

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.

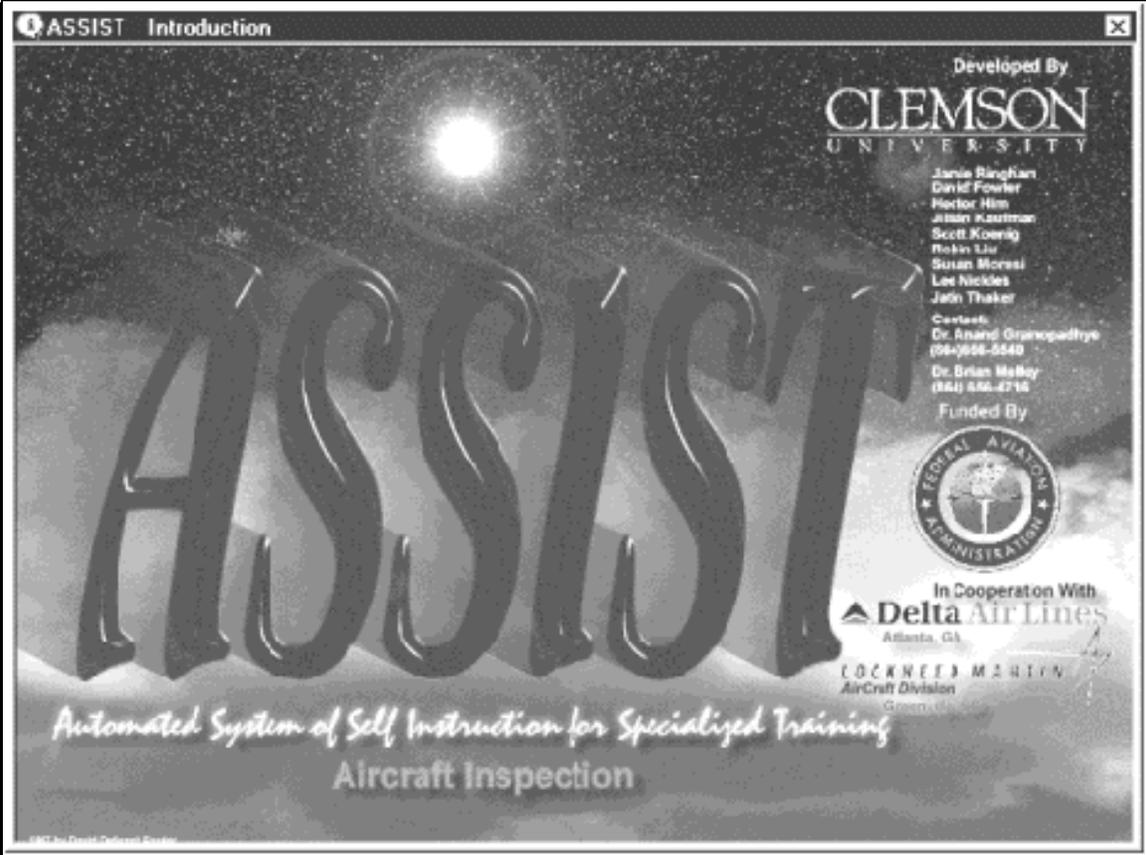


Figure 1.1 ASSIST Title Screen

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 systems[18,41](#) 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.



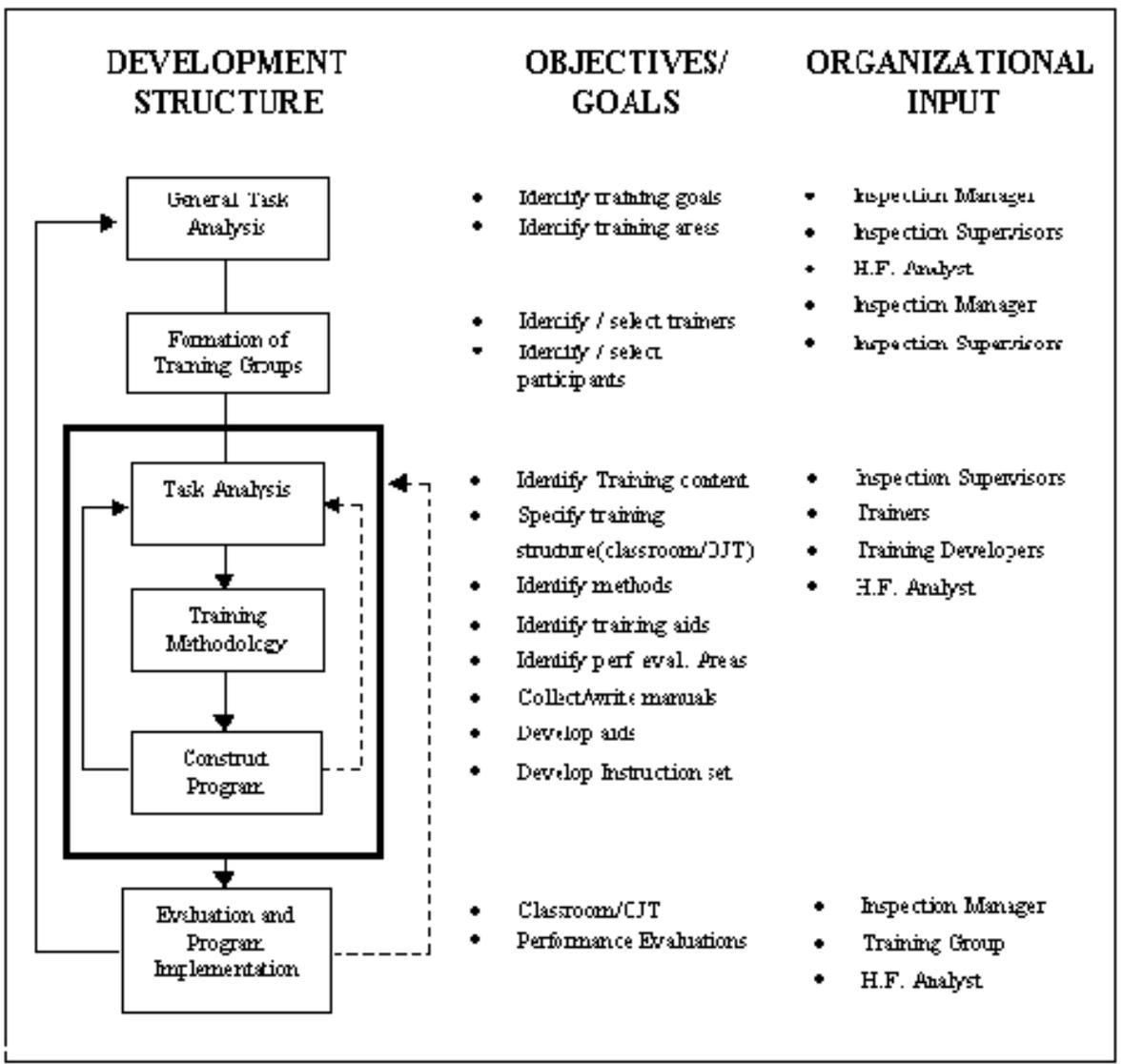


Figure 1.2 Model for Training Program Development in Commercial Aviation

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](#)).

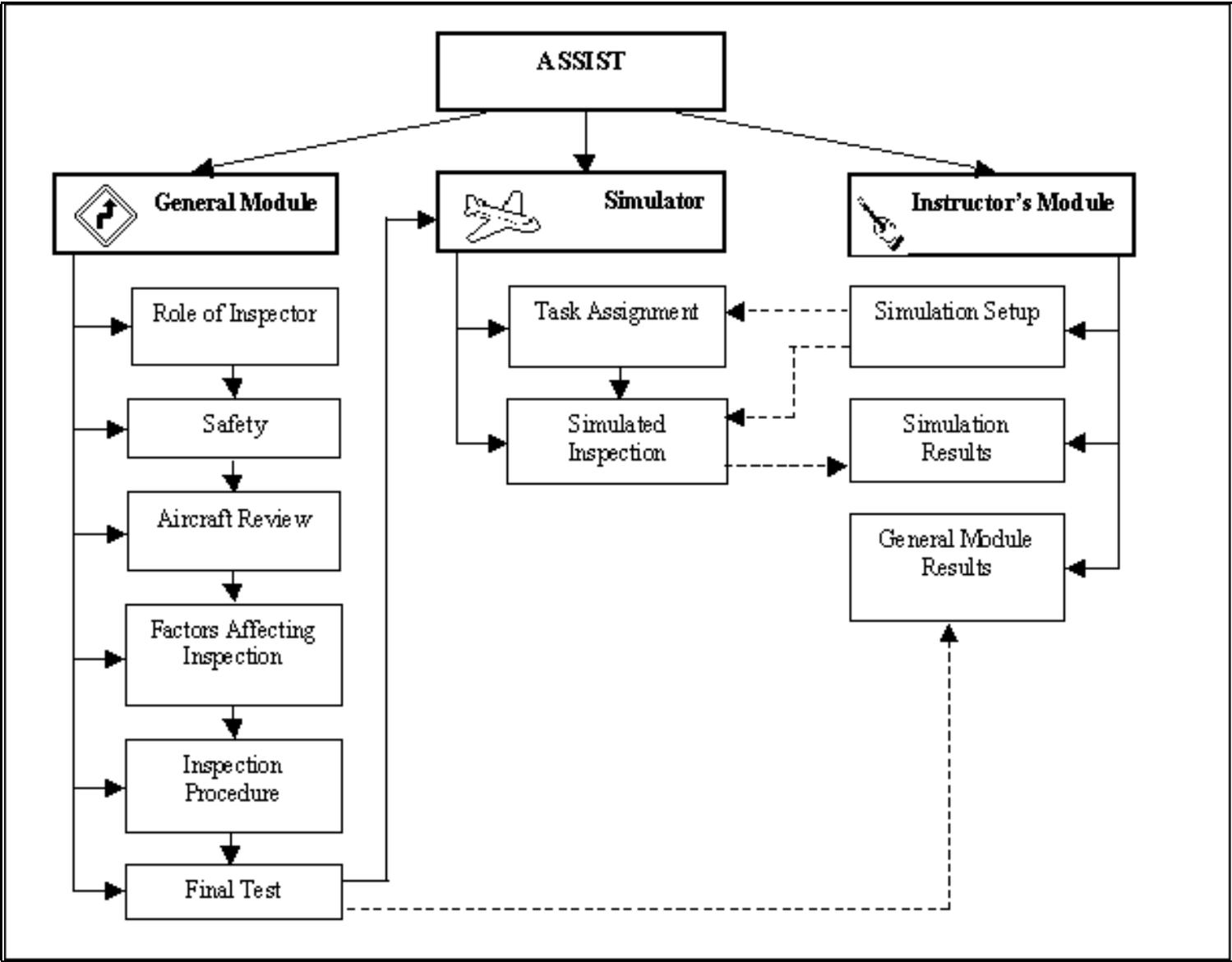


Figure 1.3 Components of the ASSIST Aircraft Inspector Training Program

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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Choose wrong action
4.5 Remember decision/ action	Enter multiple defects and complete NR card with feedback	Active and Feedback	Simulator	<ul style="list-style-type: none"> 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

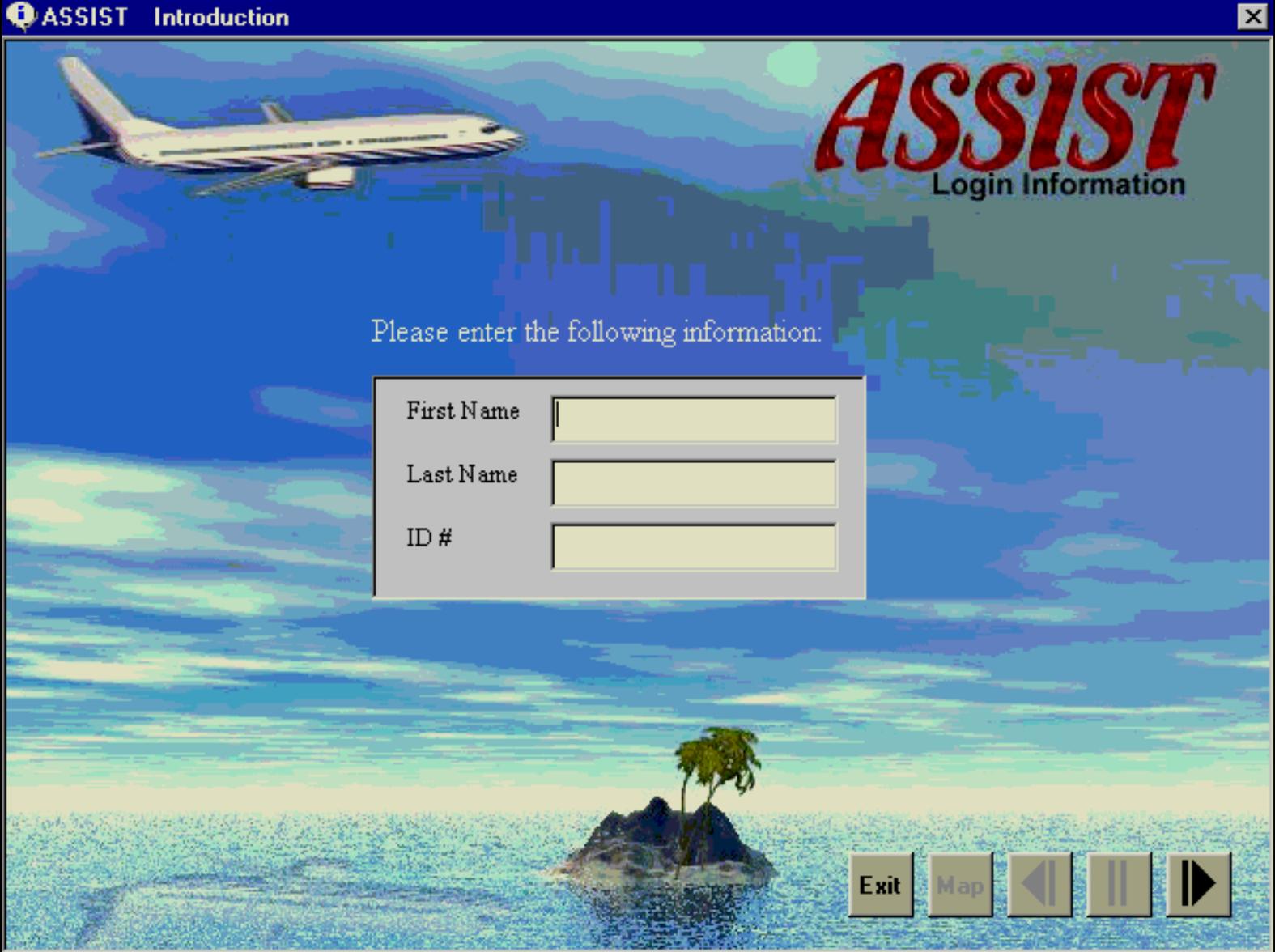
The ASSIST program needs at least a Pentium 100, with a 166 Pentium or faster suggested. A minimum hard drive space of 220 MB is required with at least 24 MB of memory, with 64 MB being the suggested memory. It runs on a Windows 95, or higher, operating system. The program also requires a SoundBlaster 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.



ASSIST Introduction

ASSIST
Login Information

Please enter the following information:

First Name	<input type="text"/>
Last Name	<input type="text"/>
ID #	<input type="text"/>

Exit Map ◀ || ▶

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](#)).

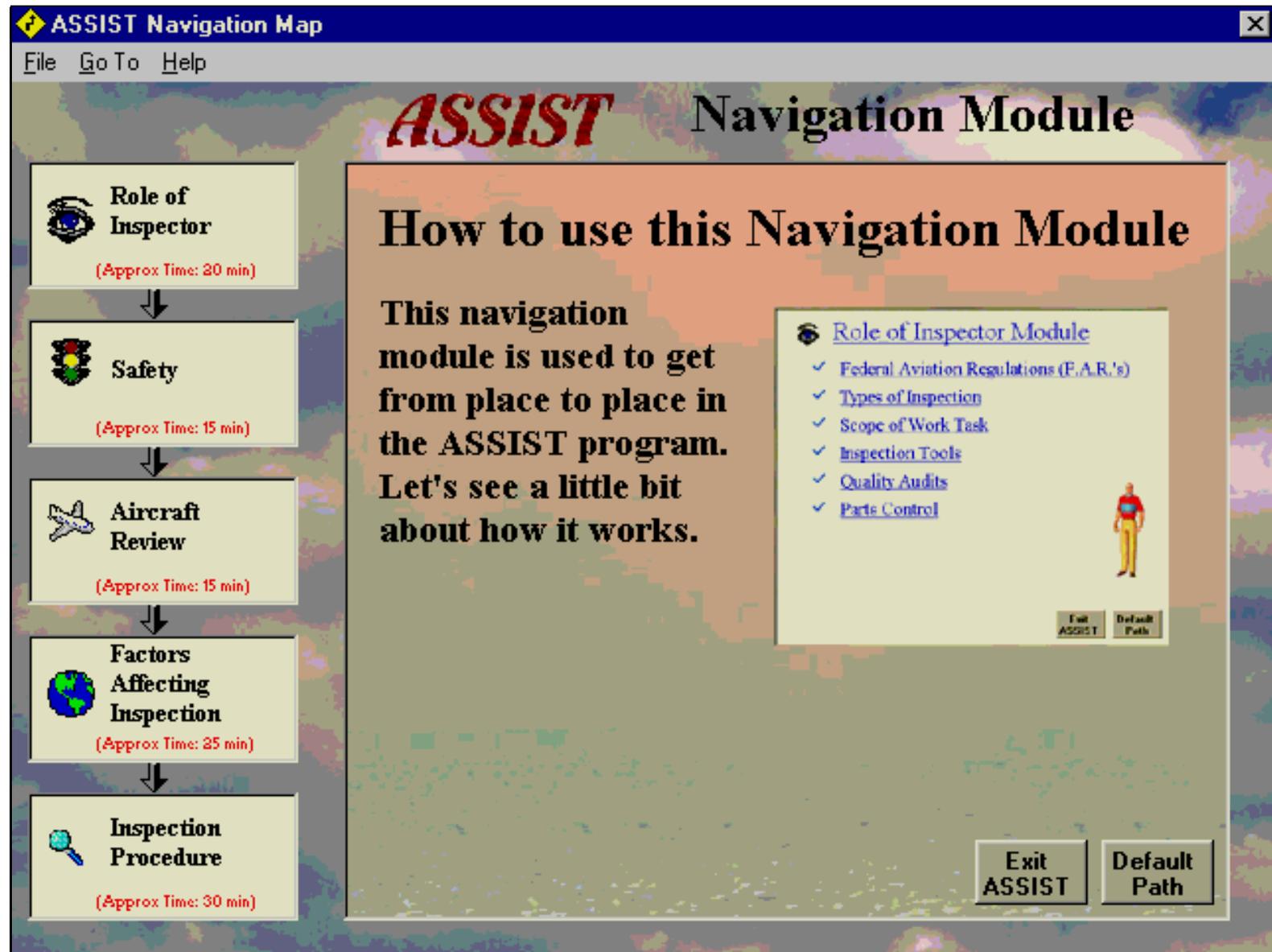


Figure 1.5 ASSIST Navigation Map for Moving within the General Module

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](#)).

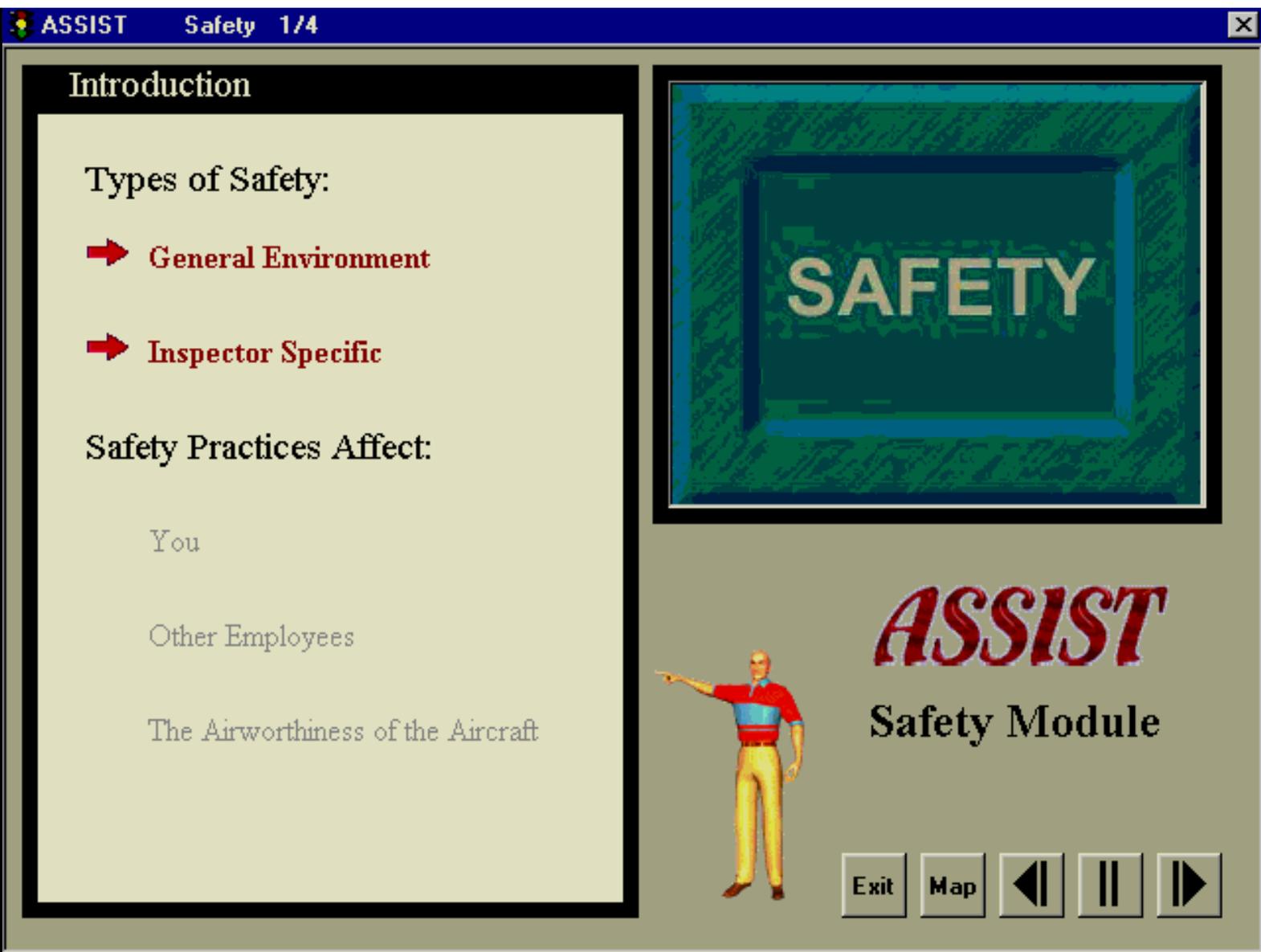


Figure 1.7 Introduction to the Safety Sub-module

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](#)).

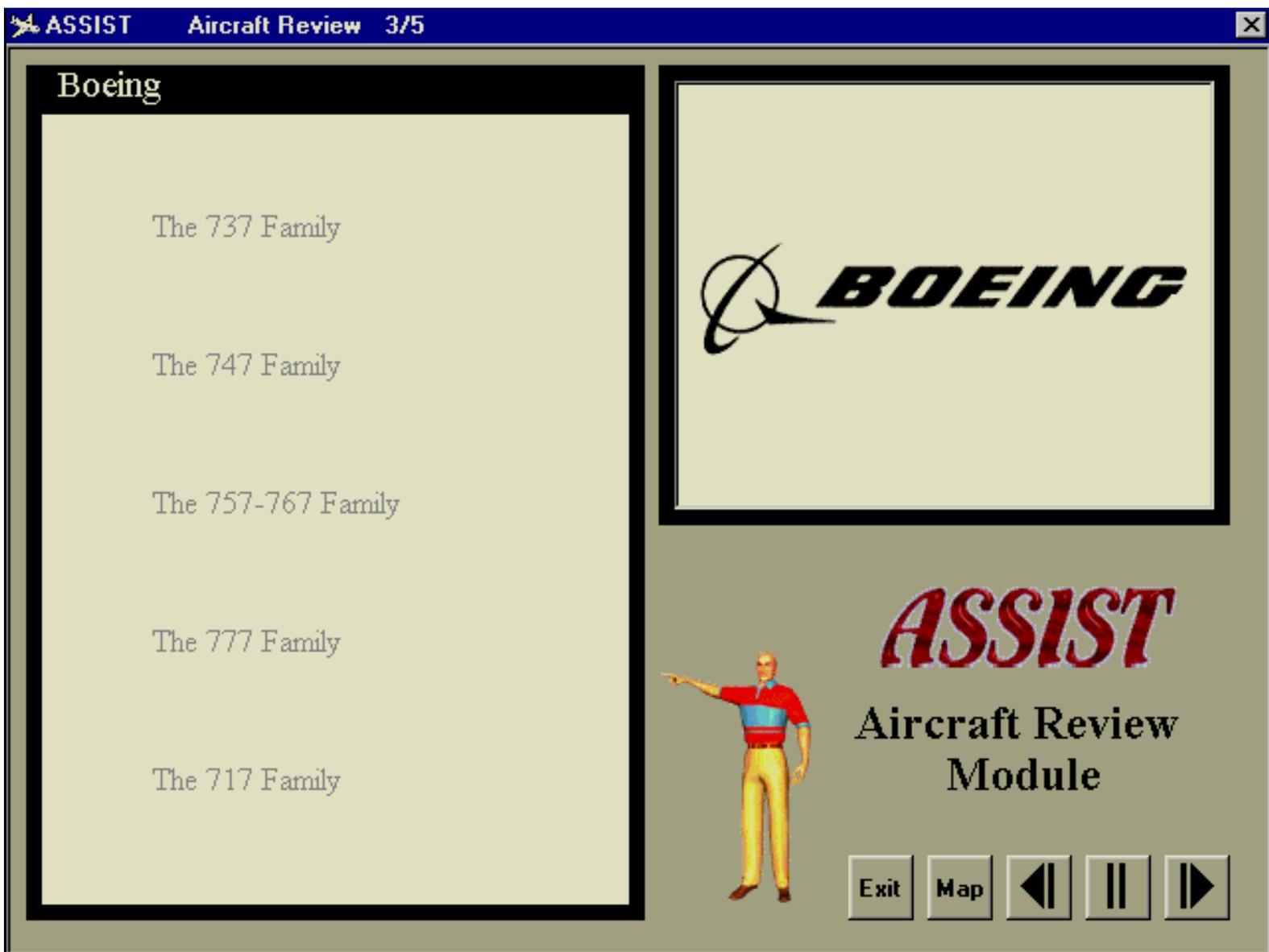


Figure 1.8 Aircraft Review Sub-module Covering Boeing Aircraft

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.

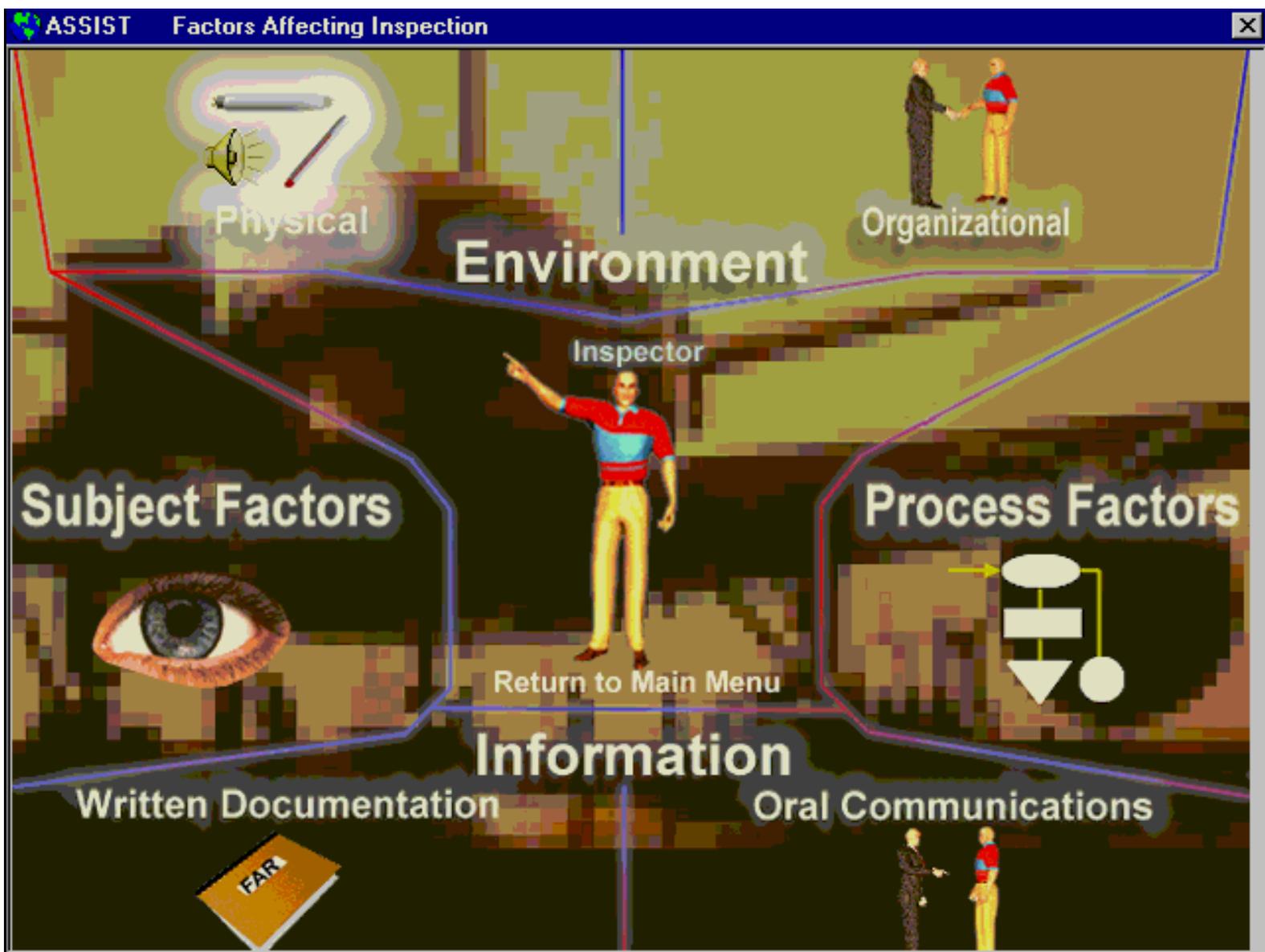


Figure 1.9 Menu of Factors Affecting Inspection Sub-Module

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](#)).

