A Unified Approach to Aircraft Inspector Training

John Harris, Hector Him, Scott Koenig, Lee Nickles, Jill Kaufman, Jatin Thacker, Brian Melloy and Anand K. Gramopadhye
Department of Industrial Engineering
Clemson University
Clemson, SC 29634-0920

Abstract

Aircraft inspection and maintenance are an essential part of a safe, reliable air transportation system. Training has been shown to be the primary intervention strategy in improving inspection performance. This paper outlines recent efforts being pursued by the Training System Laboratory at Clemson University focused on both individual and team skills training to improve inspection performance.

Keywords
Aircraft, Inspection, Maintenance, Training

1. Introduction

In order for the Federal Aviation Administration (FAA) to continue to provide the public with safe, reliable air transportation, it is important to have a sound aircraft inspection and maintenance system [1]. The inspection/maintenance system is a complex one with many interrelated human and machine components. The linchpin of this system, however, is the human. Recognizing this, the FAA (under the auspices of the National Plan for Aviation Human Factors) has pursued human factors research [2, 1]. In the maintenance arena, this research has focused on the aircraft inspector and the aircraft maintenance technician (AMT) (e.g., [3, 4, 5]).

Since humans will continue to be a part of the inspection/maintenance process for the foreseeable future, emphasis must be placed on developing interventions to make the inspection/maintenance procedures more reliable. One intervention that has been consistently effective in this environment is training. Training has been shown to improve the performance of both novice and experienced inspectors/AMTs [6, 7, 8].

Most training occurs on-the-job (OJT). Nevertheless, this may not be the best method of instruction [1, 9]. 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 (e.g., [6]), and for other reasons as well, alternatives to OJT are sought.
Alternatives to OJT are periodic retraining and off-line feedback. The most viable mode for these interventions, given the many constraints and requirements imposed by this environment, is computer-aided instruction (CAI). CAI offers several advantages relative to traditional training approaches; for example, CAI is more efficient, facilitates standardization, and supports distance learning. Yet, CAI has found limited application for inspector and AMT training in the aircraft maintenance industry. Presently, most of the applications of CAI to training have been restricted to the defense/aviation industry for complex diagnostic tasks. The earliest effort to address this problem was the development of an airframe visual inspection simulator [10, 11]. However, this simulator was somewhat limited as it used only computer-generated airframe structures and a small sample of defects. Thus, research efforts need to be extended in order to take full advantage of CAI.

The purpose to this paper is to describe a university/industry collaborative research effort to develop an off-line computer based training system for aircraft inspectors and maintenance technicians. The research effort comprises three interrelated activities. The first was the development of computer-based team training software for AMTs; this activity has already been completed. The other two activities are proceeding in parallel. One is the development of a visual inspection simulator designed to train aircraft inspectors in search and decision making tasks. The other is the creation of models that predict aircraft inspector performance. These models will be integrated into the aircraft inspector software to not only train aircraft inspectors, but also to act as a means to evaluate and improve overall inspection performance.

2. Aircraft Maintenance Team Training

The task analyses of aircraft inspection and maintenance activities [4] has revealed the aircraft inspection/maintenance system to be complex, requiring above average coordination, communication and cooperation between inspectors, maintenance personnel, supervisors and various other subsystems (planning, stores, and shops) to be effective and efficient. A large portion of inspector and maintenance technician work is accomplished through teamwork. The challenge is to work autonomously but still be a part of the team. During the entire maintenance process, the inspectors and maintenance technicians work with their colleagues from the same shift and the next shift as well as personnel from planning, stores, etc. as part of a larger team to ensure that the task gets completed ([1]). Thus, in a typical maintenance environment, the technician has to learn to be a team member, communicating and coordinating the activities with other technicians and inspectors. Though the advantages of teamwork are widely recognized in the airline industry, the work culture assigns responsibility for faulty work on individual AMTs rather than on the teams in which they work [12]. The reasons for this could be the individual licensing process and personal liability, both of which often result in AMTs and their supervisors being less willing to share their knowledge and work across shifts with less experienced or less skilled colleagues. The problem is further compounded since the more experienced inspectors and mechanics are retiring and being replaced by a much younger and less experienced workforce. Not only do the new AMTs lack
knowledge or skills of the far more experienced AMTs they are replacing, but they are also not trained to work as a team member.

The earlier problem of the development of individual AMT skills has been continually addressed by the FAA. For example, the newly established FAR Part 66 (new AMTs certification requirements) specifically addresses the significant technological advancements that have taken place in the aviation industry and the advancements in training and instructional methods that have arisen in the past decade. The FAA, through the Office of Aviation Medicine, has also funded efforts for the development of advanced training tools to train the AMTs of the future. These advanced tools include intelligent tutoring systems, embedded training, etc. which will be available to air and power plant (A & P) training schools. It is anticipated that the application of these new training technologies will help reduce the gap between current AMT skills and those needed for the maintenance of advanced systems. However, the AMTs joining today’s workforce are lacking in team skills. The current A & P school curriculum often encourages students to compete against one another, and often AMTs are not fully prepared for cooperative work in the future. To prepare student AMTs for the workplace, new ways have to be found to build students’ technological, interpersonal and socio-technical competence by incorporating team training and communication skills into their curriculum. The first phase of our research explored the potential of advanced technology for team training.

A computer-based team training program, Aircraft Maintenance Team Training (AMTT) software\(^1\), was developed as part of the effort that examines the application of advanced technology to team training. Specifically designed for training aircraft maintenance technicians in basic team skills, AMTT uses a multimedia approach with interaction opportunities between the user and the computer. The multimedia presentation includes full motion videos that provide real life examples of proper and improper team behavior, photographs and animation that illustrate difficult concepts, and voice recordings coupled with visual presentations of the main contextual material. Since the software was developed as a training and research tool, the software facilitates the collection of pre-training and post-training performance data.

AMTT is divided into three major programs: (i) team skills instructional program, (ii) instructor’s program, and (iii) printing program.

2.1 Team Skills Instructional Program
The team skills instructional program consists of introduction, team skills, team skills overview, task simulation and critical path method supplemental modules.

\(^1\) AMTT was developed in Microsoft Visual Basic and runs in the Microsoft Windows environment. AMTT uses the 486 DX2 66 MHZ platform, with a 15 inch SVGA monitor, 16 MB RAM, 2 MB video RAM, MCI compatible sound card, and a multi-speed CD.
**Introduction module**  The objective of the introduction module is fourfold. First, it provides the user with definitions of terms and concepts found throughout the software. Team and teamwork are both defined and described, and the types of teams normally found in the aircraft maintenance environment are illustrated. Second, the importance of teamwork and the resulting effects on performance are detailed for the user. Third, the user is introduced to the organization and layout of the tutorial. Finally, the introduction acquires demographic information about the user.

**Team skills overview module**  In a short 10-15 minute slide show presentation, the team skills overview module was designed to encapsulate all the general information provided in the four sub-modules of the team skills instructional module.

**Team skills module**  Team skills factors or skills dimensions have been identified and defined by a number of authors [13, 14, 15]. Gramopadhye, et al. [8] and Kraus et al. [16] describe the six team skills factors that are relevant specifically to the aircraft maintenance environment. The training material relevant to the above skills was developed and the different skill dimensions were combined to form communication sub-module, decision making, interpersonal relationships and leadership sub-modules. Each of the team skills sub-modules has a similar structure. The sub-modules start with a questionnaire wherein users ranks ten subject related questions on a seven point Likert scale. The objective of this questionnaire is to collect the user’s perception on specific team skills prior to training. The questionnaire is followed by a short test that is intended to measure the user’s current knowledge on the subject matter. On completion of the test, the user is presented with the instructional material. The tutorial material is broken down by major topics. After each topic, a test is presented before proceeding to the next topic. These embedded tests serve two purposes: first, they verify that the user has understood the material just presented, and second, it serves to reinforce what the user has just learned. The same questionnaire and test question asked at the beginning of the module are posed to the user at the end. This was done to measure the effect, if any, the subject material had on the user’s understanding of the material and changes in user’s perception related to the specific team skill.

**Task simulation module.**  The task simulation module was designed to allow the users to apply the skills learned in the team skills instructional module in an aircraft maintenance situation. To accomplish this, a virtual aircraft maintenance environment was created with a virtual team of seven technicians (one crew lead and six crew members). The virtual team had three consecutive tasks which required a team effort. These tasks were: testing the extension and retraction of landing gears, jacking down the plane, and finally, towing the aircraft to another location. A narrative was provided about the crew and their efforts to complete these teamwork tasks. Problems which involved team skills arose in the normal course of work, and the user, acting as a consultant, was queried as to the correct course of action. To simulate real life, wrong answers were carried forward to a potentially disastrous end. False problems or situations were introduced to determine if the user recognized when situations were progressing within bounds. Data concerning
the number of correct and incorrect decisions made by the user was stored in the database for analysis.

**Critical path method supplemental module.** Teamwork often leads to making decisions concerning how to perform or improve future work. Decision making, however, does not end with achieving agreement amongst all the team members. Decisions must be converted into an action plan. The critical path method (CPM) supplemental module was developed to teach the user the most common methods of scheduling and analyzing a team process [17]. After the user is introduced to the background and capabilities of CPM, the module proceeds to instruct the user on how to construct CPM diagrams using the activity-on-node approach. Users must calculate the critical path of several networks to enhance the learning experience. CPM networks answer “what if” types of questions to help determine the impact of a decision before implementation. The impact of changes are taught with a series of “what if” exercises to help clarify the process, to practice calculating critical paths, and to demonstrate how the critical path may become altered due to minor changes in resources. The supplemental module concludes with a practical exercise in which the user observes an aircraft towing task.

### 2.2 Instructor’s Program
The instructor’s program facilitates the collection and analysis of data on each user. It consists of two main modules: the report generation module and the field study module. The report generation module allows the instructor to retrieve, analyze and print performance data for all users as they complete the various sub-modules within the team skills instructional program. The field study module was designed to enable the instructor to print the questionnaires and use them to collect field data. Data obtained can be entered and further analyzed using this module.

### 2.3 Printing Program
In a situation wherein computer support is lacking, it may become necessary to present the information in an alternate format. The printing program was designed specifically to provide the instructor with the resources and structure necessary to print the different screens in the team skills instructional modules and sub-modules.

In summary, training team skills of AMTs is critical to ensure successful team performance in the aircraft inspection/maintenance environment. In the future, as the composition of the AMT workforce changes, team training will become more critical. In such an environment, computer-based team training coupled with technical instructors will provide an effective training solution. The structure and operation of a computer-based system for AMT team training has been described in this section. In the near future, this system will be evaluated in an operational setting.

### 3. Aircraft Inspector Training Software
Most of the effort in applying training knowledge to enhance visual inspection skills has been in the manufacturing industry. Training for improving visual inspection skills for aircraft inspectors is generally lacking at aircraft repair centers and aircraft maintenance
facilities[18]. Visual inspection skills can be taught effectively using representative photographic images showing a wide range of conditions with immediate feedback on the trainee’s decisions [6]. Using photographic images as a training aid in controlled practice has been shown to be superior to On-the-Job Training (OJT). The objective of this research was to develop a system which will improve the visual search and decision making skills of aircraft inspectors. To achieve this objective a computer-based inspection training system (Automated Self-paced System for Instructional Support and Training -- ASSIST) was developed. A brief description of the of the system follows.

3.1 System Structure
ASSIST consists of four major modules: (1) General Inspection module, (2) Inspection Simulation Training module, (3) Instructor’s Utilities module, and (4) Start-up module. All system users interact through a user-friendly interface. The user interface 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.

3.2 General Module
The objective of the general module is to provide the inspectors with a basic overview on the following topics: (1) role of the inspector, (2) factors affecting inspection performance, (3) safety and (4) inspection procedure. The module incorporates multimedia (sound, graphic, text, pictures and video) with interaction opportunities between the user and the computer. Figure shows a prototypical screen of the General inspection module.

3.3 Inspection Simulation Training Module
This module of the training program provides inspection training on a simulated aircraft inspection task (Aft-Cargo Pit inspection of a Lockheed Martin Aircraft - L1011). By manipulating the various task complexity factors the inspector can simulate different inspection scenarios. The training module is further divided into four major sub-modules: introduction, search training, decision training and testing. Each sub-module uses computer-generated images of the airframe structure.

Introduction
The introduction provides the trainee with an overview of the various facets of the program, information on aircraft terminology and a graphical representation of various faults. The section introduces the trainee to the search and decision making aspects of the visual inspection task. Each section is followed by a question and answer session wherein the trainee has to make an active response as each piece of new material is presented. The trainee is provided with immediate feedback as to its correctness. If an error is made, it is identified and the correct answer is supplied.

Search Training
The module trains the inspector on the search component of the visual inspection task. The objective is to train inspectors to correctly identify and locate defects. This type of training is aimed at developing cues, knowledge of where specific defects occur, and the use of feed-forward information. The trainee is provided with immediate feedback on the following speed and accuracy measures: the time to locate the
defect (search time), and the accuracy of the search process (the program lets the inspector know whether he/she correctly identified the defect and marks the defect on the computer screen).

Decision Training  This module trains the inspector on the decision making component. A series of aircraft structures are displayed with the faults marked. After each image is displayed, the inspector makes an active response. First, the trainee classifies the defect by defect name. Following defect classification, the trainee writes up a Non-Routine Report- NRR report (if required) based on the number of defects, defect type, severity and location. The inspector is provided with immediate feedback on his or her decision making performance. The general objective of this module is to train the inspector on both the rule-based and knowledge-based aspects of the decision component of the inspection task.

Testing  The testing module is designed to operate in two separate modes: with and without feedback. The non-feedback mode simulates the actual visual inspection task (as it would take place on a hangar floor). In either mode, the inspector first locates the defect and indicates this by clicking on the fault. Subsequently, the inspector classifies the defect. In the feedback mode, the inspector is provided with immediate feedback on his/her performance on the search and decision making components of the inspection task. The trainee is also provided with end-of-session performance feedback.

3.3 Instructor's Utilities Module
This module allows the supervisor/instructor to access the results database, the image database and the inspection parameter modules. The module is designed as a separate stand-alone tool that is linked to the other modules of the system. The results database allows the instructors to review the performance of a trainee who has taken several training and/or testing sessions. Performance data 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. The objective of the image database module is to provide the instructor with a utility wherein a specific image along with its associated information can be viewed on the computer screen. By manipulating the inspection parameters the instructor can create different inspection scenarios. The inspection parameter module allows the instructor to change the probability of defects, defect mix, the complexity of the inspection task, the information provided in the work card (thereby varying the feedforward information provided) and whether the inspection task is paced or unpaced.

3.4 Start-up Module
The start-up module allows the instructor to select images from the image database and store them in a batch file. Thus, an instructor can create visual inspection tasks consisting of several batch files of images which can be used with the training and testing modules.
4. Modeling Inspector Performance

Task analyses of aircraft inspection has revealed that inspection is a complex task wherein the inspector has to visually search for multiple defects occurring at varying severity levels and locations (refer to [3] for more details). The inspection task is further complicated due to the wide variety of defects that are being reported in older aircraft. Consequently, more intensive inspection programs are required for older aircraft. Also, the cost of inspection is rising. As a result, there is increasingly greater competitive pressure to reduce inspection costs (e.g., by maintaining minimal staffing levels without violating mandated staffing policies) without jeopardizing safety or disrupting flight schedules.

The establishment of inspection performance benchmarks and the determination of the relative consequences of speed/accuracy tradeoffs will improve the effectiveness of existing inspection and maintenance procedures. In principal, this information could be secured from models of inspector performance. However, although the scientific literature contains a number of models that have been developed to predict inspector performance, their application is limited to fairly straightforward tasks, and hence they are not applicable to all of the inspection scenarios in this domain.

Thus, the focus of the third phase of the research project is to develop models that are robust to the complexities of airline inspection tasks. These models will ultimately be combined with AITS to resolve the problems inherent to OJT. The development will include several steps. The first step will involve identifying factors that affect aircraft inspection performance and subsequently using those factors to develop a framework to model inspection. Based upon this framework, models of inspection will be developed. Subsequently, the models will be validated in three progressive stages. First, a detailed sensitivity analysis will be conducted to understand how each model behaves with different parameter values. Secondly, a detailed model validation study will be conducted using data from a controlled study. (The development of ASSIST makes this possible.) Thirdly, these results will be rigorously tested under actual conditions on the hangar floor. Finally, the results of these activities will govern the development of the training program.

5. Summary

The paper describes research in the area of aviation maintenance and inspection currently underway at Clemson University. Through the development and systematic application of industrial engineering techniques, the research aims at improving the effectiveness, efficiency and safety of aircraft maintenance operations. The results of the research effort have been made available to the aviation maintenance community as deliverable products. It is anticipated that the use of these products would lead to improved airworthiness of the U. S. domestic aircraft fleet.

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