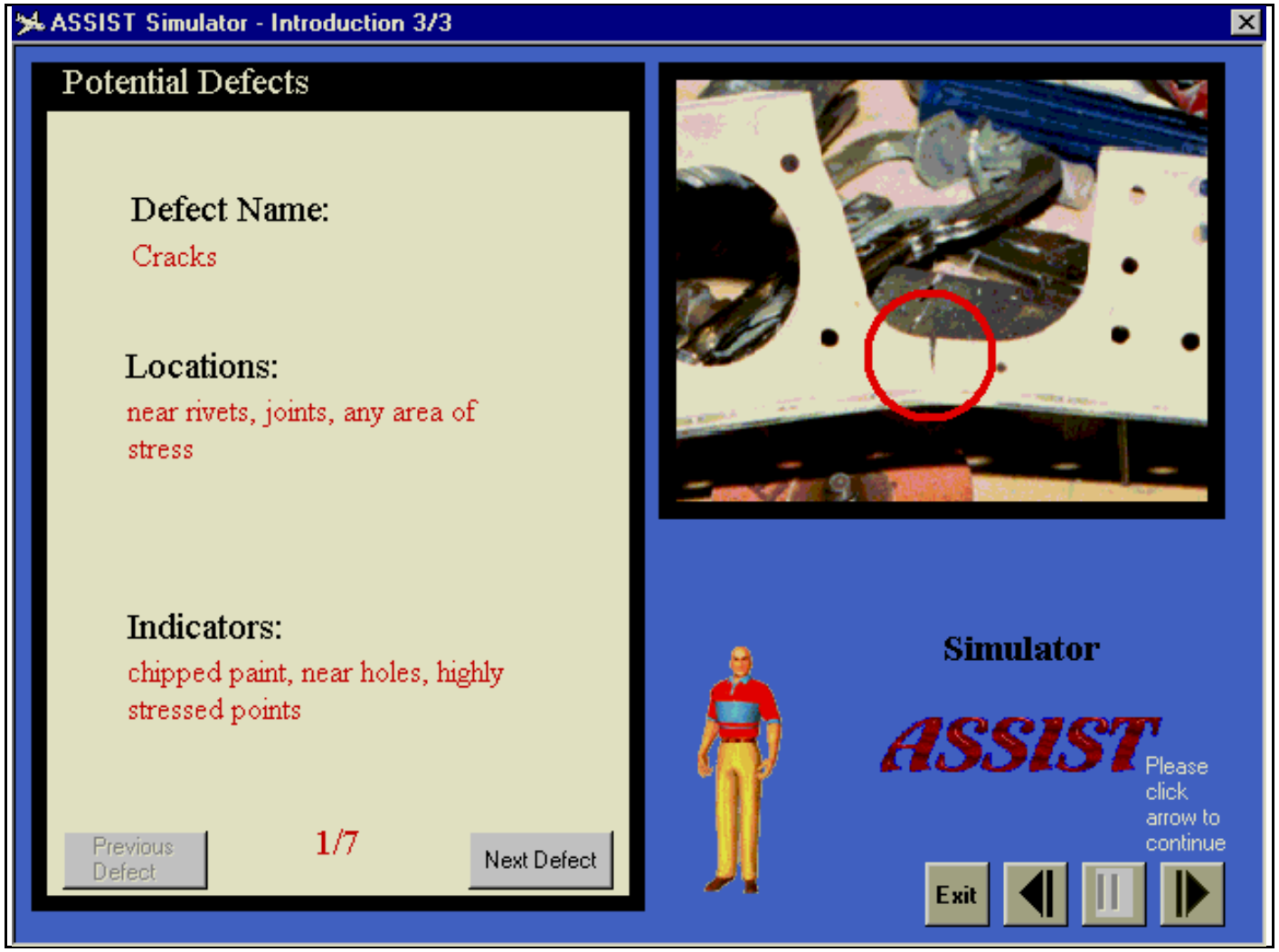


Figure 1.56 The Crack Defect Simulated in ASSIST

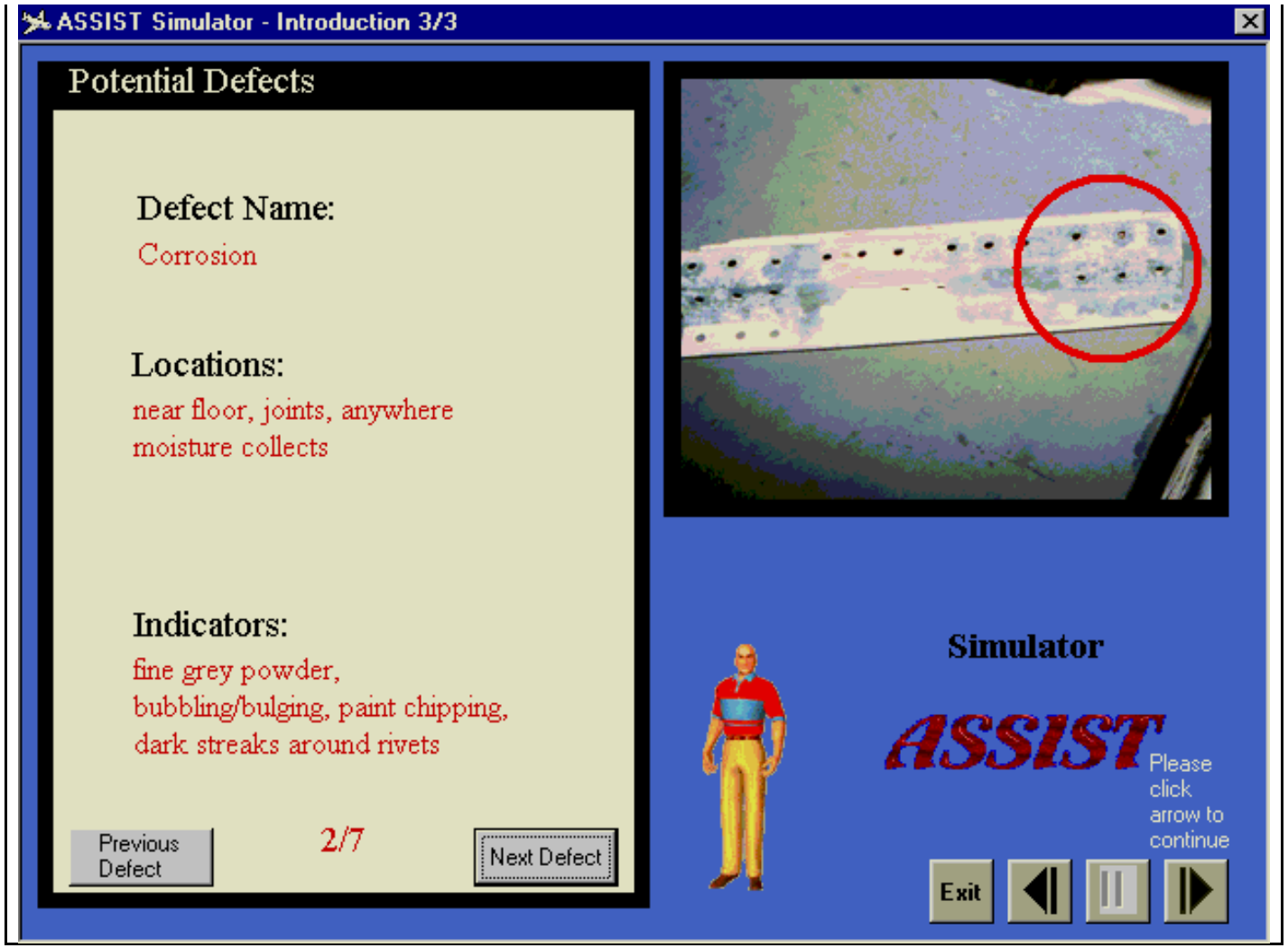


Figure 1.57 The Corrosion Defect Simulated in ASSIST

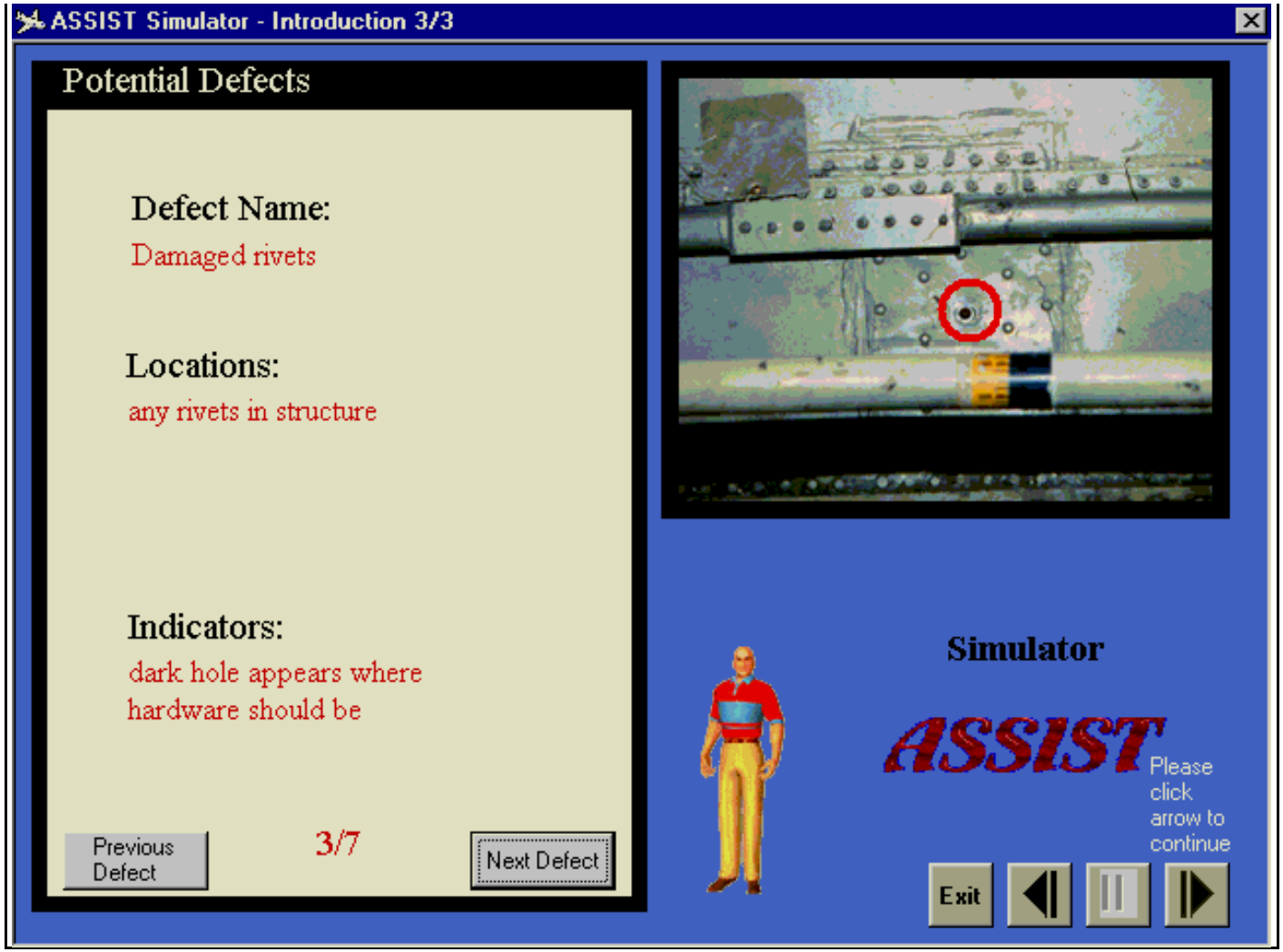


Figure 1.58 The Damaged Rivet Defect Simulated in ASSIST

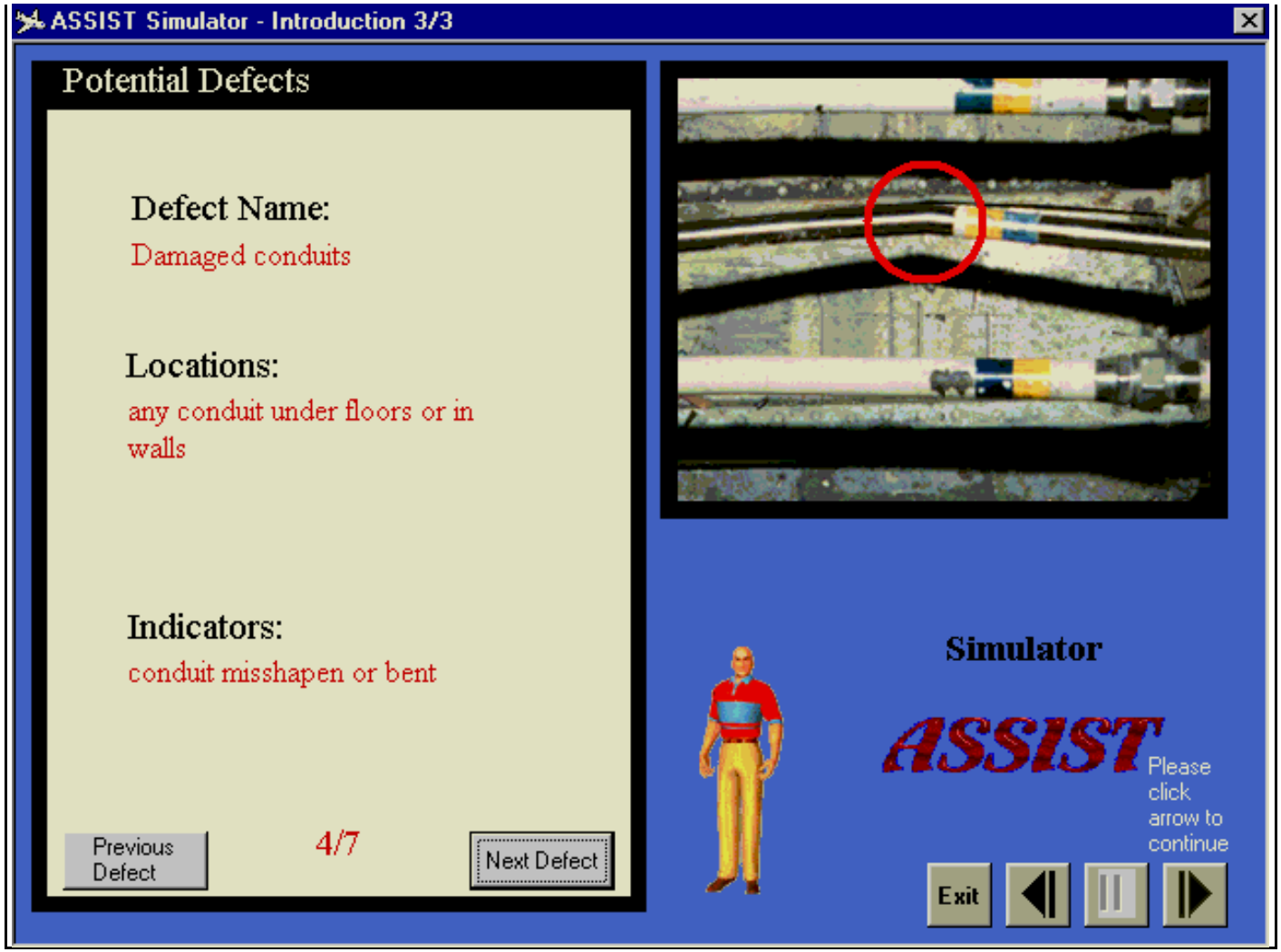


Figure 1.59 The Damaged Conduit Defect Simulated in ASSIST

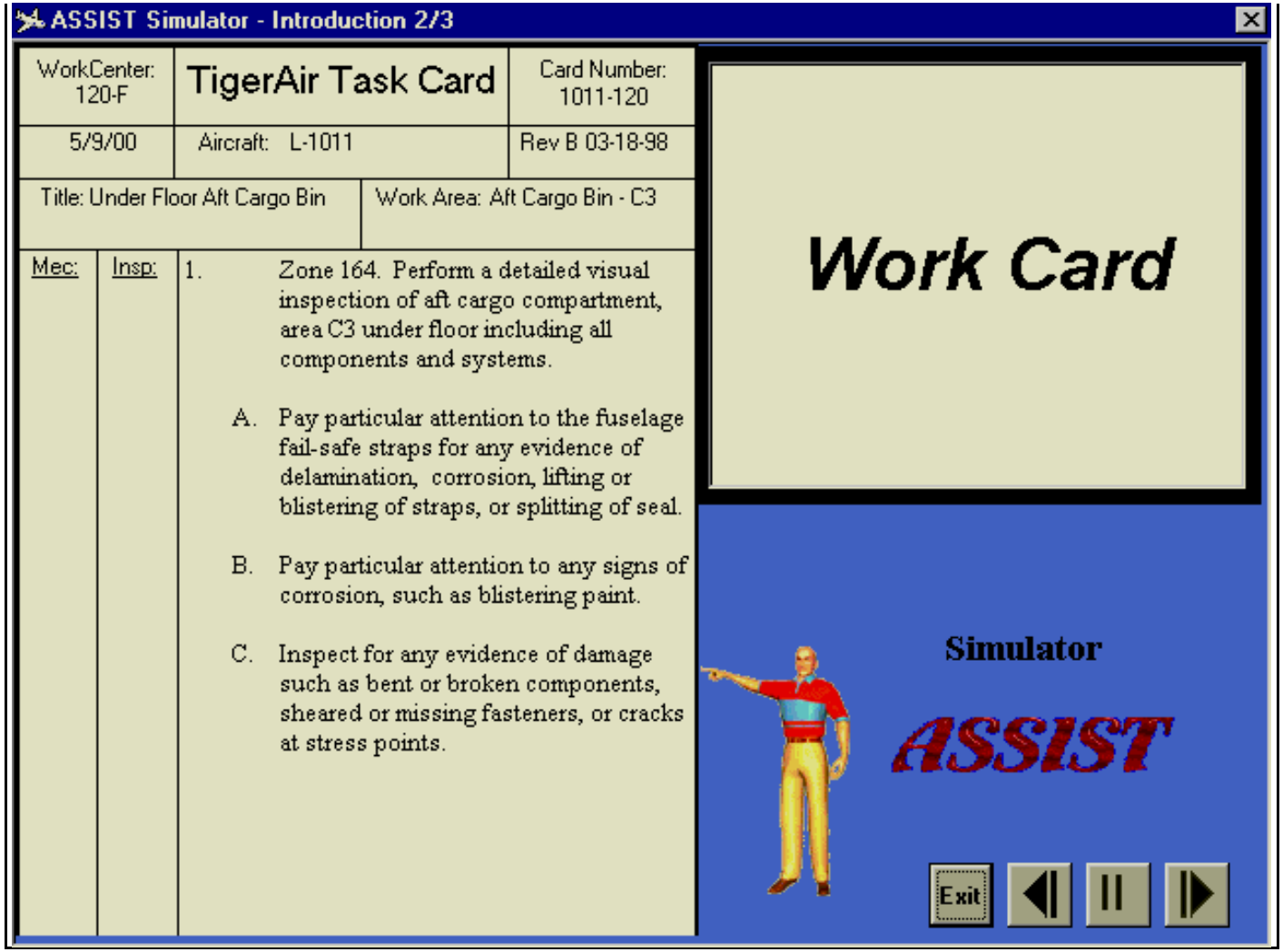


Figure 1.60 Work Card Used to for the Simulation in ASSIST

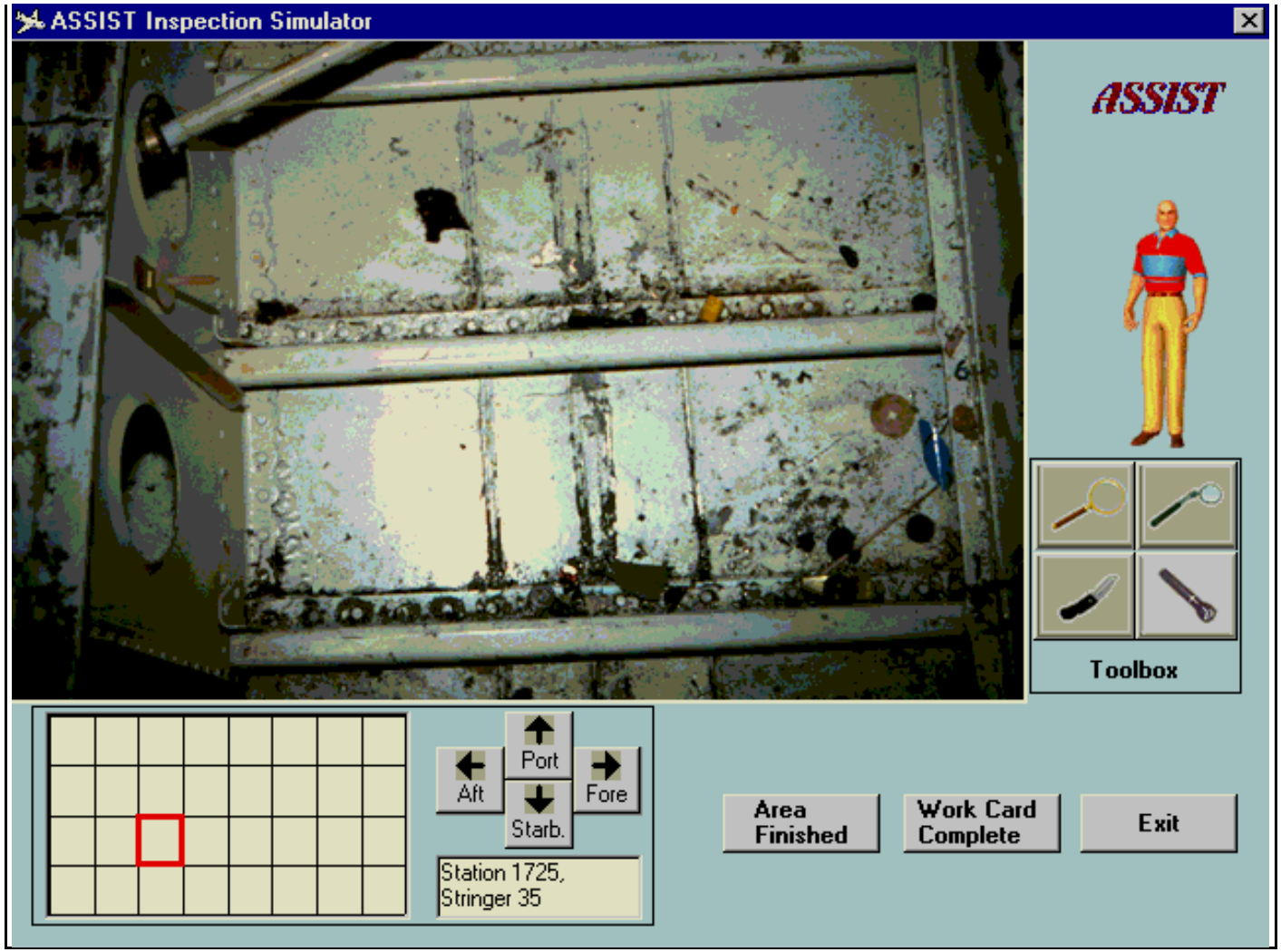


Figure 1.61 Simulation Module Containing a Picture of the Aft-Cargo Bin

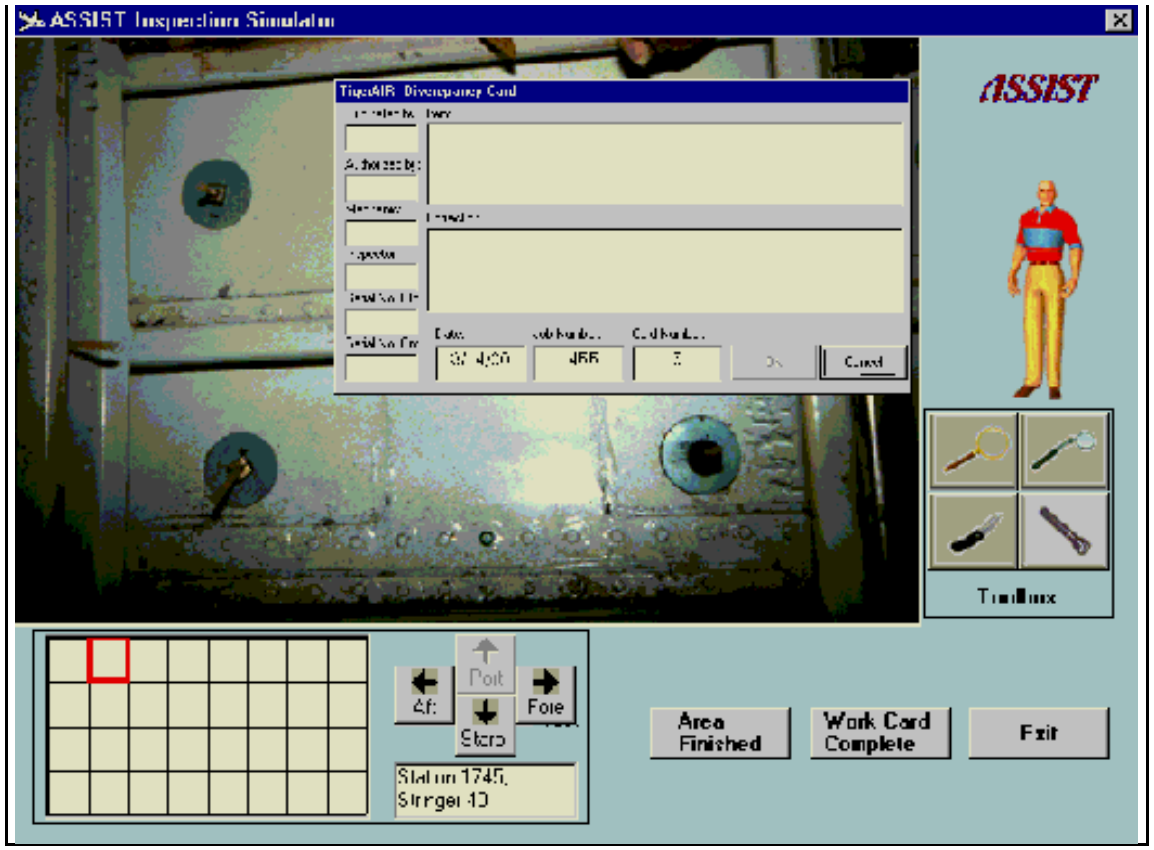


Figure 1.62 Non-routine card used to Write-up Defects Found in the Simulator

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 1.63). The elements of the simulation module are shown in Table 1.25.

Table 1.25 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

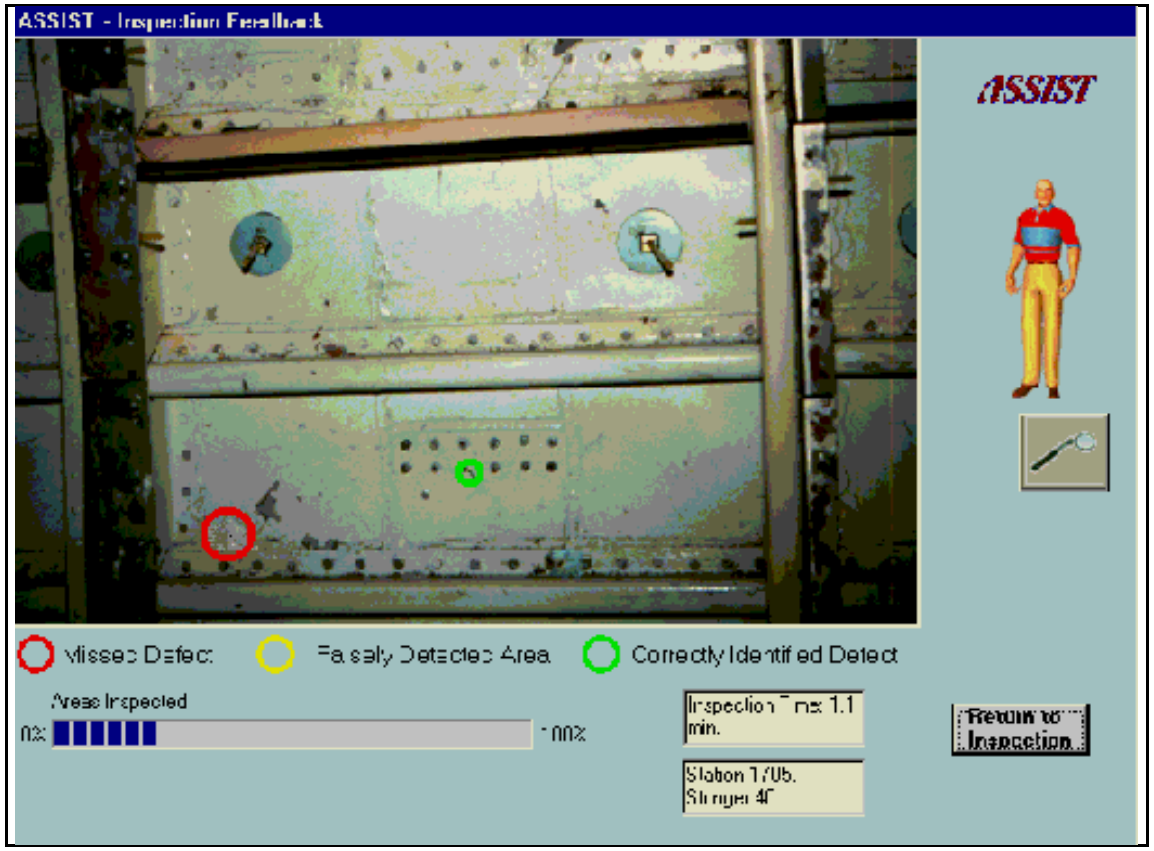


Figure 1.63 Feedback Provided in the Simulation Module

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[49]
- Group Embedded Figures Test (GEFT) [51]
- Locus of Control Test (LOC) [55]
- Responsible Risk Taking Inventory Test [63]

- 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[1] from the non-routine workcard write-up.

1.6.2 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.

Speed Measures

ANOVA conducted on mean inspection time showed a significant main effect of pacing with no significance for training or interaction effect (Table 1.26).

Table 1.26 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**

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 1.26)

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).

1.6.3 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.[15] 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.[14] 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.[30] 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.[49] 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.[19,24,57] 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.[19] 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.[19] 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.[68]

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.[46] 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”.[70] 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.[25] 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.[25] 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.[20,21,25]

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.[67] 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.

1.6.4 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.

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.32 The flow chart of the standardized protocol is shown in Figure 1.64.

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.33 Table 1.27 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.

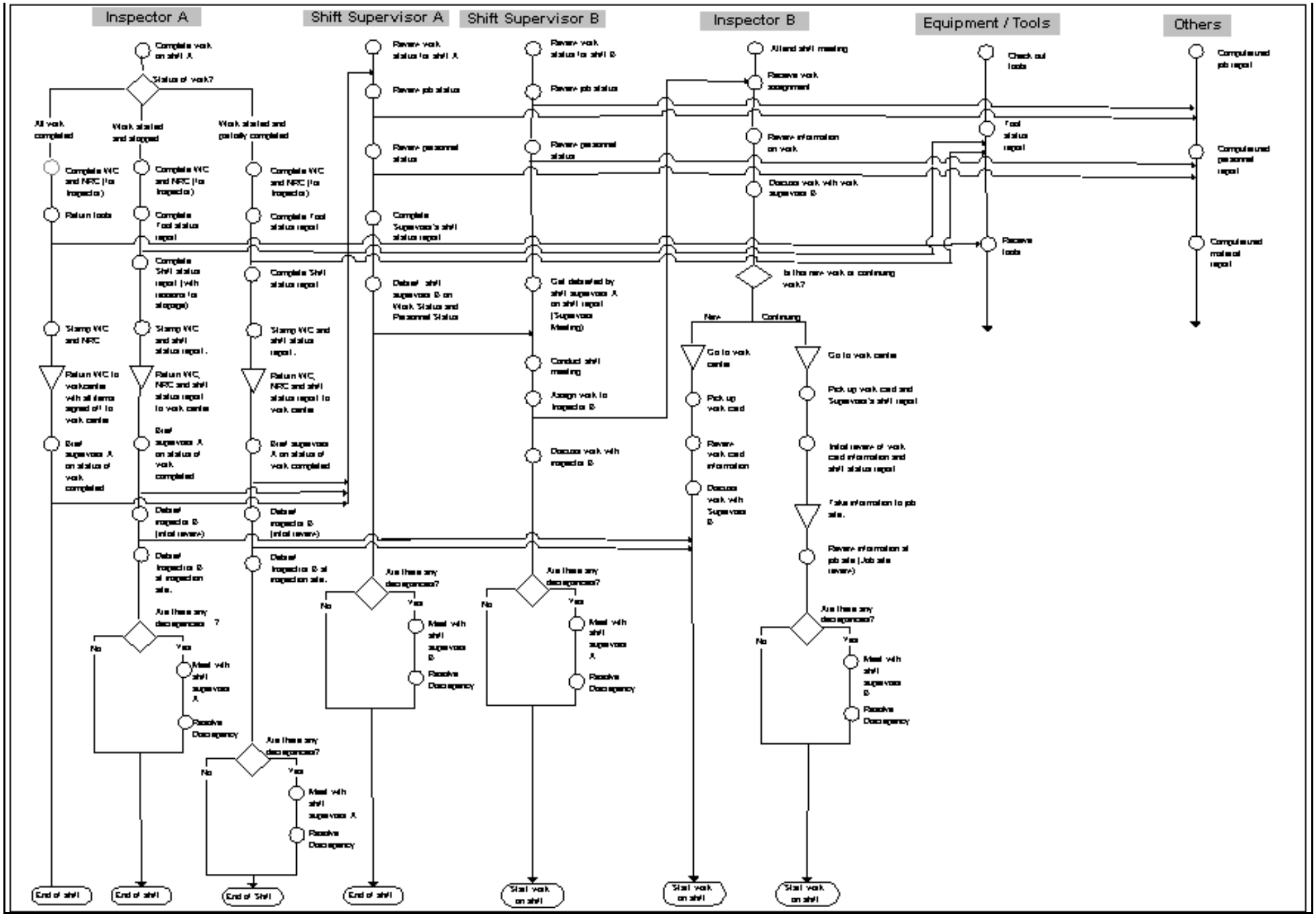


Figure 1.64 Standerdized Shift Change Protocol

Table 1.27 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
1. Wheel well hydraulic tubing conduits	• Condition • Corrosion • Fluid leakage
2. Wheel well doors linkages springs, stop cables, drive rods and hinges	• Condition • Visual damage • Corrosion • Security
3. Downlock markings	• General condition • Cleanliness
4. NLG alignment spotlight	• Check
5. NLG taxi light	• Cleanliness • Filament condition • Security of assembly
6. NLG doors	• Closed doors • Secured doors (procedure given)
7. Aircraft wheel checking placard (location given)	• Condition • Security

Structure	Defects
1. NLG shock stout, bracestrut, torque arm, ground sensing mechanism, cables, actuating cylinder, linkages, springs	• Corrosion • Visual damage • Nicks & dings • Fluid leaks • Security
2. Landing gear shock strut	• Check for normal extension • Cleanliness • Clean exposed portion of piston with red hydraulic oil & wipe dry
3. Nose steering mechanism	• Condition • Leakage • Worn cables • Release of nose steering bypass • Check spring landed to steering position
4. Torque links	• Loose bushings and bolts • Worn bushings and bolts
5. Landing gear lock pins & red warning streamers	• Condition • Secure attachment of streamers to lock pins • Length of streamers should be 24-32" long

Structure	Defects
1. Wheel hub valves, tie bolts	• Condition • Corrosion
2. Tires	• Excessive wear • Oil soaking • Correct pressure - only after 2 hours of parking • Reinflate with NL
3. Water deflector assembly	• Damage • Security of installation

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.

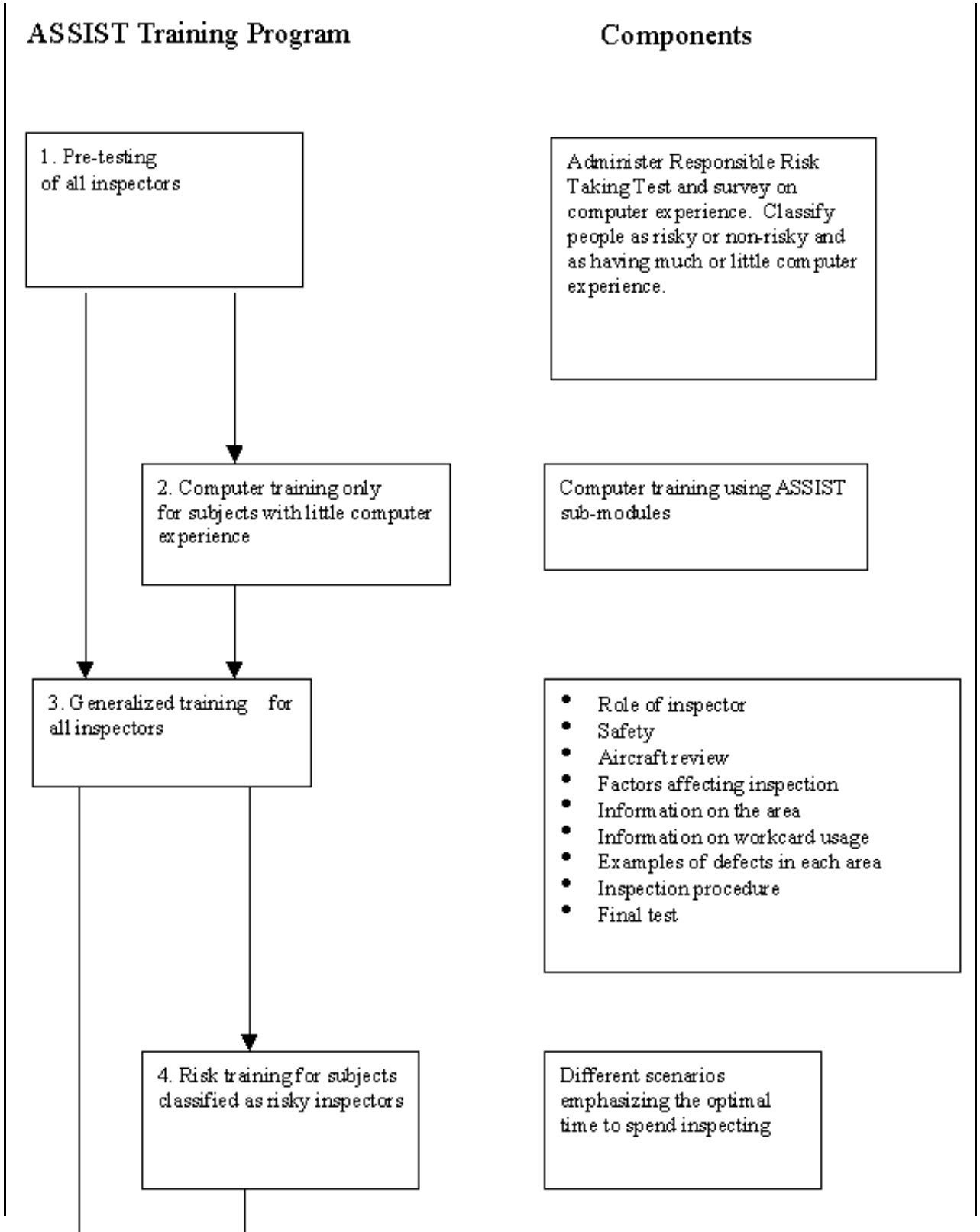
4. Risk Training. Following the generalized training, the subjects who were classified by the pretest as risky would be administered active training with feed forward information to reduce their risk tendencies by reviewing different inspection scenarios to determine their optimal search time. Since 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 1.28 and Figure 1.65 outline the steps, content, method, and delivery system of the training program described above.

Table 1.28 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


ASSIST Training Program
Components
1. Pre-testing of all inspectors
Administer Responsible Risk Taking Test and survey on computer experience. Classify people as risky or non-risky and as having much or little computer experience.
2. Computer training only for subjects with little computer experience
Computer training using ASSIST sub-modules
3. Generalized training for all inspectors
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
4. Risk training for subjects classified as risky inspectors
Different scenarios emphasizing the optimal time to spend inspecting

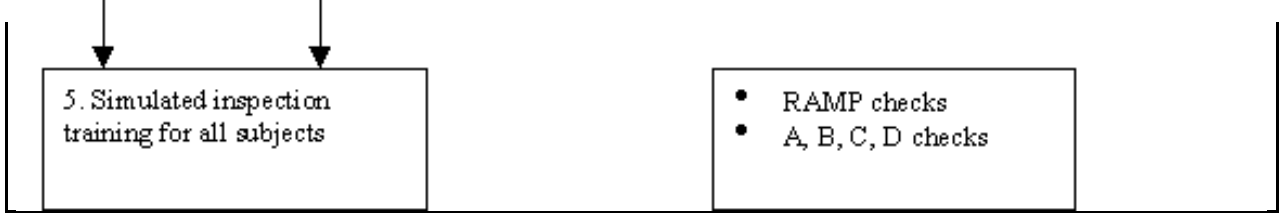


Figure 1.65 ASSIST Training Program

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.

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1.8 APPENDICES

1.8.1 Appendix A- Selection Tests

Vision tests measure the visual capabilities of the individual by quantitatively measuring eye characteristics such as accommodation and acuity.57 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.57 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.46 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.39 Studies have shown that subjects with larger visual lobes are more efficient detecting faults early in the search process.58 While Gallwey found lobe size to be a good predictor for error classification in an inspection task.25

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.6 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.27

Aptitude tests, for example intelligence tests, measure overall performance over a broad range of mental capabilities such as verbal and numerical skills.43 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.15,35

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.25

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.25

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.25

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.68 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.46 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".70 Gallwey found that EFT was a good predictor of many measures including stopping time, missing rate, size errors, decision errors, and classification errors.25 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.68 There are mixed findings using the Eysenck Personality Inventory Test to study inspection tasks.25 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.68,69

3. *The Minnesota Multiphasic Personality Inventory (MMPI).* Used to measure manifest anxiety, the degree of guardedness in responding, and falsification in responding.69 There is low correlation between inspection performance and the MMPI.69 Used to identify people with mental illness or personality disorders, it is not an appropriate test for employee selection.68

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.59 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.55 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.24 Eskew and Riche, found LOC may be related to response-wise signal detection tasks and may be useful in selecting quality control inspectors.19 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.19 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.24,57

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.5

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.54,68

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.49 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.

1.8.2 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	

* $p<0.05$

1.8.3 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	

* $p<0.05$

1.8.4 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	

* $p<0.05$

1.8.5 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	

* $p<0.05$

1.8.6 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

1.8.7 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)

1.8.8 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

1.8.9 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

1.8.10 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

1.8.11 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