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# Human Factors in Aviation Maintenance Phase 1: Progress Report

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16. Abstract

This human factors research in aviation maintenance addresses four tasks including studies of organizational behavior, job and task analysis in maintenance and inspection, advanced technology for training, and the application of job aiding to maintenance. The first phase of a three phase research program describes extensive preliminary investigation of airline maintenance practices. Each chapter describes the Phase I investigation and problem definition followed by the plan for the Phase II demonstrations. 25 * Aircraft maintenance

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Galaxy Scientific Corporation served as the prime contractor and to facilitate and conduct the research related to training (Chapter 4) and Job Aiding (Chapter 5). The organizational research (Chapter 2) was conducted by Socio-Technical Systems. The University of Buffalo, Center for Industrial Effectiveness,conducted the research related to Human Errors in inspection (Chapter 3). BioTechnology Inc. planned and conducted the four workshops on Human Factors in Maintenance.

The initial success of this research is also attributed to numerous FAA, airline, manufacturer, and vendor personnel who provided time, facilities, frank answers, and invaluable guidance to the entire research team.

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# Contents

CHAPTER ONE - EXECUTIVE SUMMARY

1.0 SUMMARY ..... 1
1.1 PROJECT RATIONALE ..... 1
1.2 HUMAN FACTORS DEFINED ..... 4
1.3 STUDY OF THE MAINTENANCE ORGANIZATION (CHAPTER 2) ..... 6
1.4 STUDY OF THE MAINTENANCE TECHNICIAN IN INSPECTION (CHAPTER 3) ..... 6
1.5 STUDY OF ADVANCED TECHNOLOGY FOR MAINTENANCE TRAINING (CHAPTER 4) ..... 9
1.6 STUDY OF JOB PERFORMANCE AIDS (CHAPTER 5) ..... 10
1.7 HUMAN FACTORS IN AVIATION MAINTENANCE - THE CONFERENCES ..... 11
1.8 ADDITIONAL RESEARCH ACTIVITIES ..... 12
1.9 REFERENCES ..... 12

CHAPTER TWO - MAINTENANCE ORGANIZATION

2.0 SUMMARY ..... 15
2.1 INTRODUCTION ..... 15
2.2 THEORY AND METHODS ..... 18
2.3 RESULTS AND DISCUSSION ..... 21
2.4 CONCLUSIONS ..... 34
2.5 RECOMMENDATIONS ..... 40
2.6 REFERENCES ..... 43

# Contents (continued)

CHAPTER THREE - THE MAINTENANCE TECHNICIAN IN INSPECTION

3.1 INTRODUCTION ..... 45
3.2 THE INSPECTION SYSTEM ..... 45
3.3 METHODOLOGY ..... 46
3.4 RESULTS AND DISCUSSION ..... 48
3.5 CONCLUSIONS ..... 88
3.6 REFERENCES ..... 89
CHAPTER THREE APPENDIX A ..... 91

CHAPTER FOUR - ADVANCED TECHNOLOGY TRAINING FOR AVIATION MAINTENANCE

4.0 INTRODUCTION ..... 93
4.1 RESEARCH PHASES ..... 93
4.2 DEFINITIONS OF ADVANCED TECHNOLOGY AND ITSs ..... 93
4.3 ADVANCED TECHNOLOGY FOR AIRCRAFT MAINTENANCE TRAINING ..... 95
4.4 ADVANCED TECHNOLOGY TRAINING PROTOTYPE ..... 97
4.5 PLANS FOR PHASE II ..... 100
4.6 SUMMARY ..... 102
4.7 ACKNOWLEDGMENTS ..... 102
4.8 REFERENCES ..... 102

CHAPTER FIVE - JOB PERFORMANCE AIDS

5.1 INTRODUCTION ..... 105
5.2 PROBLEM DEFINITION ..... 105
5.3 METHODOLOGY ..... 108
5.4 FINDINGS ..... 109
5.5 RECOMMENDATIONS ..... 124
5.6 CONCLUSION ..... 126
5.7 REFERENCES ..... 126
CHAPTER FIVE APPENDIX ..... 127

# List of Tables


Table 1.1 Percentage Increase in U.S. Airlines 1980-1988 ..... 3
Table 1.2 Aviation Maintenance Manpower Requirements Through the Year 2000 ..... 5
Table 1.3 Generic Task Description of Incoming Inspection ..... 7
Table 1.4 Potential Strategy for Improving Aircraft Inspection ..... 8

Table 2.1 Summary of Communication Analysis ..... 33

Table 3.1 Generic Task Description of Incoming Inspection ..... 48
Table 3.2 Workcard Followed for Detailed Task Analysis ..... 50
Table 3.3 Task and Error Taxonomy for Inspection ..... 69
Table 3.4 Number of Instanced of Human Factors Implications from Task Analysis ..... 67
Table 3.5 Potential Strategies for Improving Inspection ..... 77
Table 3.6 Summary Table of Practical Applications ..... 87

Table 4.1 Phases of Research Plan ..... 94
Table 4.2 Sources of Information for Technology SuNey ..... 96
Table 4.3 The Perceived Situation for Interview Discussions ..... 96
Table 4.4 Hardware and Software for Prototype ..... 98
Table 4.5 Instructional Specification for Prototype ..... 98

Table 5.1 Summary of Research Objectives ..... 105
Table 5.2 Initial Understanding of the Problem ..... 106
Table 5.3 Understanding of the Problem at the End of Phase I Research ..... 106
Table 5.4 Development Time Frame for IMIS ..... 115
Table 5.5 Steps Involved in a Feasibility Study ..... 120

# List of Tables


Table 1.1 Percentage Increase in U.S. Airlines 1980-1988 ..... 3
Table 1.2 Aviation Maintenance Manpower Requirements Through the Year 2000 ..... 5
Table 1.3 Generic Task Description of Incoming Inspection ..... 7
Table 1.4 Potential Strategy for Improving Aircraft Inspection ..... 8

Table 2.1 Summary of Communication Analysis ..... 33

Table 3.1 Generic Task Description of Incoming Inspection ..... 48
Table 3.2 Workcard Followed for Detailed Task Analysis ..... 50
Table 3.3 Task and Error Taxonomy for Inspection ..... 69
Table 3.4 Number of Instanced of Human Factors Implications from Task Analysis ..... 67
Table 3.5 Potential Strategies for Improving Inspection ..... 77
Table 3.6 Summary Table of Practical Applications ..... 87

Table 4.1 Phases of Research Plan ..... 94
Table 4.2 Sources of Information for Technology SuNey ..... 96
Table 4.3 The Perceived Situation for Interview Discussions ..... 96
Table 4.4 Hardware and Software for Prototype ..... 98
Table 4.5 Instructional Specification for Prototype ..... 98

Table 5.1 Summary of Research Objectives ..... 105
Table 5.2 Initial Understanding of the Problem ..... 106
Table 5.3 Understanding of the Problem at the End of Phase I Research ..... 106
Table 5.4 Development Time Frame for IMIS ..... 115
Table 5.5 Steps Involved in a Feasibility Study ..... 120

# List of Figures


Figure 1.1 The Complex Aviation Maintenance System ..... 2
Figure 1.2 The ATA Three-Legged Stool ..... 2
Figure 1.3 A Graph of Table 1.1 ..... 4
Figure 1.4 The Human in the Maintenance System ..... 5

Figure 2.0 Common Communication Pattern ..... 35
Figure 2.1 Maintenance in Control of Work Assignment ..... 36
Figure 2.2 Planning in Control of Work Assignment ..... 37
Figure 2.3 Inspection in Control of Work Assignment ..... 38

Figure 3.1 Example of Task Analysis ..... 49
Figure 3.2 Task Analysis of Visual Inspection Procedure ..... 51
Figure 3.3 Task Analysis of NDI Procedure ..... 60
Figure 3.4 Closed-Loop Control ..... 81
Figure 3.5 Training Versus Practice ..... 84
Figure 3.6 Training Condition ..... 85

Figure 4.1 Intelligent Tutoring System ..... 94
Figure 4.2 Advanced Technology Training Prototype ..... 97
Figure 4.3 Menu Options ..... 99
Figure 4.4 Bleed Air Supply Panel ..... 100
Figure 4.5 Fault Isolation Maintenance Manual ..... 101
Figure 4.6 Example of ECS Trainer Tools ..... 101

Figure 5.1 Expert System Diagram ..... 117
Figure 5.2 Cost of Correcting Software ..... 122

# List of Abbreviations

A&P ..... Airframe and Powerplant
AD ..... Airworthiness Directive
ADE ..... Automatic Data Entry for Aircraft Maintenance
AEM ..... Automated Electrified Monorail
AF ..... Air Force
AFTA ..... Avionics Fault Tree Analyzer
AI ..... Artificial Intelligence
AICC ..... Aviation Industry Computing Committee
AIDAPS ..... Automatic Inspection Diagnostic And Prognostic System
AIDS ..... Airborne Integrated Data System
AIMES ..... Aironics Integrated Maintenance Expert System
AIMS ..... Automated Intelligent Maintenance System
ALM ..... Advanced Learning for MSE
AMES ..... Aircraft Maintenance Effective Simulation
AMIS ..... Aircraft Maintenance Information System
AMP ..... Aircraft Maintenance Personnel
AMT ..... Aviation Maintenance Technicians
APU ..... Auxiliary Power Unit
APU MAID .. Auxiliary Power Unit Maintenance Aid
ARI ..... Army Research Institute
ASMT ..... Aircraft Simulation Maintenance Trainers
ATA ..... Air Transport Association
ATE ..... Automatic Test Equipment
ATPG ..... Automatic Test Program Generator
ATS-JEAIII ... Auto Test System for Jet Engine Assemblies
AVID ..... Automatic Vibration Diagnosis Systems
AVIM ..... Aviation Intermediate Maintenance Units
BIT ..... Built-In Test
BITE ..... Built-In Test Equipment
BRAD ..... Brilliant Reusable ADA Diagnostician
CAA ..... Civil Aviation Authority
CAD ..... Computer Aided Design
CADS ..... Computer Aided Design Systems
CALS ..... Computer Acquisition & Logistic Support
CAMS ..... Computerized Automotive Maintenance System
CASE ..... Computer Aided Software Engineering
CBI ..... Computer Based Instruction
CCP ..... Contamination Control Program
CCS ..... Component Control System
CD ROM ..... Compact Disc Read Only Memory Disc
CEMS ..... Comprehensive Engine Monitoring Systems
CEPS ..... CITS Expert Parameter System
CITEPS ..... Central Integrated Test-Expert Parameter System
CITS ..... Central Integrated Test System
CMS ..... Computerized Maintenance System
COMPASS ... Computerized Material Procurement And Supply System
CRM ..... Cockpit Resource Management
CROCOS ..... Computerized Rotables Control System
CRT ..... Cathode Ray Tube
DCS ..... Digital Control System
DMMIS ..... Depot Maintenance Management Information Systems
DoD ..... Department of Defense
DODT ..... Design Option Decision Tree
DOT ..... Department of Transportation
DVI ..... Digital Video Interactive
EAP ..... Experimental Aircraft Program
ECS ..... Environmental Control System
ED/CEMS .... Engine Diagnostics/Comprehensive Engine Management System IV
EDS ..... Engine Diagnostic STS
EICAS ..... Engine Information And Crew Altering System

# List of Abbreviations (continued)

EL ..... Electro-Luminescent

ELATS ..... Expanded Litton Automated Test Set

ETTR..... Engine Time Tracking Recorder

EVA ..... Engineering Variance Authorization

FAA..... Federal Aviation Administration

FAMIS ..... Field Asset Management & Information System

FAR..... Federal Aviation Regulations

FCMDS ..... Flight Control Maintenance Diagnostic System

FIMM ..... Fault Isolation Maintenance Manual

FTMP ..... Fault Tolerant Multiprocessor

GAO ..... General Accounting Office

IEIS ..... Integrated Engine Instrument System

IFL ..... Intelligent Fault Locator

IMIS..... Integrated Maintenance Information System

IMTS ..... Intelligent Maintenance Training System

IRAN ..... Inspect And Repair As Necessary

ITEMS ... ..... Integrated Turbine Engine System

ITS .. ..... Intelligent Tutoring System

IUSM ..... Integrated Utilities System Management System

JAL..... Japan Air Lines

JPA..... Job Performance Aid

JTA ..... Job Task Analysis

LAMP ..... Logistics Assessment Methodology Prototype

LAWS ..... Logistics Assessment Workstation

LCD ..... Liquid Crystal Display

LRU ..... Line Replaceable-Unit

MAIDEN ..... Maintenance Aid Engine

MANPRINT Manpower And Personnel Integration

MIPS ..... Millions Of Instructions Per Second

MIS ..... Management Information Specialist

MITT..... Microcomputer Intelligence for Technical Training

MSD ..... Multi-Site Damage

NAARP ..... National Aging Aircraft Research Program

NASA ..... National Aeronautic and Space Administration

NDI ..... Non-Destructive Inspection

NTDT ..... Non-Destructive Test

NTSB-AAR .. National Transportation Safety Board Aircraft Accident Report

OJT ..... On-The-Job Training

OSHA ..... Occupational Safety and Health Administration

OTA ..... Office of Technology Assessment

PC..... Personal Computer

PMI ..... Principal Maintenance Inspector

QC..... Quality Control

RAF..... Royal Air Force

SRM ..... Structural Repair Manual

STS ..... Socio-Technical Systems

TEMS ..... Turbine Engine Monitoring System

UK ..... United Kingdom

VI ..... Visual Inspection

VR ..... Virtual Reality

VSLED..... Vibration, Structural Life, and Engine Diagnostic

WORM ..... Write Once Read Many

WRALC ..... Warner Robins Air Logistics Center

# Chapter One
# Executive Summary

## 1.0 SUMMARY

The performance of aviation maintenance and inspection personnel is directly related to the design of their tasks, the training given to them, the tools they work with, and the nature of their work environment. The goal of the aviation maintenance system is to ensure the continued safe and efficient operation of aircraft. Toward that goal the Federal Aviation Administration instituted the Human Factors in Aviation Maintenance Research Team to focus on a variety of human factors aspects associated with the aviation maintenance technician and other personnel supporting the maintenance system goals.

The team was comprised of personnel from government, private industry, and academia with strong expertise in human factors. They were assisted by experienced industry maintenance personnel and certified airframe and powerplant technicians. The results of their efforts are included in five chapters, this first chapter being the combined executive summaries of the other four. Specifically:

Chapter 1 - Executive Summary
Chapter 2 - Study of the Maintenance Organization
Chapter 3 - Study of the Maintenance Technician in Inspection
Chapter 4 - Study of Advanced Technology for Maintenance Training
Chapter 5 - Study of Job Performance Aids

In addition, information dissemination was achieved through the conduct of four conferences relating to the material of the four chapters. The results of these are also included in this summary.

Each of the chapters listed above, 2 through 5, have been treated so as to be a "stand alone" or independent research report. This chapter, the Overall Executive Summary, provides the rationale for the overall program and highlights the methods, primary findings, and subsequently planned research and development.

## 1.1 PROJECT RATIONALE

The work to date has identified numerous areas where human factors research and development is likely to improve efficiency and effectiveness in the maintenance system. Subsequent research, 1991 and beyond, will develop demonstrations for implementation and evaluation within operational maintenance organizations.

The aviation maintenance system is complex. It is influenced by a variety of entities and factors as shown in ***Figure 1.1.*** The system includes the aircraft manufacturers who design, build, and sell aircraft hardware, software, accessories, documentation, and a variety of support services. The airlines, and other operators, purchase, operate and maintain the aircraft and also supply equipment and services to other operators. Vendors supply aircraft components, maintenance equipment, and support services. Repair stations supply contract maintenance services and other support. Schools, private and public, offer training services.

Regulators, like the Federal Aviation Administration (FAA), the Occupational Safety and Health Administration (OSHA), and others, provide the regulatory environment in which the system operates. These independent entities exist in an integrated environment that the Air Transport Association (ATA) characterizes as a three-legged stool shown in ***Figure 1.2.*** The crossmembers between the legs of the stool represent the on-going cooperation, communication, and dependency among the three legs.

A research and development program in aviation maintenance is driven by the following facts:

1. Public sentiment demands a continuing, affordable, and safe air transportation system following national concern over recent maintenance-related incidents and accidents.
2. Maintenance workload is increasing due to such factors as:
   - increased traffic
   - increased maintenance requirements for continuing airworthiness of older aircraft
   - increased requirements for new technical knowledge and skills to maintain new technology aircraft
3. Demographic projections predict a shortage of qualified technicians.
4. Competitive pressures demand that maintenance organizations increase efficiency and effectiveness while maintaining a continuing high level of safety.

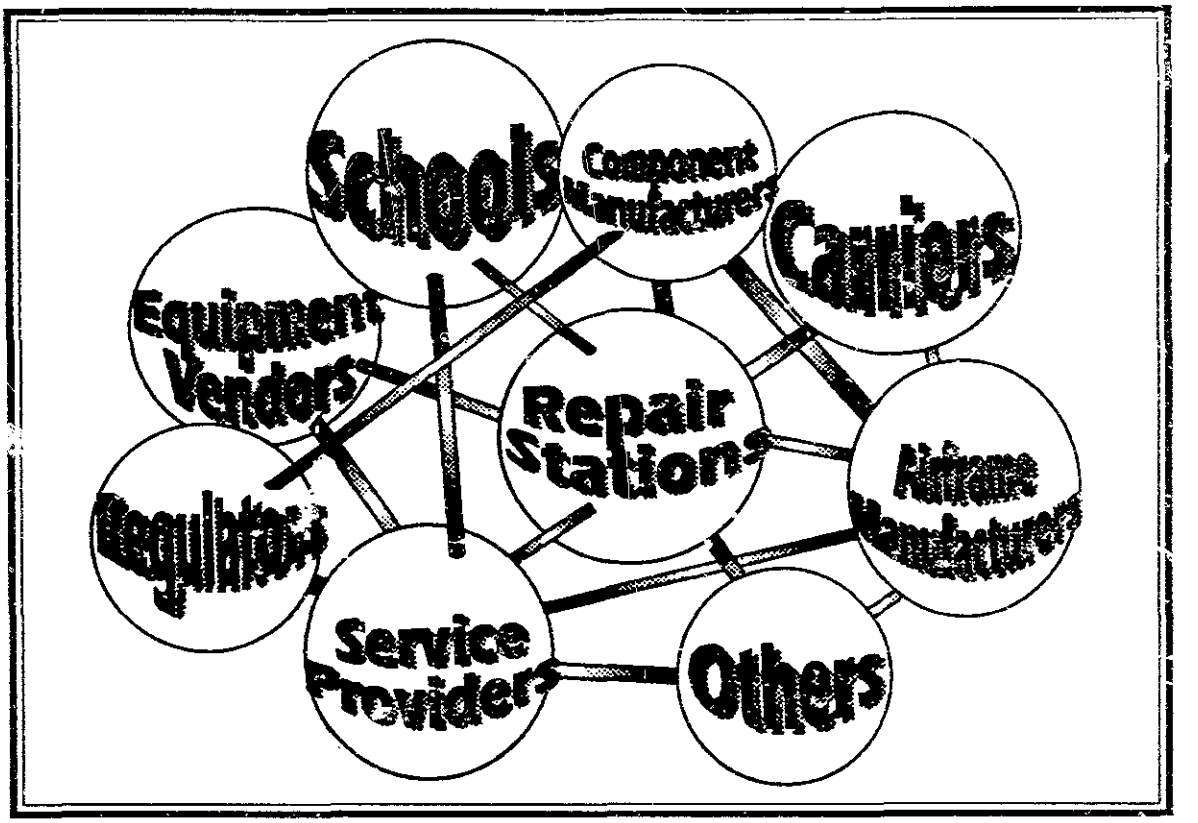


**Figure 1.1 The Complex Aviation Maintenance System**

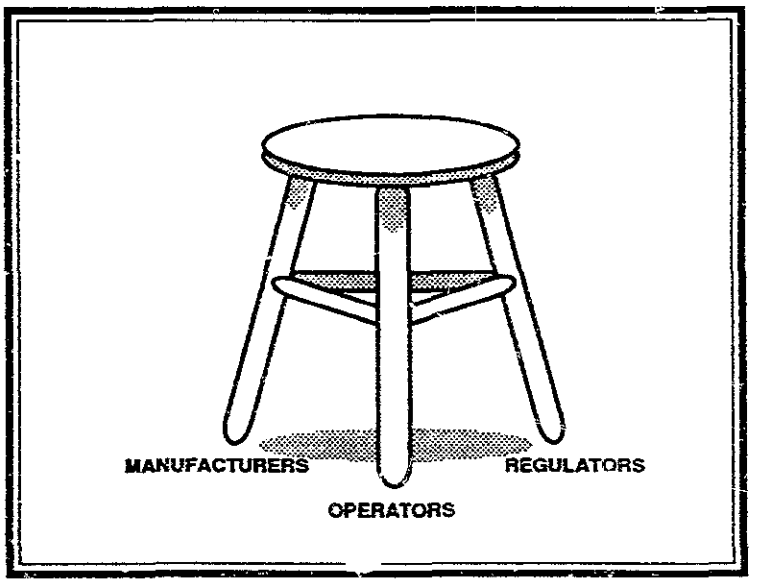


**Figure 1.2 The ATA Three-Legged Stool**

### 1.1.1 Public Demand for Continued Safe Public Air Transportation

Safe and reliable air transportation is a reasonable public demand. Commercial air transportation is, in fact, safe and reliable with trends toward ever-decreasing incidents per passenger mile flown (Office of Technology Assessment (OTA), 1988). Nevertheless, the infrequent incidents associated with air travel do influence public trust in the air transportation system. The 1990 crash of the United Airlines DC-10 in Sioux City, Iowa, raised questions about airline maintenance practices. The Aloha Airlines 737 accident showed that maintenance and maintenance training practices were the major cause of the

explosive decompression and structural failure of major skin components (NTSB, 1989). While these incidents resulted in the loss of life, the overall safety and redundancy of the aircraft combined with the training of the crews prevented total catastrophe in both cases.

Since maintenance practices were involved in the examples above, as well as in other incidents, operators and the government are paying increased attention to the human in the maintenance system. The Aviation Safety Research Act of 1988 (PL100-591) mandated that research attention be devoted to a variety of human performance issues including "aircraft maintenance and inspection."

### 1.1.2 Increased Maintenance Workload

From 1980 to 1988 the estimated cost of airline maintenance increased from $2.9 billion to $5.7 billion (GAO, 1990). The increase is attributable to numerous factors including an increase in passenger miles flown, an increase in number of aircraft added to the fleet, and increased maintenance for continuing airworthiness on aging aircraft. *Table 1.1* shows the increases in dollars spent on maintenance, passenger miles, number of aircraft, and number of maintenance technicians (GAO, 1990 and ATA, 1989 Summary Data) from 1980 through 1988. *Figure 1.3* shows that the increase in the number of aviation maintenance technicians has the lowest percentage increase of all the categories in that eight-year period. These data suggest that workload on the individual technician has increased. Therefore, research attention to the human in the maintenance system is likely to have high potential to increase maintenance efficiency, effectiveness, and safety.

### 1.1.3 Demograhics

The OTA, the U.S. Department of Labor, the Air Transport Association, the Future Aviation Professionals Association, the Aviation Technician Education Council, the Professional Aviation Maintenance Association, and numerous other groups maintain estimates regarding the projected shortage of aviation maintenance technicians (AMT) over the next ten years. There is unanimous agreement that there will be a need for 100,000 - 120,000 AMTs by the year 2000. The number is based on the current number of technicians combined with new positions related to new aircraft and increased attention to continuing airworthiness of older aircraft. Using those estimates and the estimates of the numbers of new A&P certificates, the shortage will range from 65,000 to as many as 85,000 new AMTs needed by the year 2000. *Table 1.2* depicts the estimates.

Most of the new AMT workforce will be different that the current AMT workforce, which is comprised of males over 30 years old (69% in 1988 (Dept. of Labor)), with nearly a third of this population having over 20 years experience. As these experienced technicians retire their positions will be largely filled by inexperienced personnel. The new work force will require greater training and job support systems, both of which will be products of a human factors research program.

### 1.1.4 Competition for Resources

With increasing passenger miles flown and increasing numbers of flights per day there is considerable competition for resources, especially between operations and maintenance. The operations departments need more airplanes, for more routes, for longer periods each day. The increased flight hours and emerging requirements for

| | 1980 | 1988 | % Increase |
|---|---|---|---|
| **Maintainance Costs** | $2.9 Billion | $5.7 Billion | 96% |
| **Passenger Miles** | 255 Billion | 433 Billion | 65% |
| **Aircraft in U.S. Fleets** | 3,700 | 5,022 | 36% |
| **Number of Mechanics** | 45,000 | 55,000 | 22% |

**Table 1.1 Percentage Increase in U.S. Airlines 1980 - 1988**

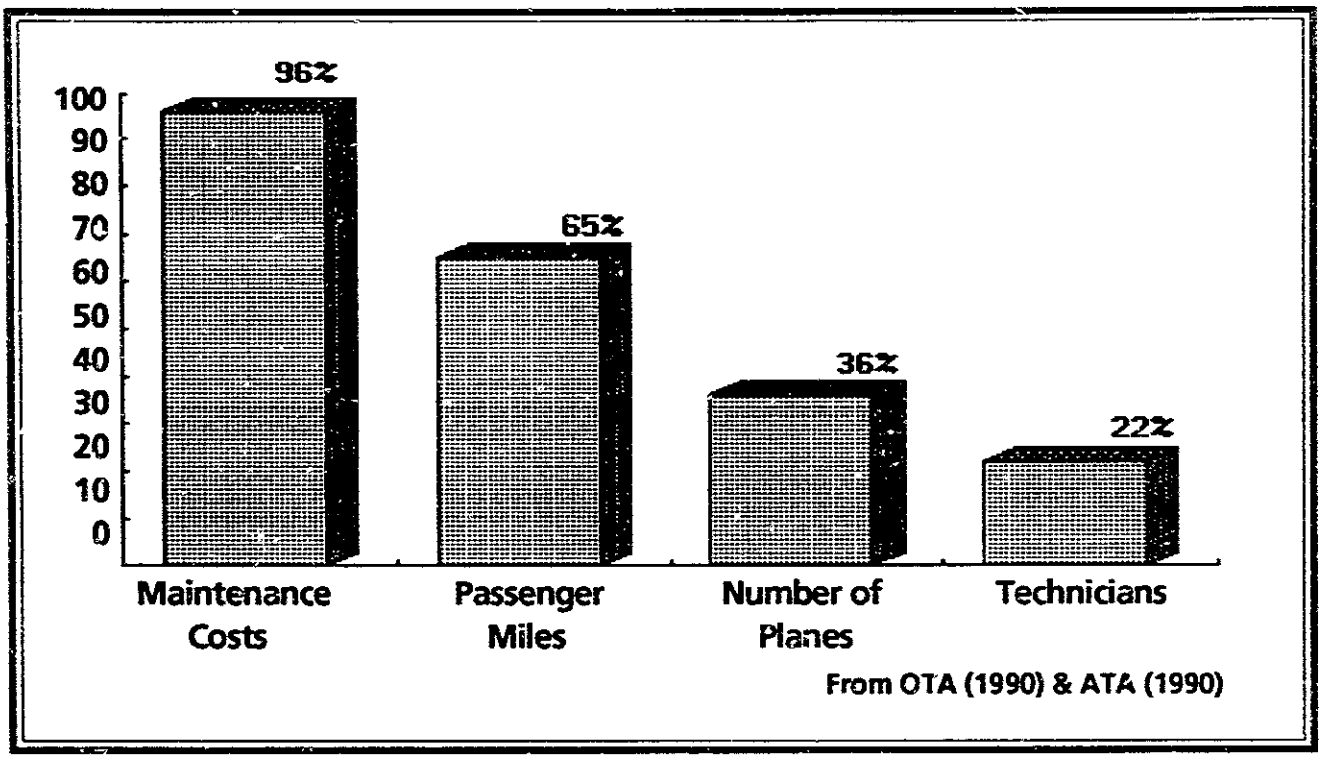


**Figure 1.3 A Graph of Table 1.1**

continuing airworthiness on aging aircraft require more maintenance. The finite resources include, as examples, time, shop floor space for maintenance, equipment for inspection and maintenance, and AMT personnel. The limited resources are competing to match aircraft availability with the transportation system demands. The increasing fleet size, matched with the fact that by 1995 nearly 65% of the aircraft will be over 20 years old (National Council on Vocational Education, 1991), suggest that there is a serious potential shortage of the resources (human, equipment, and space) to inspect and repair aircraft (GAO, 1990). There is a need to increase resources across the board. In addition, there will be a special need to help the technician work "smarter" and generally increase the overall capability of the human, as well as the system, to service the growing numbers of aircraft.

## 1.2 HUMAN FACTORS DEFINED

### 1.2.1 What is Human Factors

Human factors studies the performance of the human as an operating element within a goal-directed system. In the design and use of a system, the human is viewed in the same manner as any system component. If the system is to function effectively and efficiently, the designer must understand the operating characteristics of each component, including the human. Human Factors research seeks information on laws of human behavior, the capabilities and limits of humans, effects of environmental factors, and rules for optimizing the use of humans in present-day systems. The research team recognizes that it is not always possible to treat the human as a predictable element in a system. Human nature, work ethic, and a variety of such innate behavioral variability threatens a classical engineering treatment of the human in a system.

The broad goals of human factors research require a multidisciplinary effort drawing on information from specialities such as psychology, physiology, ecology, engineering, medicine, education, computer science, and others. Information from these sources is used to develop procedures for system design, for operational system use, and for ongoing evaluations of system effectiveness. In all cases, primary attention is given to the human operator.

### 1.2.2 Why Human Factors Research in Aviation Maintenance

The human in aviation maintenance can be conceptualized as a person-machine system, as shown in *Figure 1.4*. Input and output variables can be clearly specified. The process itself, as shown, is labor-intensive, with the Aviation Maintenance Technician being, by far, the most important system element. In order to achieve the desired system output, an understanding is required of the many factors (working environment, training, etc.) which affect the performance of technicians. Human factors examines all of these variables, their effect on technician perfor-

| | |
|---|---|
| **Projected AMT Requirement through 2000** | 100,000 - 200,000 |
| **AMTs Employed in 1988** | 55,000 |
| **Estimated New Positions** | 45,000 - 65,000 |
| **Estimated Attrition Through 2000** | 45,000 |
| **Estimated Training Completions** | 25,000 |
| **Projected Shortage of AMTs By 2000** | 65,000 - 85,000 |

**Table 1.2**
**Avaition Maintenance Manpower Requirements Through the Year 2000**
(Dept of Labor (1990), ATA (1990))

mance, and the resulting quality of system output. Using this information, a maintenance system can be designed to minimize system error and to ensure that aircraft are available as needed and are fully safe for flight.

Human factors can have significant effect on the performance of the total aviation maintenance system. Human factors can affect hardware design and manufacture; the design and implementation of maintenance tools and procedures; and the selection, training and overall support of the human as a critical component of the aviation maintenance system.

Human factors provides approaches to make efficient use of human resources, while at the same time maintaining margins of safety. Importantly, while only two to three percent of accidents are attributed to pilot error, Weiger and Rosman (1989) have data which indicates that about 40% of all wide-body aircraft accidents attributed to human error begin with an aircraft malfunction. Reduc-

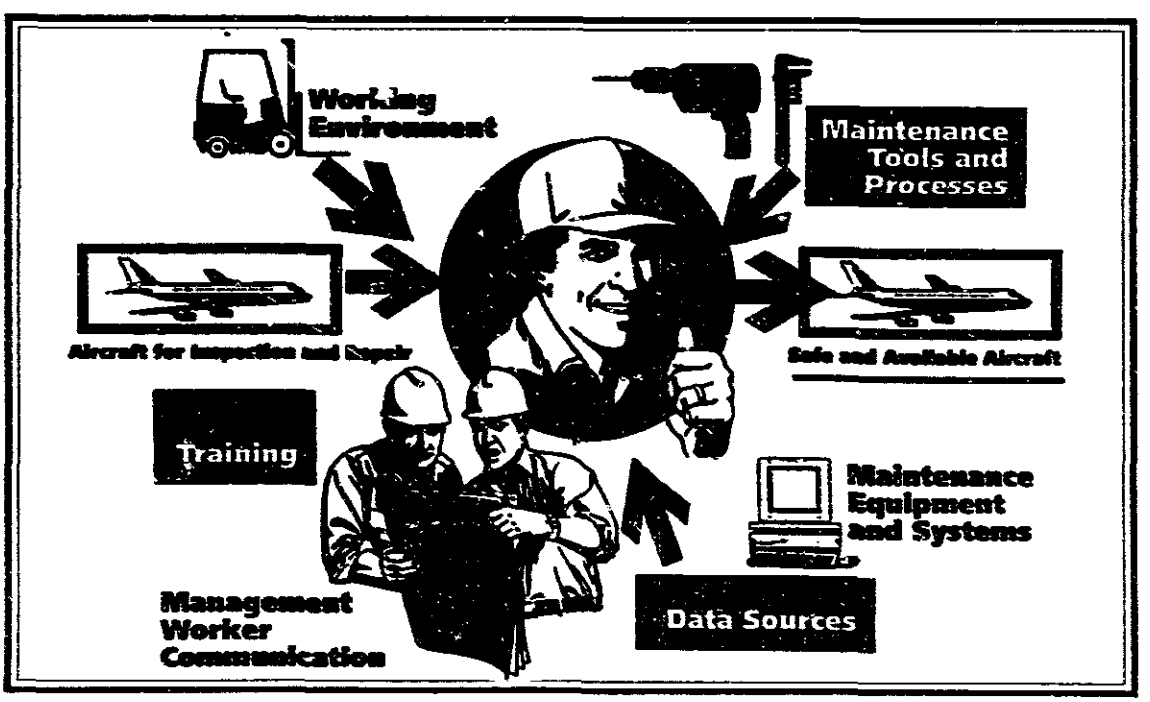


Figure 1.4 The Human in the Maintenance System

ing aircraft malfunction is a primary goal of maintenance programs and the humans who carry out those programs.

## 1.3 STUDY OF THE MAINTENANCE ORGANIZATION (CHAPTER 2)

This research was a study of maintenance organizations from an organizational psychology and systems engineering perspective. The intent was to identify how communication is accomplished within a maintenance organization. The research also focused on how maintenance organizations set and accomplished technical goals.

A rapid but systematic assessment of aviation maintenance technician interaction in eight U.S. companies was undertaken in early 1990. Over 200 AMTs, their foremen, and maintenance managers were interviewed and observed during two to four day visits of heavy maintenance checks of aging aircraft. The data from these visits were coded and classified using socio-technical systems (STS) concepts to identify organizational purpose, values, environment, product, and patterns of communication (Taylor, 1989). STS principles (Cherns, 1987) were then used to help assess the compatibility among those various components.

### 1.3.1 Awareness of Maintenance Goals

The survey suggested that individual AMTs did not always have a complete understanding of the company purpose regarding the role of maintenance. The maintenance personnel need to be able to individually describe their role in concert with the company purpose.

### 1.3.2 Competence of the Workforce

The survey, albeit not all encompassing, indicated a shortage of experienced AMTs. Several factors are responsible for this situation. In the late 1960's, the maintenance force was comprised of AMTs with experiences gained during military service, supported by skilled general foremen, scheduling cadre, and instructors to broaden the AMT knowledge as newer aircraft such as the Douglas DC-9 and Boeing 727 joined the established fleet of Boeing 707's and Douglas DC-8's. The oil crisis of 1972-73, increased fuel costs resulting in increased fares. Increased fares caused a reduction in load factors, causing airlines to lay off newer mechanics. Unfortunately, as the crisis eased, these mechanics were not rehired, to a large degree. The slow economic times of 1979-83, coupled with deregulation, generated a cost-conscious industry, a sign of which is reduced inventories of aircraft parts and leaner staffing.

Finally in 1988 through the present the "new" fleet of 1970 aircraft are now the aging aircraft, exhibiting the need for increased inspection and repair. The AMT workforce however, with the experienced AMTs retiring, being promoted and transferring, currently exhibits a bimodal distribution with the AMTs either being very experienced, or having little (3 years or fewer) experience.

With the aging fleet problems involving extensive sheet metal repair, the newer AMTs are working to develop skills and experience to complete repairs which are compatible with commercial transport damage tolerance practices. This learning process can result in delay and often in re-repair, a situation that is not acceptable to the time pressure type of maintenance operation.

### 1.3.3 Teamwork

The survey clearly indicated that above-average coordination, cooperation, and communication produced less frustration and improved work performance. Where communication was not a high priority, high turnover, low morale, and concerns about the high maintenance workload resulted. Contributing to this problem was the complexity of coordination among maintenance, planning, stores and shops.

### 1.3.4 Commitment

The overwhelming majority of AMTs contacted during the survey expressed enjoyment in maintenance and mechanical repair. A strong desire to see the "big picture" was exhibited throughout the mechanic, inspector, planner and managerial workforce. Regarding intent to remain in the maintenance operation, the planning force was the group considered most likely to move on to other areas.

### 1.3.5 Phase II Plan

In the second phase the researchers will develop a document that will be a guideline for effective communication within maintenance organizations. The document will be designed with, and written for, all levels of maintenance management. The document will address issues related to maintenance management style, the structure of the maintenance organization, job design for application of new technology, defining purpose and goals within a maintenance organization, and other topics related to the pursuit of excellence within maintenance organizations. This written guideline will be available to the industry at the completion of Phase II, in late 1992.

## 1.4 STUDY OF THE MAINTENANCE TECHNICIAN IN INSPECTION (CHAPTER 3)

The Federal Aviation Administration policy regarding aircraft structural design is that of damage tolerance. This approach accepts that cracks and corrosion in metal

aircraft do, by definition, exist through the life of the aircraft. The inspection interval applied to the damage tolerant design is that which will detect the defect before it presents a hazard to safe flight. The inspection interval is maintained by humans doing the job manually or with some form of inspection device. In either case, humans and machines are fallible. Ways are needed to make the system components less error-prone, and the system itself more error tolerant.

The approach in this chapter is to determine typical human/system mismatches to guide both future research and short-term human factors implementation by system participants. Also, by providing a human factors analysis of aircraft inspection, it is intended to make human factors techniques more widely available to maintenance organizations, and to make aircraft maintenance more accessible to human factors practitioners.

Error-prone human/system mismatches occur where task demands exceed human capabilities. The necessary comparisons are made through a procedure of task description and task analysis. Task description enumerates the necessary task steps at a level of detail suitable for subsequent analysis. Task analysis uses data and models of human performance to evaluate the demands from each task step against the capabilities of each human subsystem required for completion of that step. Examples of subsystems are sensing (e.g. vision, kinesthesis), information processing (e.g. perception, memory, cognition), and output (e.g. motor control, force production, posture maintenance).

*Table 1.3* shows a seven-task generic task description with examples from each of the two main types of inspections: Visual Inspection (VI) and Non-Destructive Inspection (NDI).

Given a generic task description, the next requirement is to bring human performance models to bear on the tasks, and hence form a task analysis. Two ways were found to perform this. First, the critical human subsystems were checked at each task step. Second, observations of likely errors, human factors improvements, and error-related issues were made from observations taken. These led to a composite task description/task analysis form as an in-project working document.

To document the human and system error potential, the approach taken was to have the analysts visit several maintenance/inspection sites and work with inspectors to complete task descriptions of representative tasks. Inspectors were observed, questioned, photographed and interviewed, often on night shifts and under typical working conditions. (The degree of cooperation, enthusiasm and

| TASK DESCRIPTION | VISUAL EXAMPLE | NDI EXAMPLE |
|---|---|---|
| 1. Initiate | Get workcard, read and understand area to be covered. | Get workcard and eddy current equipment, calibrate. |
| 2. Access | Locate area on aircraft, get into correct position. | Locate area on aircraft, position self and equipment. |
| 3. Search | Move eyes across area systematically. Stop if any indication. | Move probe over each rivet head. Stop if any indication. |
| 4. Decision Making | Examine indication against remembered standards, e.g. for dishing or corrosion. | Re-probe while closely watching eddy current trace. |
| 5. Respond | Mark defect, write up repair sheet or if no defect, return to search. | Mark defect, write up repair sheet, or if no defect, return to search. |
| 6. Repair | Drill out and replace rivet. | Drill out rivet, NDT on rivet hole, drill out for oversize rivet. |
| 7. Buyback Inspect | Visually inspect marked area. | Visually inspect marked area. |

**Table 1.3. Generic Task Description of Incoming Inspection with Examples from Visual and NDI Inspection**

professionalism of all of our "subjects" was remarkable, and reassuring to the traveling public.)

### 1.4.1 Summary Findings

There are many places where Human Factors interventions can be effective. This Chapter describes experience in applying Human Factors to inspection tasks in manufacturing industry. In summary these include:

- Changing the system to fit the operator:
  1. Improving visual aspects - lighting, contrast, target enhancement, optical aids, false colors on video.
  2. Improving search strategy - briefing/feed forward, aids to encourage systematic search.
  3. Enhancing fault discriminability - standards at the workplace, rapid feedback.
  4. Maintaining correct criterion - recognition of pressures on inspection decisions, organization support system, feedback.
  5. Redesigning the aircraft and its systems to improve access, search and decision, i.e. Design for Inspectability (Drury, 1990).
- Changing the operator to fit the system:
  1. Selection/placement - visual function, perceptual style (Drury and Wang, 1986).
  2. Training/retraining - cuing, progressive part training schemes, controlled feedback (Drury and Gramopadhye, 1990).

When applied specifically to aircraft inspection, *Table 1.4* shows a summary of the potentially-useful strategies. They range from the simple (such as improved flashlights and mirrors for visual inspection and safe, easily-adjustable work stands) to the complex and costly (such as pattern recognition-based job aids, restructuring of the organization to provide feedforward and feedback).

The FAA recognizes that communications and training need immediate attention. The aviation maintenance information environment (Drury, 1990) complicates communication between inspectors and their co-workers (e.g. feedforward information), between inspectors at shift change, and between inspectors who find a problem and those who must reinspect and approve ("buy-back") that repair. Training is largely on-the-job, which may not be the most effective or efficient method of instruction. In subsequent years, the National Aging Aircraft Research

| | STRATEGY | |
|---|---|---|
| | **Changing Inspector** | **Changing System** |
| **Initiate** | Training in NDI Calibration<br>(Procedures Training) | Redesign of Job Cards<br>Calibration of NDI Equipment<br>Feedfoward of Ecpected Flaws |
| **Access** | Training in Area Location<br>(Knowledge and Recognition Training) | Better Support Stands<br>Better Area Location System<br>Location for NDI Equipment |
| **Search** | Training in Visual Search<br>(cueing, progressive-part) | Task Lighting<br>Optical Aids<br>Improved NDI Templates |
| **Decison** | Decison Training(cueing<br>Feedback, Understanding<br>of Standards | Standards at the Work Point<br>Pattern Recognition Job Aids<br>Improved Feedback to Inspection |
| **Action** | Training Writing Skills | Improved Fault Marking<br>Hands-free Fault Recording |

**Table 1.4**
**Potential Strategies for Improving Aircraft Inspection**

Program (NAARP) and, hopefully, the maintenance/inspection providers need to pursue both short-term interventions based on solutions proven effective in manufacturing, and longer-term research to give definitive, implementable solutions.

### 1.4.2 Phase II Plan

Phase II of this research task will pursue the overall program goal to create demonstrations of techniques to improve human factors in aviation maintenance. The first subtask will identify, implement, and measure the effect of specific lighting improvements used in an inspection task. This research task will assess the lighting change with respect to potential elimination of error and with respect to cost effectiveness.

A second task under this research topic will address methods to reduce error in the calibration and operation of a variety of non-destructive inspection test equipment. This research will study the human factors aspects of NDI equipment design and various aspects of training and retraining of NDI personnel. Finally, this subtask will continue to identify human factors issues that should be addressed in the continuing effort to improve human performance in inspection.

## 1.5 STUDY OF ADVANCED TECHNOLOGY FOR MAINTENANCE TRAINING (CHAPTER 4)

Advanced technology training refers to the combination of artificial intelligence technology with conventional computer-based instructional methods (Johnson, 1990).

This chapter reports the status of a project to support the application of advanced technology systems for aircraft maintenance training. The first phase of the research was to survey the current use of such technology in airlines, manufacturers and approved aviation maintenance technician schools. The second phase of the research is building a prototype intelligent tutoring system for aircraft maintenance training. The chapter defines intelligent tutoring system technology and presents the specifications for the prototype. The chapter also describes example constraints to the rapid design, development and implementation of advanced technology for maintenance training.

The human is an important component in the commercial aviation system that provides safe and affordable public air transportation. Much attention to the "Human Factor" in the aviation industry has focused on the cockpit crew. However, the FAA and the airlines recognize that aircraft maintenance technicians (AMTs) are equal partners with pilots to insure reliable safe dispatch. The job of the AMT is becoming increasingly difficult as discussed in *Section 1.1.2*. This is a result of the fact that there are increasing maintenance tasks to support continuing airworthiness of the aging aircraft fleet while, at the same time, new technology aircraft are presenting complex digital systems that must be understood and maintained. Sheet metal and mechanical instruments have given way to composite materials and glass cockpits. These new technologies have placed an increased training burden on the mechanic and the airline training organizations. The advanced technology training research, reported here, is exploring alternatives for the effective and efficient delivery of a variety of aircraft maintenance training.

### 1.5.1 Summary Findings

The industry survey showed that there are many applications of traditional computer-based training being used for maintenance training. However, there are very few applications of artificial intelligence technology to maintenance training. Nearly all airline personnel indicated that current computer-based training was not sufficient to meet all of the demands associated with maintenance training. The survey also suggested that managers of maintenance training are becoming increasingly articulate about specifying their requirements for computer software and hardware. Numerous industry committees are creating standards that will increase compatibility across the maintenance training industry.

The FAA is in the process of modifying the regulation affecting the AMT schools. Part 147 of the Federal Aviation Regulations now recognizes that computer-based training systems are, in selected cases, as valuable for training as the use of real equipment. This change in policy is likely to create an increased marketplace for development of advanced technology training systems.

During Phase I a prototype training system was built for an aircraft environmental control system. Development of the environmental control system training prototype demonstrated that rapid prototyping is a very effective means to involve system users in the earliest stage of the system design. The software tools for rapid prototyping make it relatively easy to create reasonable examples of the final system interface. However, this prototyping effort reinforced the researchers' opinion that the "easy to use" tools are good for rapid prototyping but have limited potential with respect to building the completed training system. Subsequent development must be accomplished with programming languages rather than interface development tools.

### 1.5.2 Phase II Plan

During Phase II the environment control system training prototype will be written in a programming language. The simulation, specified in Phase I, will be written. The knowledge engineering process and formative evaluation will continue with the technical personnel. The prototype will be converted to a fully operational turn-key training system. The training system will be the key focus for the extensive evaluations planned for Phase III.

## 1.6 STUDY OF JOB PERFORMANCE AIDS (CHAPTER 5)

This research was designed to provide information for government and industry managers in their efforts to assess the utility and implementation of job-aiding technology. There were two areas in this research task - aviation maintenance assessment and technology assessment.

The first research area sought a user's perspective on job performance aids (JPAs). Current approaches to computerization and job aiding in aircraft maintenance were investigated. A survey was conducted to determine the relative level of automation at 25 airlines. Systems were observed during various phases of development and work force reactions were determined. The needs of the maintenance technician were assessed and an overall understanding of the maintenance process was obtained.

The second area focused on technologies. A survey was conducted to determine the capability of existing JPA systems. The state-of-the-art in computers and in related technologies was assessed. Current approaches to system integration were identified.

The research documented the challenges facing aviation maintenance and the current approaches to utilize technology in meeting those challenges. This information was obtained from four sources:

- Airlines - managers, data processing specialists, AMTs
- Industry representatives - groups such as the ATA
- FAA - maintenance managers and inspectors
- Manufacturers - customer support, designers

Access to these individuals was obtained through participation in numerous industry forums and site visits. The site visits lasted from two hours to one week. Information was collected through informal interviews and observation. The researchers participated on a non-interference basis in the normal conduct of aircraft maintenance. All shifts of operation were observed.

Information was collected through surveys, expert assessment, and literature research. A survey of existing JPA systems was conducted. The focus of the JPA survey was on computer and microprocessor-based systems used for information delivery, processing, or storage. In addition, applicable technologies not yet incorporated in systems were identified in anticipation of future systems. The goal of the survey was not to find the system that would "revolutionize" aviation maintenance, but to assess the overall extent and characteristics of what has been done and what is possible in terms of job aiding. The information was collected through extensive database searches, telephone discussions, and site visits. Several "new" technologies were investigated in computer displays, microprocessors, storage, and input/output devices. Finally, two small experiments were conducted to assess the realities of developing databases and graphical user interfaces (GUI) for job performance aids.

### 1.6.1 Summary Findings

The findings are divided into three areas:

- Maintenance automation
- Technology assessment
- Systems integration

The areas represent what exists, what is possible, and how to transition between the two. The findings on maintenance automation systems describe the status of maintenance automation, how they are designed, justified, lessons learned, and trends for the future. The technology assessment findings provide a realistic assessment of the utility of technologies in terms of cost, function, availability, and complexity. The focus of the systems integration findings is information on how to integrate humans into the various systems.

#### 1.6.1.1 Maintenance Automation

The process of fielding maintenance automation has largely been one of computerization. The statistics maintained on aircraft have grown exponentially. The basic structure used for the paper methods has been transferred intact to the computer approaches. This was necessary to ease transition and avoid extensive retraining that might be needed with a new approach. Most maintenance operations now use computers to track parts and aircraft status, and many organizations are moving computers into forecasting and other decision aiding functions. Efforts to computerize have reached a plateau, and only the most profitable airlines have data processing people actively developing major new systems for maintenance.

### 1.6.1.2 Technology Assessment

The survey of JPAs identified over 150 job performance aids developed during the last ten years. More than half of the developments were sponsored by the Department of Defense (DoD). Fewer than twenty systems are still in active use or development, and another twenty were searching for a sponsoring application. The remaining were shelved for reasons that usually involved lack of funding.

There are several successful JPAs, and the survey findings do not imply that JPA development is unfeasible. The survey did support the need for a more realistic assessment of how soon JPA technology can be applied to commercial aviation maintenance.

### 1.6.1.3 Systems Integration

Based on technical functionality, most of the computerization efforts for aircraft maintenance and JPA development efforts by the DoD were successful. Unfortunately, technical functionality is not good enough. Humans remain the engine for most complex systems. Even automatic test equipment (ATE) is dependent on humans for planning, design, manufacturer, installation, and maintenance. Approaches exist that incorporate Human Factors and these should be considered.

### 1.6.2 Phase II Plan

The next phase of the research on job aiding will identify a candidate technical domain in which a computer-based intelligent job aid can have potential to increase maintenance effectiveness and efficiency. During Phase Two the research team will work with an airline to identify a candidate domain and construct a system prototype. Current plans are aimed at using a portable, expert system-based job aid that has been developed in a non-aviation industry. The next phase of the research will focus more on the specification and development planning than on completion of the job aid for an operational aviation maintenance environment. Sewell and Johnson (1990) have described how prototype systems can be used for system design and development. The intelligent job aid prototype will be used for concrete systems specification for Phase III development.

## 1.7 HUMAN FACTORS IN AVIATION MAINTENANCE - THE CONFERENCES

The combination of factors described in *Section 1.2* highlights the importance of communication among all entities involved in the aviation maintenance system. Broderick (1990) suggested that industry communication "ties the maintenance operation together and, in fact, is the thread that runs through aviation safety from any point of view...." This project was a direct intervention to present Human Factors information to the aviation maintenance community, and to provide a forum for direct interchange of relevant information between system participants. This sub-project organized a series of Human Factors seminars for personnel associated with aviation maintenance.

As noted in *Section 1.1*, the air carrier industry in the United States can be viewed as a three-legged stool consisting of the aircraft manufacturer, the airline operator, and the regulatory agencies, principally the Federal Aviation Administration. For carrier maintenance to work as it should, communications among these three elements must be efficient and meaningful. The cross braces in the stool represent the communication.

The FAA and industry have noted a need to develop some other mechanisms to foster ready communications among airline operators, aircraft manufacturers, and the FAA. This should exist in some form that would allow members within each of these three groups to understand the current thinking of members of the other two groups. A free exchange of information should be allowed concerning maintenance technologies, procedures, and problems.

The Federal Aviation Administration, on reviewing the success of the 1988 meeting, established a series of meetings to address "Human Factors in Aircraft Maintenance and Inspection." The purpose was to foster communications among all segments of the aviation maintenance community. To date, four meetings have been held. While the first meeting in 1988 explored the full range of maintenance problems, each subsequent meeting focused on a specific Human Factors issues in order to obtain greater depth of coverage.

The four meetings in this series held thus far are:

***Human Factors Issues in Aircraft Maintenance and Inspection***
Alexandria, Virginia, October 1988.

> Presentations were made concerning maintenance issues and human factors ramifications by representatives of aircraft manufacturers, airline operators, the FAA, technical training schools, and others. Three presentations described the discipline of human factors and its potential contribution to aviation maintenance.

***Human Factors Issues in Aircraft Maintenance and Inspection - Information Exchange and Communications***
Alexandria, Virginia December 1989.

This meeting focused on problems in the exchange of maintenance information and possible improvements in information management and industry communications. Considerable attention was given to new technologies which might support industry communications.

***Human Factors Issues in Aircraft Maintenance and Inspection - Training Issues***
Atlantic City, New Jersey, June 1990.

The purpose of this meeting was to review the status of maintenance training for the air carrier industry, to consider problems facing those responsible for this training, and to learn of new training technologies under development. Some of the presentations illustrated new technologies now being brought into use in aviation maintenance.

***Human Factors Issues in Aircraft Maintenance and Inspection - The Aviation Maintenance Technician***
Alexandria, Virginia, December 1990.

The meeting dealt with the aviation maintenance workforce. Presentations dealt with acquiring, training, and maintaining an effective workforce. The likely impact of changing national work force demographics was explored. The impact of organizational factors on aviation maintenance was reviewed.

Attendees at each of these meetings have commented on the value of the meetings as a communications medium for the air carrier maintenance community.

### 1.7.1 Phase II Plan

There will be two workshops conducted during Phase II. The first, scheduled for June 1991 in Atlanta, Georgia, will address Human Factors in the aviation work environment. The second meeting will be in Washington, DC, during January of 1992.

## 1.8 ADDITIONAL RESEARCH ACTIVITIES

The research program is committed to be responsive to Human Factors issues related to proposed rule changes, new policies, Airworthiness Directives and/or Service Difficulty reports.

### 1.8.1 Electronic Document

One of the projects scheduled for Phase II is the development of an electronic database of all publications and presentations from Phase I of the program. The electronic document will capitalize on hypertext software technology. This research will go beyond the mere digitization of documents. The project will emphasize a document format and electronic interface that will provide greater capability than is available with hard-copy documentation. The project will create specifications for the electronic publishing of all past and new project-related documents. At the completion of the project the documentation will be available on one compact disc read only memory (CD ROM) disc.

### 1.8.2 Handbook on Aviation Maintenance Human Factors

During Phase II the research team will outline and prototype a handbook on aviation maintenance human factors. The handbook will offer basic and applied principles covering all issues of human performance in aviation maintenance. The handbook will be useful to all who are responsible for planning, managing, and conducting maintenance. It will include, as an example, the following kinds of topics: workplace requirements, workplace environment, human capabilities, workplace design principles, training design and practices, and other topics. The handbook will follow formats used in other such compendia (Boff and Lincoln, 1988; Parker and West, 1973).

### 1.8.3 The National Plan for Aviation Human Factors

The Federal Aviation Administration, in conjunction with the National Aeronautics and Space Administration (NASA) and the US Department of Defense, conducted an extensive series of workshops, during 1990, to create a National Plan for Human Factors. One of the subgroups of the Scientific Task Planning Group was dedicated to Human Factors in aircraft maintenance.

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# Chapter Two
# Maintenance Organization

## 2.0 SUMMARY

This study recognizes the considerable strengths of the airline industry's maintenance flight safety efforts. It offers suggestions for additional research, and it describes some possible areas for further improvement. It represents a combined picture of maintenance management and organizational behavior in eight U.S. maintenance operations including small and large aircarriers and repair stations.

The sample used for this study was necessarily limited. The findings, therefore, must be understood as indicative only, and not conclusive.

The study was undertaken for the purpose of benchmarking: to estimate the effect current organization and management practice may be having on the work practices of mechanics, inspectors, and schedulers, and on their attitudes and morale, and how those, in turn, may affect safety and work quality. These factors do, in fact, show a close relationship one to the other.

While there was found considerable variation among these factors from one carrier to another, none was seen to have reached the point of compromising air-safety. This is an important finding for the industry, affirming its long-standing commitment to safe air travel.

Throughout the course of the study the people observed were seen as serious about their work, dedicated, well-meaning, and bright. Everywhere in the industry, employees clearly showed their desire to do their very best for air safety. Their commitment is reflected in their excellent performance record.

At several sites, employee morale and coordination of the work were found to be below the optimum. Based on the results of this study, the timely and careful adjustment of certain practices, structures, and norms might be an early prudent step to positively affect safety in the future.

For those who see in these findings confirmation of their own careful observations and conclusions, action may be taken with a fairly high degree of confidence. For others, only a more-broadly based, more thorough-going research effort or direct evidence of successful management changes and intervention will be convincing.

The present study sets the stage and suggests avenues for additional research and action.

## 2.1 INTRODUCTION

The excellent safety record of U.S. airlines is well established. A General Accounting Office (GAO) report states that "accident rate data . . . have improved over the last 20 years and that U.S. airlines have a lower accident rate than airlines in the rest of the world" (GAO, 1988).

**Measuring the effects of maintenance on safety.** Measures of safety other than accident rates have been applied with mixed results. Financial data may prove useful, but current reporting procedures for maintenance costs present difficulties in comparing companies within the industry. Airlines differ in their labor costs and accounting practices, and in the age of their fleets. Such differences make comparisons suspect. Because the Department of Transportation (DOT) does not require smaller airlines to report maintenance costs, these companies cannot be compared on this basis at all. New measures of current safety conditions would be useful.

Measuring and comparing airline maintenance quality is obviously important. The present major method of determining maintenance quality is to assess the degree of adherence to (or deviation from) the Federal Aviation Administration- (FAA) regulated maintenance programs. This approach does not measure the outcome of maintenance efforts, but instead relies on the assumption that if programs are followed quality will result — in short, it is a measure of practice, not outcome.

Current interest in programs to measure and improve product quality (e.g. the Department of Defense (DOD) emphasis on "Total Quality Management") is beginning to be reported in the airline industry, (Doll, 1990), but such programs are apparently not widely applied yet. Comparable measures of maintenance quality, then, are still in the future. Measurement of maintenance related problems would provide a viable avenue to assess quality, but the available mechanical-reliability and unsafe-incidents data bases are designed to track short-term, not longer-term, trends (OTA, 1988). Thus, the currently available measures of maintenance on safety do not satisfy the need for measures except for historical accident data.

**Measuring and comparing human factors.** Despite recent conclusions that human factors in maintenance (and management practices specifically) can influence the judgement, attitudes and skill of aviation maintenance personnel (OTA,

1988) little research or action in this area has been reported. As will be described in further detail in the section on prior research, there is very little published about human factors in aircraft maintenance at either the individual worker or organizational levels.

This study is an initial effort to estimate the importance of organizational and management aspects of maintenance on morale and motivation, communication patterns, work-related behaviors, and quality of work for aircraft maintenance personnel (AMP). The results of this preliminary study suggest that links exist between organization, communication, attitudes and quality of work. Much more difficult to establish, but important to assess, is a link between quality of work and flight safety. That link was not intended to be validated within the scope of the present study.

### 2.1.1 Problem Definition — The Changing Environment for Aircraft Maintenance

**Deregulation as a force increasing complexity for maintenance.** During the initial years following airline deregulation (1979-1984), U.S. carriers' data reported to DOT indicated that a lower percentage of operating funds was spent on maintenance than had been the case in prior years (OTA, 1988). GAO noted recently that by 1988 the reported amount spent to maintain and repair aircraft was almost double the 1984 levels, and that current U.S. repair ability is operating at near full capacity (GAO, 1990). Such swings in maintenance expenditures, by themselves, place pressures on maintenance and inspection personnel. In another report, the GAO (1988) listed the following, among others, as "risk precursors" (their signs of problematic safety compliance) in U.S. air carriers: major route expansion, fleet expansion (due in part to mergers and acquisitions), industrial relations conflict (which can accompany mergers), and strained finances (complicated by intense competition and unstable fuel prices). Few U.S. carriers can claim the absence of these signs.

**The additional problem of aging aircraft.** Recent aging aircraft airworthiness directives (ADs) have been said to be an important stimulant to increasing short-term demand for airlines' need for maintenance (GAO, 1990). In the past decade the mean age of jetliners has risen 21% to about 13 years. With high altitude pressurized aircraft the number of flight cycles (one cycle includes a take-off and landing) is as important to age as years. Depending upon the specific model, aging aircraft are defined as those with more than 40,000 cycles. The GAO report notes that the cost of compliance with aging aircraft ADs may total $2 billion to sustain and extend the life of this aging fleet.

Inspectors and mechanics need to identify and deal with fatigue cracks in these old aircraft (especially myriad small cracks adjacent to one another, called "multi-site damage, or MSD") and corrosion in fuselage areas. This attention requires new information, skills, and time in addition to the normal work load. Demand for both airplanes and maintenance personnel continues to go up.

**Organizational communication as it relates to maintenance.** Attention to the human factor in maintenance is growing, and that human factor in aircraft maintenance is more than an individual who follows orders. In maintenance work, the human has often been characterized as "the technical system" — and this is not inappropriate. In this role, an inspector or mechanic ("inspecting") searches for flaws/defects and decides when they have been found. After searching and locating it, the flaw is repaired in a planned sequence. This search-decide-plan-repair sequence is the "human factor as technical system" in maintenance systems of many industries.

With the importance and logic of this technical system view, a complementary view, that of the "human-factor-as-social-system" risks being ignored unless a conscious effort is made to include it. In this social systems view, the web of relationships among all the parties involved comes into focus in setting and strengthening expectations among them.

The social system is thus a set of expectations (sometimes positive and constructive, and sometimes conflictual and destructive) with others in the workplace, elsewhere in the organization, and with outsiders.

**Management by design.** Often managers (still) feel capable of making significant organizational decisions based on intuition and experience. But the tasks of organizing aircraft maintenance today have become extremely complex.

Among the organizational forms that have been used successfully in the past is assigning not only inspection and maintenance to separate departments, but separating materials, tools, shop repair of components, planning and scheduling from maintenance as well. Organizing into "functional silos" this way, strictly by application domain or function, may well affect maintenance system's ability to assure safety of flight through efficient, coordinated, motivated and informed action by people doing the work.

A parallel organizational form often found in aviation maintenance ignores functional differences altogether [except where required by Federal Aviation Regulations (FARs)] and relies on the "master craftsman's" technical skill and competence to determine and carry out the work. In today's complex maintenance environment, the functional silos, or master craftsman structures, that have proven adequate in the past may be breaking down in the present.

The safety record of the aircraft maintenance organization has been admirable. But it may be possible to achieve even higher performance, with higher morale and more efficient work coordination. To do so, however, would require more than minor improvements on the current system, which seems to already work about as it was designed to. Instead, the maintenance system would require redesign, eliminating or modifying sub-department boundaries so that the people could work more easily together in controlling key technical variances.

The central purpose for any such redesign would be to better enable maintenance personnel to control variances where they occur, and before they exceed stated limits. An effective redesign would save time, money, and effort as well. Prior research shows that such an approach, widespread in other industries, could usefully be applied to aviation maintenance (Taylor & Cotter, 1983).

### 2.1.2 Statement of Objectives

To improve safety, it is important to improve quality. To improve quality we must understand employees' state of mind and the organizational and management aspects most affecting that state. This study was directed at identifying these important aspects in aviation maintenance. With the support of the FAA, the study undertook field research as a rapid diagnostic tool to understand and describe the network of relationships, commitments, loyalties, and motivations of all roles in air carrier maintenance.

This study used observation and semi-structured interviews with a sample of members in significant roles in the heavy maintenance system. The non-management employees closest to the aircraft, during overhaul, are the airframe and powerplant (A&P) mechanic, the aircraft inspector, and the maintenance planner/coordinator. These three roles are of special interest in the present study. They are in contact with one another, and together with their supervisors, they have the front line responsibility for heavy maintenance. Throughout this chapter they will be referred to as aviation maintenance personnel (AMP).

The focus of the study includes not only AMPs but their contact with their unions, their supervisors, technical trainers, production planning managers, maintenance managers, engineers, and others such as manufacturers' representatives and FAA inspectors. The object of these observations and interviews was to begin to describe the systems of coordination and cooperation used to accomplish safe and effective aircraft maintenance.

If attitudes and state of mind are influenced by how the AMP are organized, directed, coordinated and communicated with, are the differences across the industry broad enough to cause notice? Such differences can further be used to identify some innovative, insightful and appropriate alternative styles, practices, and company cultures. The result of this study is general recommendations to the industry (where possible based on best practices), in the "normal" maintenance, scheduling, and inspection process, as well as in management style and support activities.

### 2.1.3 Prior Research

A recent search of published references from the 12 year period 1976-1988 yielded only 15 papers on human factors in aircraft maintenance. Of those found, many dealt with the physiology of human response. Examples of these include discussion of the effect of location, shape, or convenience of cockpit controls serviced by mechanics (Schmitt, 1983). A few studies discussed the whole person in context (Lock &Strutt, 1981; Strauch & Sandler, 1984).

A recent article described a maintenance system with dedicated teams for each 747 aircraft which Japan Air Lines (JAL) instituted in 1985. Individual *kizuki* teams (it means "airplane crazy"), typically 15 engineers and AMPs each, were reported to be responsible for overseeing the condition of one of JAL's 747 aircraft at all times, regardless of where it may be (Ramirez, 1989). Although reported in glowing terms no specific results or costs were related.

Accounts of successful team-based aircraft maintenance organizations have recently been reported in the U.S. Air Force (Rogers, 1991). Improvements in results measured through a series of maintenance effectiveness indicators are reported.

**Use of new technology.** One reference described and reported technical advances in military aircraft engine design that were developed to make field maintenance duties "soldier-proof" (Harvey, 1987). That reference to eliminating the human factor through technology (or at least as much as possible) is an alternative to the notion of a system of informed decision making and cooperation (cf., Diehl, 1990). Based on experience in other U.S. worksites (e.g., Sloane, 1991), it is assumed that radical automation which replaces human decision making with machines isn't necessary (and may be suboptimal) where AMPs can provide timely and informed judgements based on an understanding of the "big picture."

Technical advances can be adapted to strengthen the maintenance system's human response to its complex world. For instance, one air carrier reported reforming a rule-based maintenance software system, originally intended to direct mechanical work, into a supplemental decision support tool.

The results included retaining the cost benefits of the former system while improving maintenance quality and mechanic satisfaction (Mayer, 1987). A spokesperson for the carrier said that this reform has changed the "expert [computer] system" into a [computer] "system for experts."

## 2.2 THEORY AND METHODS

### 2.2.1 The Research Methods - Procedures

**Site visits.** Eight U.S. air carrier and repair station maintenance operations were visited. The choice of U.S. maintenance sites was based on varied carrier size (including commuter line carriers), and varied location in the 50 states.

The specific focus of the study was the maintenance and inspection work process as it relates to structure (primarily fuselage) repairs in aging aircraft. This focus includes management practices as they may affect the practice of aircraft maintenance, particularly as they relate to the aging fleet. This sample included so called "heavy," or hangar maintenance only. In particular, the "C" level maintenance check proved to be the ideal intensity of overhaul for the present investigation. The C-check was ideal because it takes long enough (up to two weeks) to reveal patterns of communication (which are more difficult to observe with the varied and short jobs on the flight line), but short enough so that a visit of two to four days samples a sizable segment of it. The C-check is the third-level maintenance check for an aircraft, usually done once a year or after about 2,000 flight cycles.

Each company site visit lasted two to four days. Investigator impact on employees and management was purposefully as slight as possible. The investigator worked largely unsupervised and was present on night and evening shifts as well as during the day. Every effort was made to insure minimum disruption at the workplace.

The identity of results obtained from the individual companies agreeing to participate was promised to be held permanently confidential. In addition, data reports and summaries would not reveal the identities of individual persons interviewed or observed.

**Developing the interview format.** An observer/interviewer protocol was created to aid in collecting and understanding maintenance system communication data during site visits. This protocol was not intended to form a structured interview survey, since much of the data sought could be obtained through observation. This protocol formed the anchor or structure for obtaining the data described below.

**Obtaining site access.** The liaison to the Air Transport Association (ATA) Engineering Maintenance and Material Council helped provide access to six of the research sites used in the present study. Access to the FAR Part 145 repair station and one of the regional carriers was obtained through the cooperation of the FAA Office of Flight Standards.

Four additional maintenance sites were approached for participation in the study, but could not be visited in the time frame of the study. In all cases the airline executives approached were extremely busy during the period of the data collection and this preoccupation reflected intense activity in their organizations. This period of overload was the dominant reason that more heavy maintenance hangars were unavailable for observation.

**Collecting the interviews.** The interviews began with the first site visit in February 1990, and concluded in August 1990. Over 250 technicians, supervisors and managers were observed or interviewed. In total, 120 AMPs were observed and met with, 65 foremen or supervisors were observed and interviewed; and 80 other informal discussions were held with engineers (or other professionals), superintendents, managers, and higher executives at the sites. Most interviews were conducted at the workplace. All data collected are confidential and the names of the interviewees and the company were not discussed with others.

**Accounting for Potential Sources of Error.** The interested reader may wonder about the effects that observations of managers and AMPs have on the quality of the data collected in a study such as this one. Such contamination, when it is found, is often called the "Hawthorne effect" or "experimenter effect."

This concern can be addressed by describing the probable extent and severity of possible contamination. For instance, AMPs may want to say what they believe the investigator wants to hear, or behave in a way untypical of usual behavior at work.

The issue is whether the presence of an investigator on the hangar floor for several days does or does not substantially change work performance, or the manner or frequency of contact among mechanics, inspectors, planners, foremen, engineers and others. It needs to be emphasized that although respondents were asked to report events or results of events that had passed, the major focus of this research was the direct observation of what they were currently doing on the job, on a normal day, on an aging aircraft in the hangar for scheduled annual inspection.

With respect to the validity of the observations, it is difficult to believe that significant number of individual AMPs could substantially change their behavior during the visit. It seems even less likely that a foreman or manager could or would suddenly change the work assignment or coordination pat-

terms of his crew. Finally it would not be likely that ingrained work habits could be postponed or deferred until after the investigator had left.

The validity of answers given to the investigator's questions is presumed high as well. Typically, questions had to do with the content of an interchange between people, and multiple parties were usually asked about the same transaction. Other questions related to motives or feelings about behaviors of self or others. Such motives and attitudes are expected to vary among people, but the interest in the present study is on commonalities among AMPs. Thus motives or attitudes are not reported unless the same or similar data had been collected from a number of people at the same site.

In each site visited, the investigator first introduced the purpose of the study to local management. That purpose was described as "establishing a baseline of technician behavior," as well as job and organizational characteristics. After that, foremen on each shift were in turn introduced to the study. Their cooperation in permitting the investigator to approach their subordinate technicians was sought. The purpose of these visits was continually enunciated. Considerable time was spent helping the respondent (AMP or foreman) feel comfortable with the approach. After several days of the investigator's return to the same shifts, most respondents expressed comfort with the investigator's presence and with the purpose of the study. Once at ease with the intent of the study, AMPs and foremen then carried on their jobs, with others, as on a normal day. They were very willing to explain or clarify the reasons or purpose of their acts, interactions or behaviors of themselves or others that the investigator could not or had not seen.

This data collection then, was typically seen as a neutral event and a mild change in routine for respondents. In some cases technicians, foremen or managers expressed interest in seeing the resulting report. Departures at the end of a visit were always warm or at least cordial. Call-backs were made to the managers at several sites. In no case was negative feedback obtained — the visit had been a neutral event.

There exists one coincidental source of data which confirms that the method of data collection used is not stressful or confounding. These data result from the occasional overlap in sites sampled between the present study and the Job Task Analysis (JTA) described in Chapter 3. The study described in the present chapter followed the data collection at three sites used in the JTA. In all three, special attention was paid to the possible effects of a slightly earlier visit by other field investigators. The JTA study had been of inspection departments only and the study in the present chapter deals with the total heavy maintenance system (as far as it includes "C" checks). Thus there is only partial overlap in the people interviewed or observed at a given site. When speaking with inspectors in these sites they said either that they remembered the previous visit with pleasure, or that they barely remembered it, or only recalled being told about it ("it was so brief," took so little of their time, didn't come up in conversation with others, or was just "one of many" distractions passing through the hangar). In no case was the JTA study visit recalled with suspicion or derision. It is extremely doubtful (given all of this) that technicians or foremen had been able or willing to substantially alter their usual behavior on the job simply because investigators were there, observing a typical day.

### 2.2.2 The Organizational Model - Socio-technical Systems (STS)

**Socio-technical Systems (STS)** is the organizational model used in this study to describe aviation heavy maintenance system. STS was developed to help understand purposeful work systems in complex, environments. STS assesses "goodness of fit" among people and technology as they respond to their environment in attaining systems success. STS analysis combines a technical systems view with a social systems view to capture the strength of both (Taylor & Asadorian, 1985). STS is a theory and practice of organizational development, in use over 40 years and applied in a wide variety of industries world-wide.

**The phases of STS analyses.** STS analyses adhere generally to a series of steps or phases. Although they may differ from project to project in precise terminology or serial order the phases may be described as follows:

1) Clearly defining the system's purpose, its values, its objectives, its boundaries, and its salient environment — **The System Scan.**

2) Identifying the critical or key variances in the product, or throughput, which most determine success in meeting objectives and thereby pursuing the basic mission — **The Technical Analysis.**

3) Examining the role relationships among the system members or employees in controlling the key variances and in cooperating otherwise for the survival of the system — **The Social System Analysis.**

STS begins in the system scan with the purpose or mission of the enterprise (in aircraft maintenance the purposes of the maintenance and engineering systems should be consistent with the overall mission of the company), and examines the degree to which there is a common language and common product for this purpose throughout the whole maintenance network. Examples of possible questions revealing mission include: Is the airline the "most profitable," "the biggest," "the cheapest," "the business flyer's airline," the "best value,"

the "safest," the "highest quality" (either in aircraft, or in service), the "most reliable," or perhaps the "most visible carrier in its market?"

Public statements of such mission statements (including communications to employees) are extremely rare in the sites sampled. Some airline missions are directly addressed by maintenance performance objectives, but many are not. Of course safety and aircraft quality are maintenance deliverables, but it is unlikely that any air carriers, in any country, single-mindedly and exclusively pursue these ends alone. It is logical to expect, in many cases, that maintenance remains "the place where highest mechanical safety is pursued at the most reasonable cost." If this is true, there is little to engage the average AMP with the company's overall mission and goals. He or she "belongs," then, only to a maintenance shop, divorced from the larger purposes of the airline — purposes which could help provide a sense of context, meaning, work priorities, and congruence between maintenance and the company as a whole.

An example is available to illustrate how a public, visible (and presumably believable) airline mission can be connected to heavy maintenance activities. The Japan Air Lines "kizuki" concept of a dedicated maintenance team per aircraft has received heavy advertising exposure during 1990. It is interesting to note from the magazine advertisements that JAL is proud of its "on-time departure record," and that "kizuki ... obsession with 747 performance has helped maintain that record." While similar mission-driven innovations have led to well-documented successes in Japan's auto industry — and to various industries in America and Europe as well — no hard numbers on JAL's kizuki system are yet in the public domain. Perhaps they never will be. Some U.S. companies (Proctor & Gamble, for one) hold the details and results of a team system approach very close to the vest, on the grounds that it gives them a distinct competitive advantage worth protecting.

Given purpose or mission, it is also necessary to be clear about the deliverable or output from maintenance. Is this output consistent with and in visible pursuit of company purpose, or is it at odds with the larger enterprise? These comparisons are made during the STS "technical analysis." The technical system analysis explores the question: "what happens to our aircraft as they pass through our maintenance systems again and again?" The answers are important to understanding the maintenance function as a system, because they focus on the results of the work instead of just the functional and organizational specialties surrounding the work.

Key variances (an STS concept defined as factors in the product throughput, which determine success in meeting objectives and thereby pursuing the basic mission) in aircraft overhaul, as in any technical system provide priorities for understanding complex work. They are often interrelated, they always reside in the system's throughput, and they can be expected in the process of a "normal" day.

Examples of technical variances in aircraft repair include the following:

> **Time required for repair** [the longer, the greater priority to start with it].
>
> **Parts availability** [identifying what needs replacing early enough to order it cheaply or preclude delay of repair beyond the norm].
>
> **Nature and/or extent of flaw, defect, or damage** [more complexity requires special skills, and coordination with other skilled members].
>
> **Visibility of flaw, defect, or damage** [less visible flaws are often detected later and can delay, prolong, or defer other priority work].

Once specific variances are identified in the technical system throughput, these are investigated to determine how they are controlled, by whom, using what information. This key variance control analysis provides an important opportunity to see the degree current ways of controlling these variances through effective thinking and behaving may show room for improvement.

The social systems analysis examines the work-related communication among people in an enterprise. It permits description of the social system as the coordinating and integrating buffer between the technical transformation process and the demands and constraints of a turbulent environment. The people who are in the most central or focal roles in the social system are those who are most involved in the control of key technical variances.

In the present study social systems analysis addresses the work-related interactions among people in the maintenance system. It is an evaluation of who talks to whom, about what, and how it's working. Social systems analysis is linked to the technical analysis because the most important communications documented are about the throughput and product, but the social system is also the wider mechanism for flexible response to a changing environment.

### 2.2.3 Analysis of the data

All data from observation and discussions were entered in a database, coded by "system scan" information, "technical system" information, "attitude or morale" data, and "social interaction." This last category was further coded by the type

of social interaction specified above. These data were collated and analyzed by the investigator.

The social system analysis was conducted in the following manner. First, all of the data were combined and the responses to each topic discussed were consolidated. All of these responses to each of the topics were then tabulated by job title and summarized. The social system analysis focused on the concept of the social role as the basic link between organization demands and employee competence and understanding. The social system was defined as a network of work related actions and communications which are mediated by the reciprocal role expectations of individual employees. In this context, all relevant relationships in heavy maintenance were defined as including the following:

1) Superiors with subordinates,
2) Members of the same work group with one another,
3) Members of work groups with members of different groups within the heavy maintenance system, and
4) People inside the heavy maintenance system interacting with people outside that system.

In addition to these four relationships, attention was also focused on the relationship between role occupants (AMPs) and their jobs (or quality of working life), since job related feelings are strong determinates of morale.

The social system is further described as serving four organizational functions. The four functions that any social system fulfills are as follows:

1) Attaining the systems primary GOALS (G);
2) ADAPTING (A) to the external environment for immediate survival;
3) INTEGRATING (I) internal environment for management of conflict; and,
4) Providing for the development and maintenance of the system's LONG-TERM (L) needs.

These four functions (G, A, I, L) can be evaluated in terms of each of the four types of relationships described above, and the results displayed in a 4 × 4 grid (a 16-cell matrix of functions × relationships) where each cell in the grid is used to specify a particular type of social behavior.

The social analysis focuses specifically on the primary relationships of a "focal role." In this case the mechanics, inspectors, or planners and their foremen or managers became the focal roles around which the social analysis was developed.

Based on the responses surveyed, the investigator proceeded to evaluate the meaning of the data as classified in each of the 16 cells of the grid. A positive sign ("+") indicates a favorable rating by the investigator that the communication as observed was helpful or facilitative to the function or relationships. A zero ("0") means the communication as observed was neutral to the function or relationship. Finally a negative sign ("-") means that the communication was seen or reported to be detrimental to the function or relationship.

The social analysis was then continued by developing a "focal role network" (i.e., a map of relationships indicating who interacts with whom about what) that illustrates the activities taking place around the AMP and their supervisors. These networks were constructed basing the distance between the various roles on the frequency and importance of the interactions.

Defined this way, the social system is not mere friendship or informal support, but rather the source of adaptability and flexibility in coping with variances in the product, and with the system's complex environment. The demands of this environment go beyond merely satisfying a consumer market, or coping with supplies of raw materials, or the other aspects directly affecting the technical system. That environment is actually many environments — legal, legislative, labor, cultural, competitive, climatic, and so forth.

## 2.3 RESULTS AND DISCUSSION

### 2.3.1 Evolution of commercial aircraft maintenance, 1970–1990

During the course of the site visits for the present study a number of long-service heavy maintenance managers and supervisors described their views of the industry. What follows is the remarkably consistent picture which emerged, from these discussions, of the changes during the 1960s, the 1970s, and the 1980s in airline maintenance.

In the late 1960s and early seventies modern jet airliners (Boeing 707, and Douglas DC-8 in particular) were well established in the U.S. commercial fleet. Douglas DC-9 and Boeing 727 were newly introduced as smaller load, shorter trip, but still high altitude high speed aircraft. At that time the organization of hangar maintenance was guided by the skill and experience of general foremen. To them reported shift foremen and specialist mechanics prepared mainly by their duty tours in military aviation. Already included before the 1960s began were schedulers (or time-keepers) to monitor job assignment documents, and instructors to improve and broaden the mechanics' performance and skills on the newer aircraft. The oil crisis of 1973 sent fuel and ticket prices up, causing a reduction in passengers, and caused many airlines to lay-off newer, less experienced mechanics.

By the late 1970s and early 1980s the experienced mechanics and their supervisors had reached a high level of competence. Job cards for work assignment had been proven effective and the process of standardizing the work flow in hangar maintenance had created a need for a larger role for the "work planner." In 1979-1980 the further oil shortages, higher fuel prices, the air traffic controllers' work slowdown, and deregulation all converged to force many carriers to reduce costs further in face of increased competition. With aircraft maintenance technically under control with an ample and competent workforce, more AMP cuts were made.

Currently, in 1990, we find reduced numbers of experienced heavy maintenance mechanics and inspectors — the still-lingering result of AMP layoffs during the economic turbulence of 1979–83; coupled with the exodus of senior AMPs prompted by retirements, promotions, and interdepartment transfers to maintenance shops. Following the recession and deregulation, what we find are myriad signs of a cost-conscious industry — the most obvious signs of which are reduced parts inventories, and the lean AMP staffing levels. Finally, as we well know now, the fleet of new transport aircraft in 1970 has become "aging aircraft." Together these changes result in the typical 1990 hangar maintenance organization guided by shift foremen and/or planners. The latter are increasingly computer-literate and tasked with digitizing the job card and work planning/tracking system. With the hiring of new AMPs, and with the increasing complexity of new aircraft maintenance, training departments and their instructors have become once again an important aspect of maintenance effectiveness.

The current hangar maintenance AMP staff typically has a bimodal experience distribution of 30-plus years, and 3 or fewer years. There are relatively few heavy maintenance AMPs with company tenure between those two peaks. With the increase of aging fuselages and Airworthiness Directives (ADs) to attend to them, the greatest demand for new mechanics has been in sheet metal repair. Thus most sheet metal mechanics are new, and most of these are young. Many sheet metal mechanics hold an A&P license, but are newcomers to the field, having done other work first. In many cases these new AMPs do not have military experience, and if they do, they are not necessarily immediately qualified for A&P work with commercial transport category aircraft. For instance experience as a military aviation crew chief provides limited but deep experience in weight & balance; while repair in helicopters provides minimal understanding of repair on pressure cabins. There are also some AMPs who come into airline maintenance work after spending time in defense-related and/or commercial aircraft manufacturing. They usually know little about repair, although they are often very competent in sheet metal riveting. While some of them may know little about repair, many AMPs today are not hired as experts in aircraft repair, but to specialize in sheetmetal work only.

**In summary:** The prominent foreman role of the 1970s, reduced during the 1980s has reemerged in the 1990s in order to manage the many new AMPs in the heavy maintenance work force. An added complexity is that computerized planning systems (including the planners, schedulers, coordinators who operate them) constitute a challenge to the foreman's traditional authority, and the "authority of knowledge" held by the "master craftsman" in this industry.

The remaining results of the study will be presented as follows. First are the unfiltered results as obtained from the formal protocol developed for the visits. Next are the most frequent opinions, attitudes and feelings expressed by AMPs during the visits. These feelings or thoughts are specifically those dealing with company and maintenance system culture, mission, or values, and therefore contribute to important aspects of the system scan. Third, technical system data are described which deal with the aircraft and elements comprising the "critical path" of the overhaul. Fourth, the social system data are presented from the analyses described above.

### 2.3.2 Initial Results from the Observation/ Interview Protocol

The following section describes the overall findings from the site visits, organized by the questions or items in the protocol. The descriptions reflect a norm for the sample studied, and not necessarily any carrier in particular.

1. **Contact among mechanics**

   a. How many mechanics are working together on this aircraft?

      About 25 mechanics work together per shift for a total of about 75 mechanics total on the average C-Check.

   b. How many subgroups are employed on various jobs on the same aircraft?

      Between four and six maintenance subgroups are employed on various jobs on the aircraft during overhaul. These subgroups consist of the occupational specialties of sheet metal mechanics, riggers/general A&P, cabin mechanics, cleaners; and sometimes painters, and contractors (specializing in particular repairs such as fuel tanks).

c. Are subgroups involved in the overhaul that include occupations other than mechanics?

Other regular subgroups or occupational specialties involved in the normal C-check are inspectors, parts or materials clerks (two or three to a group), and planners or coordinators (usually organized in groups of two to four).

d. Did the subgroups meet together or reform themselves so that mechanics work with various others during the period of the visit?

These groups were not observed or reported to meet together as such. The subgroups do not change themselves in composition during the check although they may change in membership as usual members rotate through their individual shift schedules, or work overtime on another shift. Occasionally a mechanic was reassigned by the foreman to work with mechanics in another subgroup, or a foreman would request all available members of a subgroup to assist in a task to which they normally would not be assigned.

e. How often do the mechanics (or other AMPs) meet during the visit? What is the content of the meetings, How large are the meetings, How long are they, When do they fall in the shift, Who conducts the meetings?

The frequency of formal meetings among mechanics during the visit varied widely by site. In one case, all mechanics on a crew are brought together daily (for about 10 minutes) at the beginning of the shift by their shift foremen. The content covers the range from the day's work and assignments, to what's new in the company, to personal items about people on the shift crew.

In another site a weekly safety meeting was observed where the foreman spent a few minutes at the start of shift reading to all inspectors on that crew a safety memo prepared by the vice-president of operations.

In another site, a shift inspection foreman arranged a brief meeting between all of his inspectors and the investigator. This was really an extension of the otherwise informal "get-togethers" inspectors held before each shift. These informal meetings of inspectors, and of mechanics, are described in more detail below.

No formal meetings of mechanics was otherwise noted, although some sort of monthly (or less frequent) meetings with their AMPs were reported by foremen in nearly every site.

f. How much informal contact among mechanics (and other AMPs) is there during breaks and lunch?

Considerable informal contact was observed among mechanics during breaks and meal times. Typically, this took the form of conversation among friends around the picnic style tables in the break areas. These groups did not often exceed six or eight people and were usually smaller. Regular cliques of larger and mutually exclusive groups were seen or reported only rarely.

Even more informal contact was noted among inspectors. Their shift group size is smaller (about 6–10 in the typical carrier) and this makes it easier for the entire functional group to sit around the same table before shift, and "swap stories."

Planners tended to stay to themselves and took breaks with neither inspectors nor mechanics.

g. How much contact is there among mechanics between shifts, Are meetings held between shifts, Who attends these meetings, Who conducts them?

Little to no contact between mechanics on different shifts took place. In no case were meetings between mechanics from two shifts observed.

Inspectors were much more likely to communicate with counterparts on other shifts. In several sites their shifts actually overlapped by an hour or more, so they could work together. Generally inspectors on the same shift took part in meetings (daily or less frequently) conducted by their foreman.

Planners usually also met their counterparts, and the foremen, on other shifts to discuss work assignments.

2. **Contact with Foremen**

a. How often are foremen in contact with individual mechanics on a daily basis?

Maintenance foremen are in contact with each mechanic an average of three times a day.

b. How much foreman contact during the visit is work assignment? How much is work guidance? How much is administrative (payroll, vacation scheduling, sick leave)? How much is training? How much is disciplinary?

This daily contact primarily concerns work assignment (unless the labor contract restricts this task to lead mechanics, as it did in two of the eight sites). Other usual reasons for daily contact include work guidance or instruction, and administrative matters.

In the typical case about half the foreman's contact with a mechanic is work assignment and reassignment during the shift; about one-third involves work guidance/instruction (especially in the smaller operations), and about one-sixth is administrative (payroll, vacation scheduling, and sick leave). A small proportion of time was observed in employee discipline.

3. **Contact with Inspectors**

a. Does this carrier have a separate inspection staff and department? If so how often do inspectors and mechanics talk together in general?

Separate inspection departments and staff were found in all of the major airlines visited, the repair station, and one of the regional airlines. In the two smaller regional airlines (but operating aircraft large enough to be covered under FAR Part 121) a separate quality control (QC) department existed, but had no inspectors dedicated to it full time. In these sites certain mechanics were authorized to act as the inspectors for the QC department. These inspectors were usually the most experienced mechanics and often acted as lead mechanics or assistant maintenance foremen as well as inspectors.

In the larger sites, mechanics usually try to speak directly with inspectors about quality matters. In the two smaller sites the contact is much more frequent because the inspectors are also a mechanic's colleagues or mentors.

b. How often do inspectors and mechanics talk together about the aircraft they are working on? What is the content of their conversation; if it is not advice or direction what is deliberated, and what is resolved?

Mechanics' face to face contact with inspectors averages three times a day in the larger sites. These contacts are usually requests by the mechanic for the inspector to "buy back" or approve a repair.

A mechanic following a non-routine defect report is in reality in indirect contact with an inspector who earlier determined that the defect required action. Sometimes the mechanic and foreman would contact the inspector or QC foreman to clarify the request, or to withdraw it for cause.

c. How much training do inspectors provide mechanics during the visit?

Training varied greatly among the sites visited. In some large carriers, inspectors were sought out by mechanics for advice or instruction, while in others (particularly in larger carriers) the inspector's role was limited to inspection only, and mechanics were kept at a "social distance." Advice and instruction were clearly a part of the relationship between the combination inspector/mechanics' and the mechanics in the smaller carriers.

d. How much informal contact between inspectors and mechanics is there during breaks and lunch?

Very little informal or non-work contact was observed in the larger sites.

4. **Contact with upper management**

a. How much contact was noted, during the visit, between AMPs and upper management (from maintenance management, or elsewhere in the company)? [This can include memos, video communication, electronic mail, and "waving as they pass through," as well as face to face communication.]

In one large overhaul operation, multi-media communication from upper management was

virtually continuous during the visit. This included video monitors outside the cafeteria showing current news stories of relevance to the company; a company newspaper was available; well organized bulletin boards containing announcements on a variety of topics; plus (during the time of the site visit) the president made a series of "hangar briefings" to personally inform employees and take questions about important upcoming events.

In the other large operations visited, communication from upper management was limited to written announcements (posted on bulletin boards, or read out by foremen or supervisors in meetings), and in company newspapers. In more than one site, many AMPs could not remember the name of the company's president.

In the smaller companies, upper management was visible in the hangar during the visit, and it was reported as normal for the owner or president, and his management staff, to drop in several times per week. Such visits were not reported to involve work-related communication between AMPs and executives.

5. **Contact with FAA Principal Maintenance Inspector (PMI)**

   a. Is there a PMI on site? How often are AMPs and maintenance foremen in contact with the PMI during the visit? What is the content of their conversation? What is the setting (meeting, in the plane, in the break room, foreman's office, etc.)

   A PMI was seen in the overhaul area at two sites. In one case the PMI spoke with day shift inspectors, at the aircraft, about the non-destructive inspection (NDI) task they were doing. In the other the PMI discussed repair procedures with maintenance and inspection managers, both at the plane and in their offices. (The number and duration of the observation visits made it difficult to know how often the PMI was present)

6. **Contact with Trade Unions**

   a. If employees are represented by a union, how much contact between AMPs and their union rep, and/or inspectors and their union rep was noted or reported during the visit? What was the content of the contact?

   In sites with trade union representation, AMPs were in informal contact with their local stewards often on a daily basis. In larger sites, where mechanics may not be able to sit at the same table with a union representative during breaks or lunch, the contact was less frequent. In the largest sites visited, the union officials had their own office space allocated near the hangar work area and tended to remain there. Few AMPs were seen in contact with officials in these offices during the visits.

   b. How much contact was noted or reported between union representatives and management (including maintenance foreman) during the visit?

   Some contact by union officials or stewards to foremen was observed. The content included questions about work assignment and potential jurisdictional disputes, personnel issues and benefits.

7. **Contact with Trainers**

   a. How much contact between trainers and mechanics, was noted during the visit? What was the nature of this contact?

   In several of the larger sites, experienced maintenance personnel (often close to retirement and recently transferred to training or planning departments) were assigned "On the Job Training" (OJT) duties. In only one of these sites were these OJT trainers observed in the hangar and in contact with mechanics. In that case mechanics reported benefiting from the OJT trainers' advice or hands-on instruction.

   Mechanics often doubled up for training, and the more experienced were directed by foremen, or sometimes requested by other mechanics, to provide OJT.

The same relationship was noted among inspectors. OJT was requested by less experienced inspectors, directed by QC foremen, or offered by the more experienced AMP.

b. How much contact between trainers and inspectors, planners, and/or foremen was noted during the visit?

No formal trainers were seen in contact with either inspectors or planners/coordinators during the visits, since formal training is conducted at the training site.

Classroom training for new mechanics was usually going on in or near the hangar during the visits. Typically, formal trainers or teachers conducted these classes.

Classroom trainers occasionally contacted shift foremen in the latter's office at the completion of a day's course or segment.

c. Was any kind of training provided during, or immediately preceding the visit? Was that training specific to the repairs on the visit aircraft?

As noted above, nearly all the larger sites visited were in the process of aircraft orientation training for new mechanics. At some of these sites, other mechanics' classes were underway, dealing with more advanced topics or recurrent training. In all cases, this training was related to aircraft (as distinguished from safety training, personnel or communication, or administrative matters).

In the smaller sites, no formal training was observed or reported. These sites had no training departments or dedicated specialists for instruction.

8. Contact with Flight Crew(s)

a. Was information passed from the flight crew or cabin crew to anyone in maintenance about this aircraft? If yes, who was the maintenance contact; and what was the content, form (formal report, note, face to face, etc.), and timing of the communication?

In two cases in the larger carriers, was a flight crew observed in contact with heavy maintenance hangar personnel. These were cases where the finished aircraft was being released to the pilot and crew. Limited information about the overhaul was formally transmitted to the flight crew.

In the smaller sites, frequent contact was noted between flight crews and AMPs. In addition to written communication in the aircraft logs, pilots would sometimes verbally describe the performance of the plane to a lead mechanic or inspector. Mechanics or inspectors sometimes accompanied the flight crews to the ramp for engine or systems run-ups; or actually joined the flight in cabin or cockpit. The information passed in these flights often dealt with cabin pressurization and door seals.

### 2.3.3 Common Attitudes and Opinions: The System Scan

There were similarities, across the various sites visited, in how AMPs saw things and felt about them. These common attitudes can help yield a systems scan of the "typical" heavy maintenance systems sampled in the present study.

**Organizational purpose and mission.** In all sites, a typical statement was, "everybody wants quick turnaround." Whether this was cause for AMPs' frustration, or stoicism, or pride depended on the degree to which they saw this as realistic and relevant. AMPs observed in this study consciously accepted safe and fast turnaround as relevant, but not always realistic. Most sites visited had no explicitly stated maintenance mission, beyond finding and fixing flaws as directed.

In one site visited AMPs' immediate work assignment and the larger mission seemed clearly connected. In this site, maintenance foremen held a brief start-of-shift meeting with their crew. In these meetings the foremen described the work to be done, the system's performance to schedule, and made (or explained) general assignments. Mechanics had usually obtained the job cards from the scheduling window before the meeting and would go on to gather materials and tools at its conclusion. During the meetings AMPs had the opportunity to query the day's assignment and the overall scope of current aircraft in for overhaul. This was the only one of the sites visited in this study which revealed a strategy of maintenance which was both acknowledged and successfully pursued by AMPs. AMPs and foremen at this site took pride in airworthy repairs and fast turnaround of the aircraft. They reported that they made a direct contribution to the efficient and timely delivery of quality aircraft.

In several other sites the work was arranged so that AMPs continued a job from one day to the next, without turning it over to another shift. Although their mission may or may not be clear in these locations (and rapid turnaround was never seriously believed as important by AMPs there) the AMP could usually feel secure in knowing what was the job at hand.

### 2.3.3.1 Organizational Culture

Hackman, (1990, p. 495) has reported that even though the advantages of teamwork in the cockpit are widely recognized in the airline industry, the culture of that industry still emphasizes individual rather than team aspects of cockpit work. In the present study it was found that this same culture influences the maintenance functions as well. Aircraft mechanics are proud of what is called their "macho" style. And individual licensure and personal liability has, in some cases, had an added effect of making AMPs and their supervisors less willing to share work across shifts, or with less experienced or less skilled colleagues. The resulting performance is slower (actually incurring delays when key employees are absent), and the ability of AMPs to exchange ideas or information is sometimes limited. This restricted communication further supports traditional emphasis on the individual contributor as the basic work unit.

Another part of aviation industry culture is the passion for flight. In the past, the aviation industry could aptly be called "boys' own airplane club," because the people who chose it loved airplanes, and flying. It was a boys' club, in heavy maintenance at least. Even today few women AMPs or managers were seen during the visits. The airplane passion, however, has largely gone the way of wooden propellers and fabric wings — held only by the long-time employees and few of the new-comers. From the top to the bottom jobs, people today join airlines for many reasons beyond the love of planes. This clear shift plus other changes in labor force confounds the long-service employee. Older AMPs are sometimes dismayed with the newer mechanics' acquired skills, their laissez-faire attitude, and their higher turnover. The new mechanics often profess to "like it okay here," but admit they are not "excited" about it. In some of the sites visited the company's reputation is of little concern to them, because many can see themselves as moving on to other companies or even other industries. These contrasting attitudes suggest a culture undergoing a considerable transformation.

### 2.3.3.2 Control over Work Assignment

An organization can have a clear locus of control, whether or not it has a mission or conscious purpose. Such control is invariably in the control of other peoples' activities, especially in the performance of the work. This control of behavior is sometimes structural, combined with behavioral norms, and sometimes the norms themselves, over time, can yield control in one group over the others. When control over one's actions is diminished, "ownership" or pride of work declines too. In the present study, this lower pride was sometimes associated with lower care/attention to the work — leading to slower work, fewer "buy-backs" by inspectors, lower morale and higher reported employee turnover. Usually the struggle for control over maintenance work was found between maintenance and planning.

**Computers and control.** The struggle for control takes on a different and more complex dimension as computerized planning becomes more common. Control by the computer can take on a life of its own, seeming to rise above both the maintenance and planning people in its rigidity and singular focus. In some sites both maintenance and planning seemed confounded by the computer-based system of work planning. Complaints were heard primarily about the quality of computer-produced job cards and the absence of associated graphics. Other complaints were voiced about the rigid decision models the computer used for scheduling.

**Attitudes about training.** Younger workers' attitudes toward recurrent training are mixed. In companies where some training is provided they wanted more; in those that didn't provide much training, the AMPs didn't complain (but they literally may not know what they're missing). Many older AMPs were able to describe the OJT procedure and its paperwork (they usually know it well), but they also say when they show younger guys something, it isn't long before they "think they know everything." Such younger employees' attitude toward training, if true, could work, over time, to stifle the amount and quality of OJT.

**Occupational Safety Practices.** Safety is important everywhere, but practices vary widely. At some sites, it was assumed that if no accidents have been reported, then the safety policy is okay. At one site, safety policy required leads completing a start-of-shift check list on housekeeping and safety each day. In another, the foremen reported that they hold 30-minute safety meetings with their AMPs once a month. Yet another site had a new operations vice president who, among his first official acts, required weekly safety reminder sessions. Another site used blanket rules such as not allowing tennis shoes on the base. In some sites there is much safety equipment around. Such equipment includes auxiliary lighting, overhead cables and harnesses for working on the aircraft crown, safety rails on scaffolding, protective clothing, rubber gloves, safety glasses, safety shoes, ear plugs, respirators. Some safety posters were in evidence. It was gratifying that at a personal level mechanics and inspectors were often seen to remind their co-workers to act safely. At several sites, foremen were observed refusing to assign work

to their shift in unhealthy conditions (e.g., where painting or paint stripping was going on nearby).

In the main, personal safety in aviation maintenance is not always emphasized to the degree seen in other industries. Some examples are that AMPs were observed to take individual responsibility for spreading absorbent clay on oil spills, but only after somebody slipped. Several sites evidenced a variety of casual lightweight sport shoes. In others, few AMPs wore earplugs or muffs, were seen not to use overhead harnesses when working on the crown, and made little use of auxiliary lights (in favor of many flashlights). Some of the foremen observed were very attentive to safety issues during the visits and some were not.

**Housekeeping in the overhaul area.** In several of the sites visited, one can walk to stores or break areas only by passing through dimly lit, cluttered areas, with hoses and wires in profusion on the floor. Despite the frequent attention of janitorial crews, hangars at several of the sites visited were dirty, dusty, or oily not only on the floors but on other surfaces too. Work areas where AMPs demonstrated a pride in cleanliness or tidiness were noted in only about half the sites visited in the present study.

### 2.3.4 Technical System Findings

**Planning the overhaul.** How the work is planned and performed in heavy overhaul of aging aircraft varied among the sites visited. In about half the sites the day-maintenance foreman was responsible for assessing the extent of repair necessary, and managing the course of the overhaul, following the preliminary inspection by the quality control (QC) department inspectors. Sometimes the planning group, instead of the foremen, was responsible for scheduling and managing the overhaul. In one case QC had taken unwitting control for managing the "C" check, through close control of the issuance of job cards.

**Key variances in aging aircraft.** Large and complex repairs were often called the "critical path" for the overhaul. Defects such as cracked doors or door frames, or extensive corrosion of floor structures or pressure bulkheads were usually judged as critical items or key variances to plan the overhaul around. Key variances do not always require the most time consuming repairs, but they may demand exotic parts or special engineering planning, or intricate scheduling of other repairs.

Management in several carriers expressed particular pride in corrosion control programs they had developed in-house. Those programs were later confirmed by AMPs, who said that the company was willing to spend the extra time early, inspecting and treating corrosion-prone areas, to control these variances in advance which prevented "surprises" later. If used aircraft were acquired from other carriers, the special efforts to cope with their new-found corrosion demonstrated the quality of the original fleet and the positive efforts of corrosion prevention when it is employed.

At some other sites visited such variances were not as well prevented, and might not be detected in the preliminary inspection. Occasionally the extent of a defect detected during preliminary inspection (particularly hidden corrosion) would not be revealed until late in the overhaul. In a majority of the sites visited, corrosion (particularly when accompanied by fatigue cracks) and sometimes ramp-originated damage to skin, baggage doors and holds resulted in repairs that required more than the original estimated time. This optimistic time estimation (coupled with poor coordination or miscommunication between shifts or with shops, or from engineering or QC which led to rework at least some of the time) meant that there was some kind of regular "surprise" that thwarted AMP efforts to complete the overhaul on time or in budget.

Some key variances in aging aircraft [e.g., multi-site damage (MSD), or extensive corrosion to aircraft structure] demand special knowledge about structural repairs to adequately fulfill either "damage tolerance" or "fail safe" requirements. The existence of several such variances on the same aircraft were observed to require the simultaneous employment of very high (and scarce) AMP competence, and a considerable degree of engineering or shop support. During these special work reassignments progress on other aircraft in the hangar was sometimes delayed.

#### 2.3.4.1 Organizational structure and work performance

A certain degree of coordination difficulty and miscommunication results from the way the systems were structured.

What differences do variations in the organization chart seem to have on maintenance performance? What structural similarities do companies in the sample share which may threaten to impair their currently enviable performance record?

Some heavy maintenance is organized with maintenance, materials, inspection, and planning/scheduling functions all reporting to separate vice presidents. In other companies, scheduling and maintenance report together at a lower organizational level. In yet others, materials department reports to the maintenance organization. These differences are reflected in the degree of cooperation among the depart-

ments and the degree of shared purpose felt and expressed by incumbents.

Differences were found among the sites in organizational structure (chain of command, span of control). Where strong functional chains existed, communications between AMPs in the separate departments were often limited. Stores, shop, and toolrooms were sometimes seen, or were reported, to act unsympathetically or unsupportively to maintenance's need for parts, components or tools. For instance urgent parts shipments were observed to arrive, and mechanics or their foremen were not notified of this by stores within the same shift. Communications breakdowns between those chains were never, during the present study, seen to compromise aircraft safety.

To minimize that possibility, however, the industry must continue to invest additional time, effort and money in cross-functional communication and controls.

Separate reporting structures were usually found to create struggles for power and authority among departments (e.g., maintenance, supply, shops, and planning). Such conflicts are resolved in a variety of ways, but they usually result in one department gaining a degree of control over the other. In those cases where maintenance retains control over planning, the foremen and mechanics often express a sense of triumph, and planners and coordinators feel some (usually minor) distress at their perceived decline in significance.

Where planning is the more powerful department, the planners were seen to act apprehensively (and often defensively), and QC and maintenance foremen and their AMPs feel confused and frustrated. In these cases, the planners and/or coordinators controlled job cards (and thus job assignment), and access to them by any others was strictly discouraged. In these several sites, high control of repair by planning was seen to diminish the pride of ownership and competence that mechanics, inspectors, and their supervisors felt. Planners described their major function as "responsible for the aircraft," while maintenance was seen as merely responsible for completing repairs. Associated with mechanics feeling of lower pride was lessened care/attention to work performed. "Good enough to be safe is all we can manage," was heard from several mechanics in the sites where planning controlled work assignment.

### 2.3.4.2 Differences in behavioral norms and work performance

Norms are customary behaviors, not necessarily based on policy. Norms of work assignment, or of managing AMP absences and overtime can have advantages and disadvantages simultaneously for maintenance effectiveness. Mechanic overtime and high use of temporary labor in several sites were both observed to be effects of a lack of planning. Mechanics in turn felt part of an "ad hoc" organization with little ability to forecast or plan for overtime. Occasionally foremen were observed not to notify their shift replacements of AMPs who had called in sick — sometimes hours before. The resulting lack of control of initial work planning for maintenance foremen and scheduling supervisors caused them confusion and frustration.

Many of the sites visited displayed effects of expectations of maintenance about stores. Typically, AMPs expected storekeepers to be uncooperative, unfriendly, or slow; and maintenance supervisors expected stores to be often out of stock, and slow to reorder frequently used parts and supplies. Whether by self-fulfilling prophesy, policy considerations, or by structural arrangements, the materials functions were often in a defensive posture in management meetings and at the parts counter because parts and supplies were not available when needed.

### 2.3.5 Social System Analysis Results

The social analysis involves the examination of the roles and relationships within the whole work process. This activity actually includes mapping both the persons who have work-related interactions in the system and the reasons for that contact. Because a comprehensive analysis of all positions would be too time consuming, the social analysis focuses upon the role or roles most involved in the control of key variances, based on the assumption that every organization exists in order to meet the short-term goal of producing its product. This is the social system analysis, which maps the cooperation and coordination undertaken between the focal roles and others within and outside the work process. The focal roles identified in the heavy maintenance operation are the mechanic, the planner, or the inspector.

Every organization exists in order to meet the short-term goal (G) of producing its product. However, in doing so it must not adversely impact its capacity to survive as an organization. To do so it must adapt (A) to, and be protected from short-term changes and pressures in its immediate environment. It must also combine or integrate (I) activities to manage internal conflict and to promote smooth interactions among people. Finally, it must ensure the long-term (L) development of knowledge, skills and motivation to cope with goal-related, environmental and systems requirements in the future. In the social analysis, the letters G, A, I, L are used to indicate what type of functions are affected in contacts among people.

Many organizations have separate departments to perform these functions. For example, industrial engineering, planning, personnel, and training departments can have the formal responsibilities for one or another of the four basic functions. Typically this specialization acts to narrow and limit the ability of other employees to act appropriately when a response from them in that function is required. The only clear exception to this are training specialties because the expert trainer serves to enlarge the roles and response repertoires of individuals without complicating lines of command or the allocation of responsibility. Not surprisingly, perhaps, a good many of these functional behaviors are performed through informal activities at the level of the focal role. Not only are these behaviors informal, they are often unrecognized even though they may be more frequent and more influential in affecting performance than the existing formal methods and policies. The task for the social analysis is to better understand the ways that these necessary social system functions actually get carried out, and to evaluate how effective these methods are for satisfying the human and technical requirements of the organization.

### 2.3.5.1 The Social System Grid

The examination of the presence or absence of a fixed set of functional relationships in a social system is aided by charting them in a way that combines both the four functional requirements (G, A, I, L), and the particular relationships (vertical and horizontal, internal, and cross boundary contacts) describing the work process. This combination is charted in a 4 × 4 table or "grid" of social relations.

*Table 2.1* shows an overall evaluation of information summarized from interviews and observation classified by the four essential social functions. *Table 2.1* presents evaluations of those typical contacts observed, and an approximation of the relative frequency of those contacts.

*Table 2.1*, row "G," reveals that communication about goal attainment is frequent (many contacts were coded "G"), but effective only to some degree (about 20% of the total goal attainment contacts were evaluated by the investigator as positive, while about 40% each were evaluated either neutral or negative in their contribution to maintenance performance).

Mechanics and inspectors play a central role in accomplishing the essential task or mission of maintenance. The results in *Table 2.1* indicate that these AMPs play this central role with considerable guidance from their foremen, with some cooperation from others in their work group, and much direct contact (although some of it is negative in outcome) with other employees in the maintenance system.

Row A (*Table 2.1*) reveals that there is very little contact among focal roles and other members of the maintenance system about matters dealing with relevant outside environments. Some foremen mentioned that cooperation in borrowing or lending spare parts is good between the maintenance departments of different carriers.

The same pattern, found in Row G, of frequent but less than effective communication between mechanics or inspectors and others in the maintenance system is repeated for row "I." Those contacts affecting systems integration (coded "I" in *Table 2.1*) had a larger proportion of negative evaluations in peer group and supervisory communications than did contacts for goal attainment. Rows "G" and "I" in *Table 2.1* provide evidence for the observation that AMPs work with strong support and guidance from foremen and other members of the maintenance system, but their work relations with co-workers in the same occupation is less developed. Mechanics do talk to one another about opportunities and requirements for employment at other carriers, which if it helps an AMP make a decision to resign could surely be considered "disintegrative" for the current employer.

Row L in *Table 2.1* reflects a need for formal training programs, a small management role in on-the-job training, and a limited, though high impact role for AMPs in training co-workers in their same occupation. Most mechanics and inspectors said they obtained OJT from senior employees. However, in some situations there may not be enough experienced technicians to ensure that there is enough high-quality OJT for the junior personnel.

### 2.3.5.2 Focal Role Network

The "focal role analysis" maps the work-related communication between the focal role(s) and others in the work process.

The first figure that follows shows the general role network (displaying the common pattern) for all sites visited. Subsequent figures show specific differences in three different situations revealed during the site visits. The networks each reflect a norm for the sample studied, and not necessarily any carrier in particular. The focal roles identified in the heavy overhaul maintenance system sampled in the present study are the mechanics (both sheet metal and A&P), or the planners or coordinators, or the inspectors involved in a "C" check equivalent on an aging aircraft.

In all cases their leads, foremen, or supervisors are also considered focal roles. In the role networks displayed here (*Figures 2.0, 2.1, 2.2,* and *2.3*), the shorter length of the lines between roles reflects a higher frequency of communication observed. The arrows indicate one-way or two-way commu-

nication observed. Double arrows pointing in opposite directions (e.g., *Figure 2.2*) denote equally-frequent initiation of essentially one-way communications.

The relationships depicted in *Figure 2.0* (the common pattern of communication found in all sites) are repeated in the following three figures, but in lighter contrast to enable the reader to more readily see the unique communications depicted in each figure.

The *Figures 2.1* and *2.2* display two major communication patterns observed during the present study, and *Figure 2.3* displays one unique pattern (observed in only one site during this study), for contrast. *Figure 2.1* depicts the web of frequent contacts in several sites where the maintenance department (maintenance foremen and their managers) are in control of the AMP work assignment process. *Figure 2.2* shows an alternate network of frequent communication in sites where the planning department played a major role in mechanic and inspector work assignment. Finally, *Figure 2.3* displays the unusual case described earlier in which the QC department controlled work assignment.

*Figure 2.1* portrays a composite of typical communications patterns in the sites where maintenance is in control of AMP work assignment. *Figure 2.1* shows frequent contact between maintenance foremen, leads, and mechanics. In addition it shows close coordination between maintenance and QC foremen. Finally, *Figure 2.1* reveals a close (daily) interaction among all executive managers responsible for supporting the maintenance effort.

This kind of communication pattern is particularly effective in maintaining aging aircraft when there is a clear maintenance mission that is supported from above, and when foremen are in close touch with AMPs.

**Use of pre-shift briefings.** In one site visited, AMPs and foremen were proud of their on-time and high quality "C" check completions and this mission was supported by upper management. This site is the model for the network shown in *Figure 2.1*. At this site the foremen hold a brief meeting with their AMPs at the beginning of each shift, in which a focus on purpose is maintained by describing status of the aircraft in the hangar, the critical aspects for timely completion of those aircraft, and briefly explaining work assignments. In this case, mechanics have usually already obtained the job cards from the scheduling window, and immediately following the meeting, they go on to the storeroom for material and tools.

These shift foremen were trained in how to conduct meetings. In general the meetings kept AMPs informed of the unit's performance to goal, and of their own role in the overhaul. The AMPs in turn took pride in successful accomplishment. Lead mechanics kept their foremen informed of progress throughout the shift. Occasionally, the leads or planners would also tell foremen of AMPs whose performance was below standard. Foremen acted to guide and reward good performance, and to understand and correct substandard performance. Maintenance foremen also kept in close touch with QC foremen to discuss approval of complex repairs.

**Less effective use of goals and communication.** Several examples of less effective maintenance systems were observed during the visits. These were systems also typified by the network in *Figure 2.1*, where maintenance was in control of work assignment. In one of these less effective sites, a mission for maintenance (beyond airworthy repair of aircraft) was unknown to AMPs: little urgency for timely work completion was observed, and management urged expense containment.

In other less effective sites, disparate goals were set for the various departments in the maintenance system. For repair, overhaul turn-around times were set too high for a largely inexperienced work force to meet without an unusual degree of cooperation from materials department and the shops. Materials departments and shops in turn were given goals to contain costs, and therefore could not respond to maintenance demands by always having needed parts in ready inventory.

Inspection goals could also conflict with maintenance as illustrated by the number of rejected, "non-routines" allowed by QC management reported in several sites. Some inspectors required engineering variance authorizations (EVAs) for reportedly minor deviations from structural repair manual (SRM) repairs. Where multiple and conflicting goals and missions were set, and management continues to press for them, time and/or cost performance would necessarily slip. Besieged by conflicting demands foremen tended to ignore AMP training, or coordination between shifts, or forward planning for spare parts acquisition, almost all of which alienated AMPs, and were reported as leading to lower cost and performance-to-time results. The cycle, once established, apparently continues in these sites without resolution.

The effectiveness of these sites could be hampered even further if lead mechanics were (by labor contract) in strict charge of work assignment of AMPs. Where this situation was found, *Figure 2.1* would have to have been redrawn to show less frequent contact between AMPs and foremen. This system resulted in generally less effective coordination between shifts because foremen, not now in direct contact

with AMPs, would make the face-to-face transition between shifts. In some cases also, high seniority AMPs would bid into lead jobs without sufficient breadth of technical experience to always understand the work they were assigning to AMPs and the results of which they were describing to foremen.

There were other examples of how communication in an inexperienced workforce created errors involving miscommunication. The combination of inexperienced mechanics and long tenure foremen often caused the former to be unassertive with the latter. These subordinates are reported to seldom voice their uncertainty or their lack of experience when assigned to a job, except at sites where there are *strong* sanctions against remaining quiet. There were also accounts of new AMPs who did not report problems when they occurred. Cases were reported of relatively inexperienced employees being assigned to work beyond their abilities—with ensuing repair errors. Those errors reported were discovered and safety of flight was not compromised, but extra expense and time were incurred and in some cases little positive was seen to be learned by foreman or AMPs. In most cases of serious errors or incorrect repairs, the AMPs involved were said to have quit or were dismissed from the firms shortly thereafter.

*Figure 2.2* portrays a composite picture of the communication pathways in sites where the planning department or function closely controlled the work assignment and job cards. In these cases, the planners and/or coordinators kept access to job cards strictly controlled. Planners described their major function as "responsible for the aircraft," while maintenance and inspection were seen as merely responsible for using the tools and undertaking assigned repairs. In these sites, high control of repair by planning was seen to diminish the pride of ownership and competence that mechanics, inspectors, and their foremen felt.

The algorithm often used by planning, in the sites visited, to set priorities is based on length of time required for repair; with little or no attention paid to the complex interactions among a number of repairs (both "routine" and "non-routine") called for in the typical overhaul. Both maintenance and inspection foremen in these sites claimed that the planners lacked maintenance experience with repairs or with aircraft to enable them to effectively prioritize a series of complex repairs. This arrangement frustrated foremen and caused them to lose confidence in their own abilities. This, and lower pride was often associated by interviewees with lower care/attention to work performed — and with slower work, lower quality work, fewer "buy-backs" by inspectors, and more rework. For AMPs, the visible absence of control their foremen had over the order in which work was performed, and the ambiguity about what was to be done next, was reported to lead to diminished job satisfaction.

*Figure 2.3* shows the communications patterns for one site in which inspection took control of work planning at the beginning of a maintenance check. In this case the inspection foreman closely controlled the overhaul planning by rewriting all routine job cards dealing with opening (and subsequently closing) the aircraft for inspection as specific non-routine orders to only open access areas. Separate non-routine orders were subsequently issued to close all access locations only after QC inspectors had scrutinized those areas. For the Boeing 727 aircraft observed at the site during the visit, over 400 extra non-routine orders were created for this purpose.

This unusual behavior presumably was based on a mistrust of the many inexperienced mechanics employed by this company to read and understand the routine cards as written. Although that solution worked, and all inspection locations were checked by QC, the "cure" was almost as painful as the "disease." The resulting lack of control of initial work planning by maintenance foremen and by scheduling supervisors created confusion and frustration. For instance, when parts were received and the planners and maintenance foremen were notified, they were unable to locate the associated job card to begin work if that work (and card) was still under QC control. These parts were often set aside until they could be identified, and sometimes became lost or misplaced. Sometimes, because job cards were "missing," parts were not ordered on time. Waiting for QC to schedule "closing-up," the aircraft sat with fuel tanks open and vulnerable control joints and bearings exposed to airborne contaminants. Because of management pressure to complete the overhaul on a timely basis, mechanic overtime and high use of temporary labor were both among the unwanted "products" of this system. Mechanics in turn felt part of an "ad hoc" organization with little ability to forecast or plan for overtime.

## Summary of Role Networks.

One of the major findings of the role network analysis is that many of the roles closest to one another on the network chart (*Figures 2.1, 2.2,* and *2.3*) are between people in different occupational groups (except for AMP and foremen or lead). Thus the people in close contact with each other are not only the foreman and the mechanic, but also the mechanic and the planner/coordinator, the mechanic and the inspector, the mechanic with other employees in stores, and the foreman with production control, the various support shops, and engineering. These are all examples of people communicating between functional silos.

**Table 2.1**
**Summary of Communicatrion Analysis**
**"G, A, I, L" Functions Against Four Types of Social Contacts**
**Airline Maintenance Personnel / Heavy Check Service**

| | 1. Contact Between Supervisors and Suborcinates | 2. Contact Among Peers in the Same Work Groups | 3. Contact Between Groups in the Same Mainten. Systems | 4. Contact Between Maintenance Systems and the Outside |
|---|---|---|---|---|
| "G:" GOAL ATTAINMENT | +++++<br>0000000000<br>- -- -- | ++<br>0000<br>- | ++++++<br>0000000000<br>000000000<br>- -- -- -- --<br>- -- -- -- -- | +++<br>000<br>- -- -- -- --<br>- |
| "A:" ADAPTION TO ENVIRONMENT | +<br>0<br>- | 000 | +<br>000<br>- | 00<br>- - |
| "I:" SYSTEM INTEGRATION | +++++<br>0000000<br>- -- -- -- -- -- -<br>- -- -- -- -- -- - | +++++++<br>00000<br>- -- -- -- - | ++++++<br>0000000<br>- -- -- -- --<br>-- -- -- -- --<br>-- -- -- -- | ++++<br>- -- -- -- |
| "L:" LONG-TERM DEVELOPEMENT | +<br>0000<br>- -- -- - | +++<br>0000<br>- -- -- | +++<br>000<br>- | 0<br>- |

## Legend:

"+" = Communication as observed is helpful or facilitative to the function or relationship
"0" = Communication as observed is nuetral to the function or relationship
"-" = Communication as observed is helpful or facilitative to the function or relationship

### 2.3.6 Organization, Attitudes, and Performance

#### 2.3.6.1 Linkage between management practices and attitude

Three of the eight sites visited exhibited higher levels of communication than the rest. These three sites include the large carrier in which foremen conducted pre-shift meetings; and the two smallest carriers where inspectors were also the senior mechanics. Communication in these three sites included a great deal of "technical" or goal-related contact/communication within and between occupational groups and hierarchical levels, as well as expressions of employee good-will and personal support for one another. These communications were observed in frequent or regu-

lar group meetings as well as in individual face-to-face contacts. These three sites also evidenced the clearest maintenance and company missions. The large carrier among these three reported consistently high levels of timely completion of "C" checks. Finally managers, and AMPs in all three of these sites expressed the greatest individual satisfaction with their timely performance and/or high quality as was expressed in any of the sites studied.

The other five sites varied in the amount of communication and contact observed and reported. All of the five had less frequent communication than the three sites already reported. Among the five sites, lower levels of communication were associated with greater observed and reported conflict between shifts and occupational groups. Whether past conflict reduced present contact, or if conflicts arose through misunderstandings caused by inadequate or incomplete communication, is impossible to say with the data available — a combination of both is most likely. Expressions of personal satisfaction were lower among AMPs in these five sites. AMPs were less likely to say they planned to stay with that employer, and in a few sites mechanics and/or planners said they were considering leaving aviation maintenance altogether.

### 2.3.6.2 Quality Performance Information for heavy maintenance ("C" check)

"Hard numbers" were not available to AMPs at most sites visited, but the following indicators were often at the core of their concerns and discussion with others about final results — "getting safe aircraft out on time."

1) **Maintenance.**

   **Doing it right the first time.** Indicated by the time (and/or iterations) required to perform a repair that will be approved by inspection; this includes rework of completed work rejected by inspection, as well as "false starts" caught by lead mechanics, foremen, engineers or inspectors, and begun again during the repair process.

   **Underestimated repair severity.** Includes severe defects identified as minor, or identified after initial inspection, indicated by underestimated repair time or adjusted coordination of repair jobs to accommodate for omissions or optimistic assessments of defects identified early.

2) **Inspection.**

   **Absence of Turnbacks.** Involves the assessment of severity of a defect such as corrosion or fuselage cracks — less severe defects that were identified were indicated by the presence of some number of non-routine defect "turnbacks" to inspection by maintenance.

3) **Planning.**

   **Dynamic but realistic schedules.** Measured by the ability to adjust the maintenance schedule and spare parts ordering so that revised check completion dates can be realistically met. This performance relies on being able to account for complex interrelations among the individual repair jobs contained in the heavy check.

### 2.3.6.3 Linkages between Practices, Attitudes, and Performance

Quality performance, as measured above, was highest in the three sites described earlier as having higher levels of communication. The high degree of "technical" or goal-related communication within and between occupational groups and hierarchical levels in these sites contributed to a focus on timeliness of repair and/or quality.

In the two small sites of the three, scheduling changes were performed by the foreman in consultation with lead mechanics, while in the larger site the maintenance foremen stayed in close touch with planning and QC as work progressed and the schedules changed.

In association with the less frequent communication and contact observed at the remaining five sites, AMPs displayed and reported greater conflict between shifts and occupational groups. The five sites also displayed or reported lower quality performance as measured above.

## 2.4 CONCLUSIONS

Among the accepted causes of work quality is the committed attitude, the high level of knowledge, and the positive state of mind of employees performing that work. Conversely, negative attitudes, lack of knowledge, and disquieted mind relate to poor quality and a reduction of safe conditions and outcomes. This study obtained measures of the amount of communication about the work and interpersonal support, the levels of trust, and the degree of frustration or facilitation of human needs. Important sources of employee attitude and state of mind in aviation maintenance were found. The conclusions to follow are directed at stressing these important aspects.

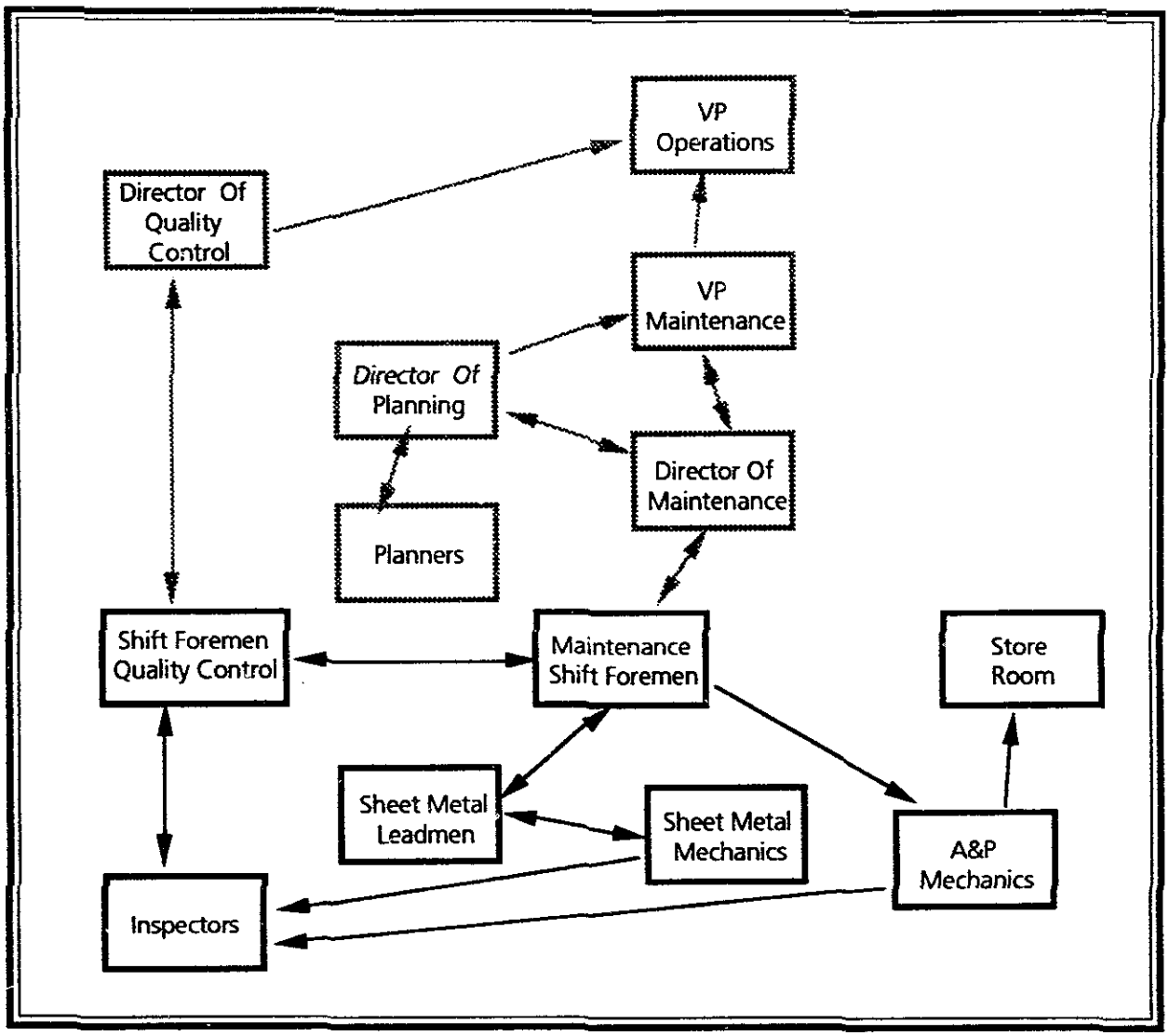


**Figure 2.0**
**Common Communication Pattern - All Sites**

### 2.4.1 MAJOR ORGANIZATIONAL COMPONENTS Identified as a Result of the System Scan Analysis

DEDICATION: It is not an exaggeration to state that all employees and managers of the heavy maintenance systems visited in the course of the present study are dedicated to safety of flight. To their credit, most mechanics, inspectors, planners and their managers want to be able to see the "big picture," and to have real competence in complex detection and repair technologies. Throughout the course of this study, the people observed were serious about their work, well meaning, and bright. These are people who want to do their best for safety.

ENJOYMENT OF WORK: It is also true that an overwhelming majority of mechanics truly enjoy maintenance work and mechanical repair.

RESPECT FOR COWORKERS AND MANAGERS: In the main, AMPs also like and respect their co-workers and managers. In the smaller, regional carriers in particular, the relationship between inspectors and mechanics is mutually respectful and professionally useful for both parties. These mechanics learn advanced repairs and detection from the more experienced inspectors, and the latter learn by and from the teaching.

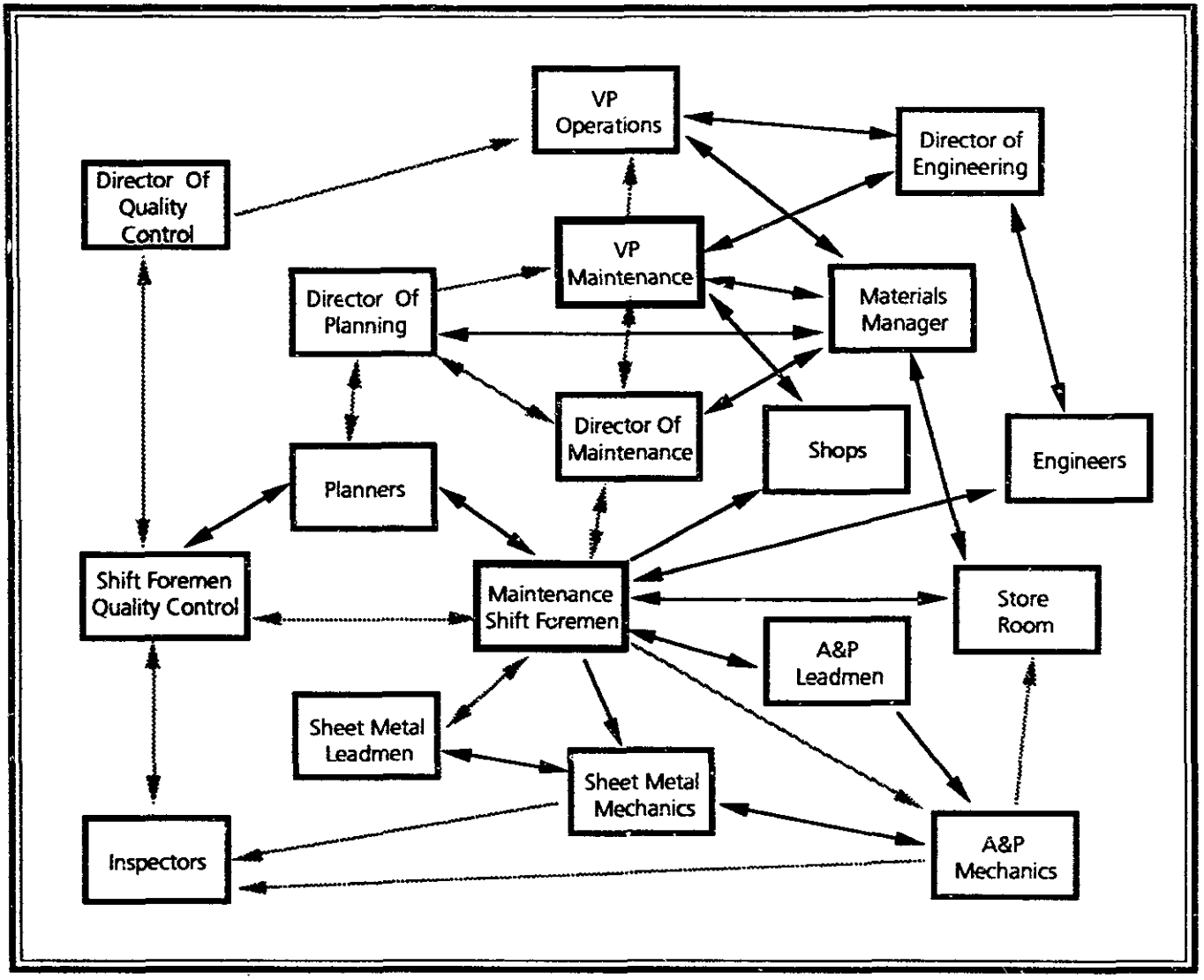


**Figure 2.1**
**Maintenance in Control of Work Assignment**

PARTICIPATORY MANAGEMENT: Excellent and well proven management practices, and resulting high performance, were observed in the course of the present study, but they were not the norm. Participatory management in combination with high performance organization, was observed consistently in just one site, and noted to a lesser extent in two others.

In the one truly excellent site visited, shift foremen behaved quite differently than in the other companies. These foremen had been trained in, and encouraged to hold, daily work-related meetings with their AMPs. They met at least weekly with other foremen and their superior. In addition, they were responsible for the pursuit of a conscious and public maintenance mission and for setting and achieving measurable objectives. They were expected to provide work direction, encouragement for high AMP performance, as well as insight and action when performance was poor.

Many of the other sites observed reflect a pattern of management practices and results that roughly matches the American national norm for completely standard practices: functional organization, firm goals, traditional supervision, and sufficient controls to guarantee minimal required outcomes. These practices do not seem to measure up in the current environments for motivating or developing employees; even as they may continue to turn out acceptable repairs.

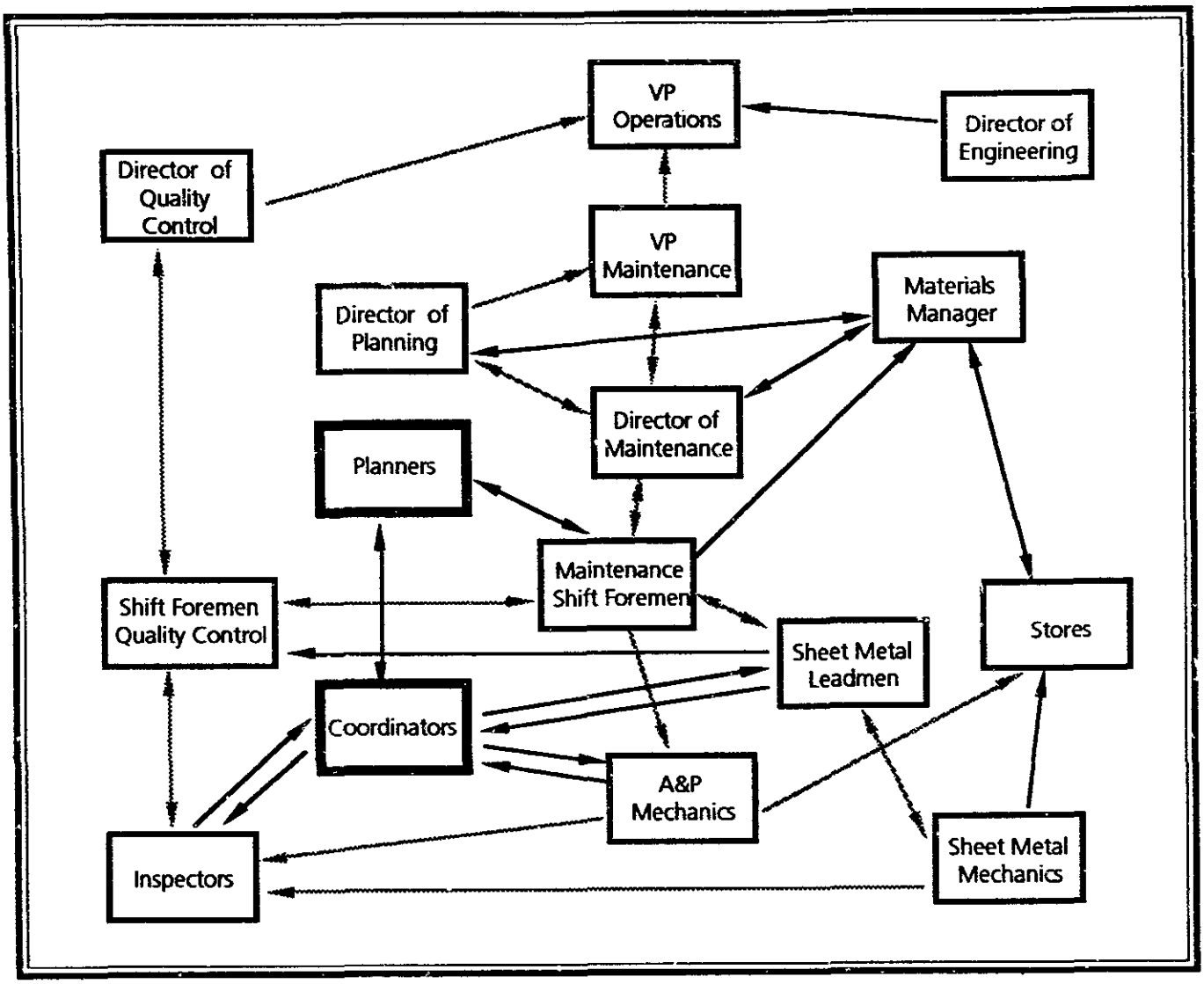


**Figure 2.2**
**Planning in Control of Work Assignment**

## MISSION

1. **Definition:** An effective mission — published, discussed, internalized and acted upon — is no mere slogan. It can be the driving force in ensuring worksystem excellence. It guides and unites the people of the organization in their pursuit of product "perfection," and it thereby also helps to cement the link between the organization and its customers.

2. Findings:
   a. **Most sites had no explicit mission, for Maintenance or the Company.** None of the AMPs interviewed had participated in developing a written mission statement for their department or for their company. Nor did any report having seen or heard of any such formal statement. As to their own understanding of their mission, two statements were typical. The usual statement was: "We all want safe aircraft." In addition, some AMPs reported that "the Company wants fast turnaround." Combined — and with a course of action specified — these two statements might serve as the nucleus for a truly effective mission, serving and uniting the interests of workers, managers, passengers, shareholders and even regulators. Yet only in three of the sites visited was such an integrative mission and action plan observed in print, speech or practice.

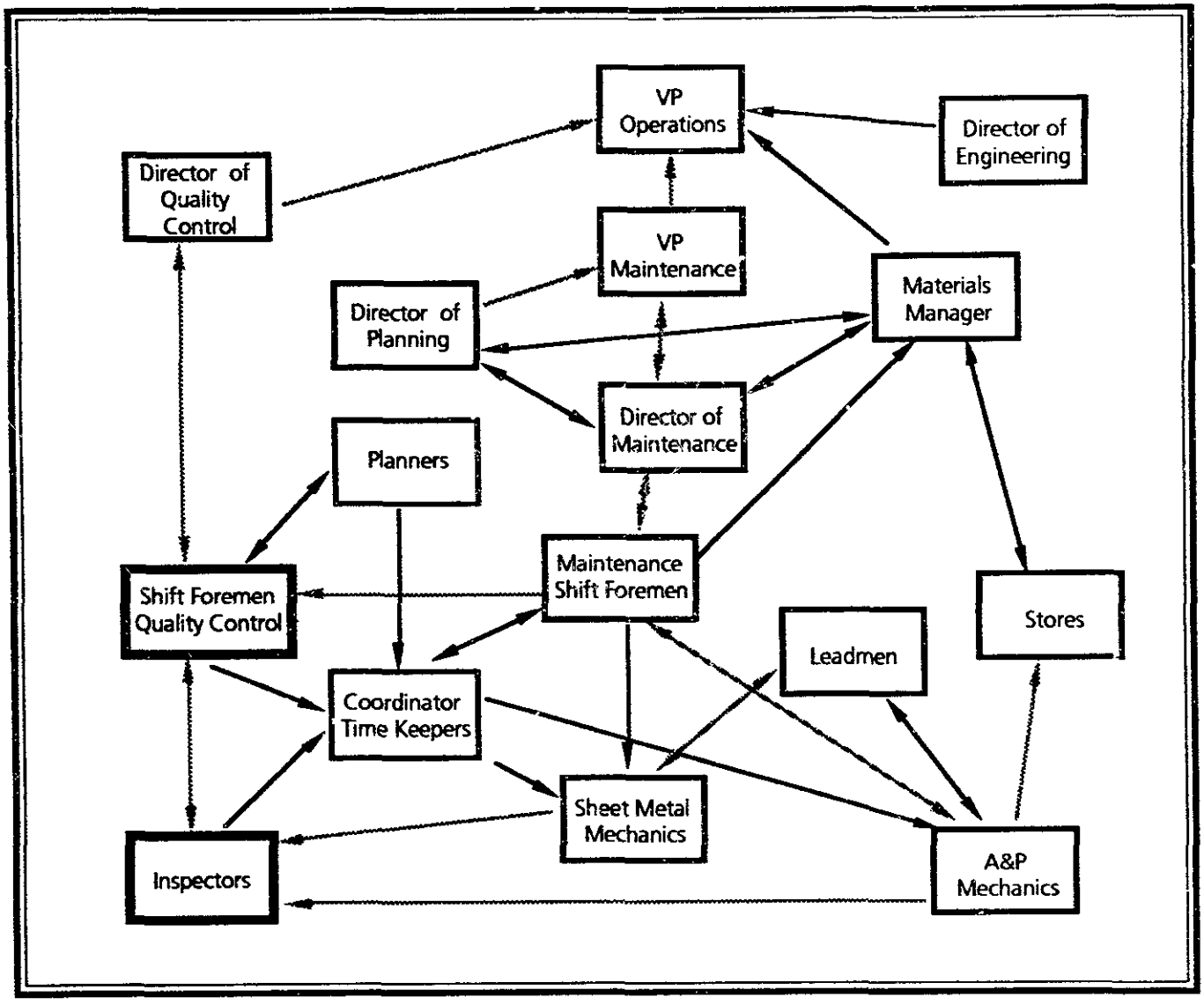


**Figure 2.3**
**Inspection in Control of Work Assignment**

b. **Having two 'sub-missions' is not seen as realistic.** The AMPs observed in this study clearly accepted the dual "mini-missions" of quality repairs for aircraft safety, and speed of turnaround as relevant. They know that both of these aims are important. But which way to lean? Without a sense of success in achieving both, the essential unity of these aims is replaced by feelings of organizational confusion, psychological stress and interpersonal strain. Most of the time, in many of the sites, the expectation that they will fulfill both sub-missions at the same time is felt by the AMPs as clearly unrealistic.

c. **Most choose 'safety' as their mission; in conflict with 'speed.'** In response to their conflicting-aims dilemma, the AMPs interviewed and observed favored safety (quality/accuracy) as their everyday work priority. Under the normal demands for fast turnaround, they did make their best efforts to move the work along however, but not so quickly that flight safety was put at risk. And, of course, that is the right thing to do. But doing the right thing leaves many AMPs in conflict over the other right thing. It makes their private choice in favor of safety of flight feel inconsistent, and it leaves them feeling at odds with their management's rightful demands for speedy turnaround.

d. **Under pressure, the 'mission' reverts to 'fixing things.'** When the workload went up, with considerably more turnarounds and repairs expected, AMPs at several sites were observed to wait passively for their work assignments to be handed out by the supervisor. Their "mini-mission" then could be seen as neither safety nor speed. Instead, their guiding rule was clearly to "just fix things (safely), as assigned."

As the work was assigned, the AMPs performed their allotted tasks with all the care, skill and effort required. But their aim had dropped: from the safety mission (with an awareness of the clock), to merely doing the immediate task at hand (with flight safety still in mind, and the inescapably clanging clock considerably more in mind than usual).

CULTURE

The prevailing culture in heavy maintenance contains an individualistic attitude among mechanics, combined with a cooler passion for airplanes and flight among the newer employees than was common with an earlier generation.

Increasingly, people are taking airline jobs at both the top and the bottom levels for more prosaic reasons than a love of airplanes. Employees today seem to be generally less willing than their counterparts in the past to share responsibility by working closely with others. The obligations an individual A&P mechanic takes with the FAA license, and the personal liability that entails, were reported to have the effect of making AMPs and their supervisors less eager to share work across shifts, or with less experienced or less skilled colleagues. One result of this is slower turnaround (incurring delays when key employees are absent). Another result is a considerable limitation of the opportunities for AMPs to effectively exchange ideas or information. Learning was therefore hampered, too, and with it, skill development so important to the quality of work performed.

AMP EXPERIENCE

Most heavy maintenance sites visited had AMPs with very long service, very short service, and very few in the middle. The "younger" AMPs (those with less experience) were often specialists in the large sheet metal repairs or laborious inspections called out by recent airworthiness directives (ADs). Many of the AMPs with less experience had less than complete advance preparation for complex structural repairs thus OJT and formal training were necessary.

Most of the companies studied hire new mechanics and planners directly from A&P schools. These new employees learn model-specific information about large passenger aircraft in formal classroom training conducted by their employers. For more specific details of airframe technical repairs, new AMPs mainly learn on the job.

Although many companies encourage AMPs to hold A&P licenses, there remain AMPs who do not, especially among the sheet metal mechanics. Sheetmetal mechanics who do have an A&P license report they received little preparation for this specialty at school. Few AMPs in the study felt well prepared from either school or subsequent training to undertake complex structural repairs or use complex NDI equipment. Such skill is developed on the job.

CONTROL OF WORK ASSIGNMENT

A struggle for control over maintenance work was observed between maintenance and planning in several sites. This struggle is beginning to take on a different and more complex dimension as computerized planning becomes more common. Where such a system is not very carefully managed and designed, it can become "control by computer," with a rigidity and singular focus that can act against the intentions of its sponsors and creators.

## 2.4.2 MAJOR ORGANIZATIONAL COMPONENTS Identified as a Result of Technical System Analysis

### Key Variance Control

Early key variance corrections have reduced costs and raised morale. Not getting the needed cross-department cooperation sometimes blocks the path.

Maintenance foremen in some sites could not always obtain the coordination and cooperation they needed from other departments in order to attend to "critical path repairs." Critical path items were those minimum critical repairs (in particular kinds of flaws, defects, fatigue wear, and damage to the aircraft) which determined the course of the overhaul: These particular defects in aircraft condition were understood as the "key variances" in overhaul. When key variances were detected early and repaired correctly the first time, long-term maintenance costs were reported to go down while maintenance morale rose.

Sometimes these variances were not detected during the preliminary inspection, and occasionally the extent of fatigue damage (particularly corrosion) would not be revealed until late in the overhaul. Apparently this latter situation is not unusual. In many of the sites visited, the aircraft observed had corrosion or (less frequently) ramp damage that required more than the original estimated time to repair. This situa-

tion meant that there was a regular, but nasty "surprise" that defeated efforts to complete the overhaul on time or within budget.

### 2.4.3 MAJOR ORGANIZATIONAL COMPONENTS Identified as a Result of Social System Analysis

#### Organizational and Group Teamwork

Individuals and groups at several sites did not always work together effectively. Several factors appear to be contributing to this less-than-ideal state of cooperation and coordination.

Interviewees listed difficulties with work organization, guidance, and training in the face of an increasing work load along with the increasing complexity of repair for aging aircraft. AMPs at several sites reported that they were too often unable to obtain parts in a timely manner. This contributed to an uneven work flow complicating work coordination and creating additional frustrations for mechanics and supervisors. Fairly frequent and sometimes even heated discussions with others about the correctness of repairs, when no prior standard seemed to exist, was also reported as disconcerting to everyone involved. In summary, despite the best efforts of all concerned, a truly effective level of teamwork was not the norm at several of the maintenance work systems studied.

In some cases, more experienced mechanics questioned the motives and performance of younger mechanics. In these sites, mechanics and inspectors on a given shift did not approve of work performed on a preceding shift and/or would not trust their own work to the oncoming shift.

Although there appeared to be some misunderstanding and negative feeling between mechanics and inspectors, the main feeling was one of mutual respect for the separate roles and a civilized agreement to disagree. Mechanics in some sites said that they did whatever work the inspectors required. Foremen and mechanics in other sites said that inspectors were inconsistent, and this caused them to over-process and unnecessarily replace parts. Sheet metal foremen in many sites felt that the inexperience of new inspectors was a major issue. Inspectors said that there were occasional issues between themselves and the mechanics over the interpretation of standards in the structural repair manual (SRM). Inspectors in many sites reported requiring more engineering variance authorizations (EVAs) before approving non-SRM repairs. Inspectors in some sites said that the quality of the mechanics' work needed to be improved.

The production control or planning group was often identified by respondents in the sample (including planners and coordinators themselves) as the least salient, most overstaffed unit. They reported having (and were reported to have) less training and less well-defined standards than they would need to best contribute to an effective hangar maintenance system. When the planning group obtained, or was granted, control over work assignment, the results on productivity and hangar morale were usually described in negative terms.

#### Internal Maintenance System Boundaries

Existing organizational boundaries are not appropriately drawn in several sites. Their current boundaries tend to create separate organizations within the same system, encourage finger-pointing, and promote more politics than productivity. The necessity to cross these boundaries (for example between materials and maintenance or between shops and maintenance) has built-in difficulties in negotiating demands in support of the systems requirements. When these separate departments have conflicting goals, and diverging or incomplete understanding of the maintenance and company mission, these difficulties would occasionally escalate near the limits of the system's ability to cope.

In a number of the sites visited, both management and AMPs reported that morale was lower than it had been in the past, and that absence and turnover among AMPs was increasing. Respondents said turnover caused by poor morale was in part the outcome of frustration over work coordination, concerns about being asked to do more than can be done, and lack of cooperation and communication among separate departments.

Despite all this, mechanics and inspectors said they liked aircraft maintenance work and most of them expected to remain in the industry. Many, however, were not sure if they would stay with their present employer. Planners, on the other hand, said they were less likely to stay in maintenance at all. They reported that their jobs were less challenging and, as a group, felt they were held in low esteem by other AMP groups.

## 2.5 RECOMMENDATIONS

### 2.5.1 Guidelines for Management

Based on the results of the general overview produced by this study, it is important to strengthen the relationship between AMP technology, coordination and cooperation, and performance.

The goal of this first set of recommendations is to create guidelines which draw conclusions about the effective use of the human factor — in patterns of communication for effectively getting work done, together with satisfying the AMP work force; and to use these findings to create guidance to maintenance managers and supervisors for improvement of such communication in the maintenance function. It is recommended, therefore, to develop management guidelines for improving communication in maintenance work. In particular, the guidelines should emphasize communication styles and techniques useful in applying new or known effective AMP technologies.

Outlines and draft guidelines should be field tested with maintenance managers for feedback of those outline materials. From this feedback the guidelines for effective communications within maintenance organizations would be developed.

Guidelines as created should be consistent with the development of maintenance teamwork training derived from cockpit resource management (CRM) experience in the industry. Further, the guidelines should be written in a style and format for use by maintenance management personnel.

1) Deliver an outline for communication guidelines which
   a) specifies:
      AMP attitudes about the local organization.
      Maintenance management style.
      Maintenance organization purpose, long-term objectives, and short range goals.
      Maintenance organizational structure.
      Job design for applying the technology.
      Patterns of coordination and communication in applying the technology.
      Success in attaining goals and objectives in pursuit of purpose.
   b) Describes the outline topics in terms of case study and observations already collected in AMP studies described in this report.
2) Present this outline to maintenance managers in the industry and obtain feedback of topics and concept. Deliver an interim report describing the results of analyses of data collected received during feedback and field tests. The deliverable at this interim stage will provide further elaboration of the outline topics based on field test of the previous case studies and observations and added illustrative material obtained during the field tests.
3) Deliver a final and detailed report of the Communication Guidelines for effective communications within maintenance organizations. The Guidelines shall be written for maintenance management personnel.

### 2.5.2 Industry Validation of the Findings from the Present Study

The present study, as described, was intended to provide a rapid diagnostic picture of current U.S. experience. The study necessarily focussed on a narrow slice of aircraft maintenance, it employed informal measures of collecting data, and it was produced from a small sample rather than from the comprehensive population of companies comprising the industry.

The second major recommendation suggests more formal and comprehensive measurement by and for the commercial aviation maintenance industry itself. For a permanent and definitive record of the industry it would be valuable to quantify and expand the present study through the development of a formal survey questionnaire, designed and administered by the industry itself. For such a questionnaire a larger and representative sample of companies and their employees and managers nationwide would be drawn, and the area of interest would be extended from heavy maintenance of fuselage to all heavy maintenance activities in all areas of the aircraft, and to maintenance at the flight line as well. The data collected should also include the experience of working with newer aircraft.

**Specific steps to quantify and expand the present study:**

Develop a formal survey questionnaire from the findings reported here. Extend the area of interest from heavy maintenance of fuselage alone, to at least all heavy maintenance activities in all areas and systems of the aircraft.

Specify questions the answers to which can be quantified into scaler values.

Obtain response and advice about the questionnaire items from both management and labor representatives of the commercial aviation maintenance industry.

Pretest the resulting survey instrument with a representative sample of airline maintenance employees, and correct or change items as required. Promote the support and cooperation of the industry's leaders for the survey.

Encourage company managements, local union representatives, and relevant professional societies to support the survey.

Draw a large and representative sample of companies and their employees and managers nationwide for an initial administration of the survey.

Make the preliminary results available to the sponsoring parties for aid in interpretation of findings.

Publish and distribute the final report within one year of the survey.

Develop and conduct a series of industry-wide meetings to discuss the results of the survey and plan changes to be made on the basis of those discussions.

### 2.5.3 Undertake Changes in Maintenance Organization and Management

This study may, in itself, provide sufficient validation of the state of maintenance safety efforts to prompt some managers and executives to take action based on its findings. The third set of recommendations therefore includes the following.

**Increase the workforce competence.** Increase and improve on the job (OJT) training by using experienced AMPs or qualified trainers who have themselves been trained in approaches to effective learning. Improve and expand company sheet metal and composites training for inspectors as well as mechanics. In addition to better OJT, new intelligent tutoring systems should lend themselves to efficiency in this recurrent training. Expand and emphasize teamwork training. Extending the effective training methods and curricula of cockpit resource management to maintenance managers, foremen, and AMPs is suggested.

**Emphasize and support maintenance system centrality in company purpose.** Each company should concentrate on developing a clear company mission statement, and help the maintenance system enunciate its role in it. Maintenance mission for each company should likewise be developed, for which clear-cut goals and objectives can be created and pursued. All maintenance personnel should be able to describe their role in achievement of these objectives and how these fit with company purpose.

**Develop commitment to human values which reflects the desired practices of management and employees, and which enhances the logic of those practices.** Each company and maintenance system should have a statement of values about people, including (at least): employees, managers, shareholders, contract personnel, competitors, passengers, and the travelling public. These values should be able to link with management practices, and the rationale for them.

For example, if an AMP closes out the current job card close to the end of the work day, why should the use of personnel time clocks also be required? Dedicated workforce attendance and timekeeping for personnel systems is neither required by labor law, nor is it the only effective way to acquire such data. AMPs are inconvenienced at the time clocks by waiting a second time each end of shift for the convenience of personnel departments. Time clocks may not be in keeping with values which announce trust in employees and respect for their abilities.

Another example of the logic of human values relates to policies and practices of employee furlough, or lay-offs. The value statement that claims employees are a most prized resource is difficult for AMPs to reconcile with past lay-offs. Of course a management cannot guarantee lifelong employment, but such value statements invite the creation of a logical and visible set of steps to be taken by a company before any employee is laid off. Consistency in values and practice and an open attitude to communication with employees creates greater commitment to the company.

**Create and endorse teamwork in the maintenance system.** Eliminate or modify the boundaries between the various function specialties in the maintenance system. This would include planning, shops, and certain parts of engineering and materials groups. Even inspection can be designed to enhance cooperation with maintenance while continuing to comply with FARs for a separate QC department which reports, independently, to top management.

Reduce the emphasis on the individual contributor as the basic work unit in aviation maintenance, in favor of greater teamwork among AMPs. Consider enhanced company role in *ab initio* AMP orientation training. Surely the current experiments with aircarrier operated A&P schools will prove effective in imparting up-to-date technical knowledge and skills.

Promote excellence in management performance. Encourage foremen to hold daily meetings with their AMPs. Encourage maintenance managers to hold at least weekly with their foremen. Emphasize management and foreman responsibility for the pursuit of a conscious and public maintenance mission and for setting and achieving measurable objectives. Expect foremen to provide work direction, and encouragement for high AMP performance, as well as insight and action when performance is below par. Involve AMPs in decision making and problem solving about matters that affect them at work. Ensure that communication throughout this management system is two way.

### 2.5.4 Communication Guidelines

The first year of this research was focused on identification and observation of communication practices in maintenance organizations. During 1991 a handbook will be developed to provide practical advice to improve such communication practices.

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# Chapter Three
# The Maintenance Technician in Inspection

## 3.1 INTRODUCTION

The problem of improving the reliability of aircraft inspection and maintenance is multi-faceted, so that this chapter only details one part of the Federal Aviation Administration and Galaxy Scientific Corporation approach to solutions. Justification in terms of fleet age, and maintenance philosophy is presented elsewhere in the NAARP and this report.

The objectives of this task can be stated as:

This aspect of the NAARP Human Factors plan is to determine typical human-system mismatches to guide both future research and short-term human factors implementation by system participants. Also, by providing a human factors analysis of aircraft inspection, it is intended to make human factors techniques more widely available to maintenance organizations, and to make aircraft maintenance more accessible to human factors practitioners.

To meet these objectives, the context of aging aircraft inspection is important to show the relationship of this task to improved airworthiness and public safety. If an aircraft is to be properly maintained, the maintenance system must either be error-free or error tolerant. Cracks and corrosion in the metal structure of commercial aircraft are a fact of life; there will always be defects present. Correction of defects demands detection of defects, and this is one area where systems improvements should be looked for. The system for defect detection consists of a human inspector aided by various machines. Humans and machines are both fallible, so that ways are needed to make these system components less error-prone, and the system more error tolerant. The detection/repair strategy used throughout the world is to specify a maintenance interval such that if the defect is too small to detect on one check, it will be both large enough to detect and small enough to be safe on the subsequent check. However, failure to detect a crack or corrosion which was in fact large enough to be detected does not give the same level of assurance that it will not cause a problem before the next check.

The aircraft inspection system is a complex one, taking place at sites ranging from large international carriers, through regional and commuter airlines, to the fixed-base operators associated with general aviation. Inspection, like maintenance in general, is regulated by the FAA in the U.S.A. and equivalent bodies in other countries. However, enforcement can only be of following procedures (e.g. hours of training and record-keeping to show that tasks have been completed), not of the effectiveness of each inspector. Inspection is also a complex socio-technical system (Taylor, 1990), and as such, can be expected to exert stresses on the inspectors and on other organizational players (Drury, 1985).

Just as effective inspection is seen as a necessary prerequisite to maintenance for safety, so human inspector reliability is fundamental to effective inspection. The inspection system will be described briefly to provide a background for the inspection Task Analysis which follows. Data was collected from six sites in the United States, two each for three major national/international carriers. (In addition, some observations were made at the maintenance sites of two European carriers, but no detailed Task Analysis data was collected at either site.) Major carriers were chosen to reduce the variability of inspection systems observed, with the aim of collecting usable data within a limited time frame. Regional and commuter airlines, and aircraft repair stations will be added during the second year of the project.

## 3.2 THE INSPECTION SYSTEM

Aircraft for commercial use have their maintenance and inspection procedures scheduled initially by a team including the Federal Aviation Administration, the aircraft manufacturer and start-up operators. These schedules are then taken by the carrier and modified, in a process which must meet legal approvals, to suit the carrier's requirements. For example, an item with an inspection interval of 5,000 hours may be brought forward to a 4,000 hour check so that it can be performed during a time when the aircraft is undergoing other planned maintenance. Within the carrier's schedule will be checks at many different intervals, from flight line checks and overnight checks, through A, B and C-checks (often in themselves subdivided, e.g., C-1, C-2, ...) to the "heaviest" level or D-check. This project has concentrated on C- and D-checks because these are the times at which most detailed structural inspection of airframe components is undertaken—the focus of the National Aging Aircraft Research Program (NAARP).

As an aircraft is scheduled for a heavy check, all of the required inspection and maintenance items are generated by a Planning Group within the carrier's maintenance organization. Items included scheduled known repairs (e.g., replace an item after a certain airtime, number of

cycles or calendar time), repair of items discovered previously (e.g., from pilot/crew reports, flight line inspections, items deferred from previous checks), and scheduled inspections. The inspections are expected to lead to repairs in certain cases, i.e. if a defect is found by the inspection system. With the aging fleet, it is of some interest that scheduled repairs now account for perhaps 30% of all repairs, rather than the 60-80% seen in earlier years, due to the finding of more age-related structural defects in the aircraft.

Because such a large part of the maintenance workload on a particular check is discovered during inspection, it remains an unknown to the Planning Group. Maintenance technicians (AMTs) cannot be scheduled until the workload is known, and replacement parts cannot be ordered until they are discovered to be required. For these reasons, it is imperative that the incoming inspection be completed as soon as possible after the aircraft arrives at the maintenance site. This aspect of the organization of the inspection/maintenance system gives rise to certain peculiarities of ergonomic importance.

As it is imperative that all defects requiring repair be discovered as quickly as possible, there is a very heavy inspection workload at the start of each check. To keep the number of inspectors within bounds despite this sudden workload requirement, most airlines use considerable overtime during "check-in" of an aircraft. Thus, if there are ten inspectors regularly working each shift, double shifts can give effectively twenty inspectors for a short time. Hence, for the first, perhaps, six shifts after check-in, inspectors expect considerable overtime, leading of course to prolonged hours of inspection work. Also, as an aircraft typically arrives after service (e.g., 2200 to 2359) much of the incoming inspection is on night shift. Another factor predisposing towards night shift inspection work is Non-Destructive Inspection (NDI, or NDT for testing) involving hazardous materials such as X-ray or gamma-ray sources. For safety reasons, such NDI work is typically performed during work breaks on night shift when a minimum number of people need to be inconvenienced to prevent radiation exposure. Note that any time spent at the maintenance site between about 2300 and 0700 will not generally incur a loss of revenue as curfews prevent landings and take-offs between these hours at many U.S. airports.

Before each inspection can be performed, there are certain activities necessary for correct access. The aircraft may need to be cleaned inside and out (e.g., cargo hold below galleys and toilets), paint may need to be removed (e.g., on fuselage crown for NDI of lap-joint areas), parts of the aircraft may need to be removed (e.g., seats and cabin interiors for internal inspection of stringers or flaps and slats to inspect their tracks), or access panels may need to be opened (e.g., panels in vertical stabilizer for access to control wires and control actuation mechanisms). As inspection is performed, each defect found leads to a report being filed. This, variously called a Non-Routine Repair (NRR) report, or a Squawk, is added to the work pack of repairs required before the aircraft can complete its check. This NRR in itself generates the new workcards necessary for its completion, often via the Planning Group or Production Control. It may also generate the need for additional inspections, for example, to ensure that certain nuts are torqued correctly during installation, or that a skin patch ("scab") has been correctly added. These subsequent inspections are called "Buy-Back" inspections in the U.S. Typically, as a check progresses, the inspection workload both decreases due to completion of incoming inspection, and changes in nature due to a greater preponderance of buy-backs. Also, the rhythm of the work can change, as incoming inspection starts out with relatively few interruptions, but interruptions increase in frequency as AMTs call in inspectors to perform buy-backs of completed repairs.

## 3.3 METHODOLOGY

With the objective being to locate human/system mismatches which could lead to error, the basic methodology had to be one of direct observation of, and interviews with, system participants. Although an understanding had to be developed of how the system **should** work, the major emphasis was on how the system **does** work. The aim was not to evaluate the observed systems against published, legal standards, but to determine how the system functioned. Promulgation and change of regulations is only one way of enhancing system performance. In systems as large and complex as aircraft inspection it is natural to expect a variety of ways to accomplish multiple (often *conflicting) objectives within an existing legal framework.* All data was collected anonymously to enhance its validity. Two points should be noted:

1. All system participants were open and honest with members of the Task Analysis team. Every person we met was highly motivated, and honest, as well as genuinely concerned to improve system effectiveness.

2. If the team's task had been to measure compliance with existing regulations, it would have used an entirely different methodology.

Error-prone human/system mismatches occur where task demands exceed human capabilities. The necessary com-

parison is made through the formal procedure of Task Description and Task Analysis (Drury, et. al., 1987). Task Description is the enumeration of necessary task steps, at a level of detail suitable for the subsequent analysis. Task Analysis uses data and models of human performance to evaluate the demands from each task step against the capabilities of each human subsystem required for completion of that step. Examples of subsystems are sensing (e.g., vision, kinesthesis), information processing (e.g. perception, memory, cognition), and output (e.g. motor control, force production, posture maintenance). Thus, the system functions and tasks must be observed, and analyzed, *through the filter of human factors knowledge, if more* than superficial recommendations are to be made. There were two good starting points for this endeavor:

1. Existing human factors theory and case studies of inspection in manufacturing industry (Harris and Chaney, 1969; Drury and Fox, 1975; Drury, 1984).

2. Existing investigations of human capabilities in aircraft inspection (e.g. Lock and Strutt, 1985).

Although general Task Analysis systems are widely available (e.g. Drury, et.al., 1987), it is advantageous to use a system directly relating to inspection. Much human factors research in industrial inspection (quality control) has produced the following four major task steps for any inspection job:

1. Present item to inspector.
2. Search for flaws (indications).
3. Decide on rejection/acceptance of each flaw.
4. Take appropriate action.

*Not all steps are required for all inspections. Thus, some* processes require no search (e.g. judgement of the color match for painted surfaces), while others require no decision (e.g. noting the complete absence of a rivet head on a lap splice). In the aircraft inspection context, a rather longer Task Description is required, expanding the "Present item to inspector" task to include both setup of task/equipment, and access to the correct point on a large and complex aircraft. ***Table 3.1*** shows a seven-task generic Task Description, with examples from each of the two main types of inspections: Visual Inspection (VI) and Non-Destructive Inspection. Visual Inspection is still the dominant mode, at least 90% of the total workload. NDI includes eddy current, ultrasonic, X-ray and gamma-ray inspections to render cracks visible, as well as augmented visual inspection, such as dye-penetration testing and borescope use. Note that in both cases the Task Description unit is the workcard, or worksheet, and that the task is seen as continuing until a repair is completed and passed as airworthy. The workcard is the unit of work assigned to a particular inspector on one physical assignment, and can have a work content varying from one to eight hours, or perhaps longer. Typically, a workcard is expected to be completed by an inspector within a shift, although arrangements can be made for continuation across shifts. Because the workcard was taken as the unit of analysis, and given that a workcard can contain many inspection items, the count of workcards observed during the Task Analysis in fact includes a great quantity and variety of inspection *tasks. As an example, the C-check workcard for detailed* inspection of the empennage can include checks for broken or worn external parts (friction tabs), checks of each of several hundred rivets for integrity, checks for bumps, dents, buckling or other damage to skin, checks of freedom of movement of flight surfaces (elevators, rudder, time taps, servo tabs), checks of wear/play in activating cables or bushings, and checks for cracks or corrosion in internal structures.

From the Lock and Strutt (1985) report had come some detailed Task Descriptions of one particular inspection task (empennage inspection on B-707), and the Task Description/Task Analysis methodology used here was tested to ensure that it would cover such descriptions.

The methodology employed was to perform site visits to obtain detailed Task Descriptions. On a typical site visit, interviews with system participants at *all levels* helped to collect data on the structure and functioning of the system (e.g. organization, training) as well as collecting data on rare events such as system errors. Direct observations were performed by having human factors analysts work with an inspector during completion of a workcard. They followed the inspector, asking probe questions when necessary, and taking photographs to illustrate points such as lighting, field of view, access problems or appearance of discovered defects. Task Descriptions were then transcribed onto standard working forms (***Figure 3.1***), with a new page for each of the five steps in the generic task analysis. At a later time, knowledge of human factors models of inspection (e.g. Drury, 1984) and of the functioning of individual human subsystems (Sinclair and Drury, 1979) was used to list subsystems required (A, S, P, D, M, C, F, P in ***Figure 3.1***) and any potential human/system mismatches under Observations in ***Figure 3.1***, to complete the Task Analysis.

In addition to this work, other NAARP activities were undertaken, including CAA/FAA liaison, STPG Human Factors in Aircraft Maintenance contributions, and delivery of papers at FAA/NAARP meetings (see Appendix A). All contributed to system understanding.

| TASK DESCRIPTION | VISUAL EXAMPLE | NDI EXAMPLE |
|---|---|---|
| 1. Initiate | Get workcard, read and understand area to be covered. | Get workcard and eddy current equipment, calibrate. |
| 2. Access | Locate area on aircraft, get into correct position. | Locate area on aircraft, position self and equipment. |
| 3. Search | Move eyes across area systematically. Stop if any indication. | Move probe over each rivet head. Stop if any indication. |
| 4. Decision Making | Examine indication against remembered standards, e.g. for dishing or corrosion. | Re-probe while closely watching eddy current trace. |
| 5. Respond | Mark defect, write up repair sheet or if no defect, return to search. | Mark defect, write up repair sheet, or if no defect, return to search. |
| 6. Repair | Drill out and replace rivet. | Drill out rivet, NDT on rivet hole, drill out for oversize rivet. |
| 7. Buyback Inspect | Visually inspect marked area. | Visually inspect marked area. |

**Table 3.1 Generic Task Description of Incoming Inspection with examples from visual and NDI inspection**

## 3.4 RESULTS AND DISCUSSION

The basic system description has already been presented in the Introduction, so that only examples of Task Analyses will be given here. The total numbers of workcards for which Task Analyses were performed are shown in *Table 3.2*, classified by aircraft general area or zone.

No statistical sampling method was used to choose these particular tasks, rather the aim was to schedule visits when heavy inspection was taking place and follow one or more inspectors during the observation period. Interviews with inspectors helped to ensure that all aspects of inspection were covered. The aircraft types involved were Boeing 727, 737, and 747 types, and McDonnell Douglas DC-9 and DC-10s. Some engine inspections were observed where they contributed techniques of interest, e.g. borescope or X-ray film reading (*Figure 3.1*). With NDI tasks, the area of concentration was the strictly inspection activities, e.g. film reading, while the extensive safety procedures required to clear the area for film exposure were not recorded. Again, the aim was to discover sources of inspection error rather than aspects of system safety.

*Figures 3.2* and *3.3* show the Task Analysis documents for a VI and a NDI procedure, respectively. It would be pointless to provide over thirty such analyses, as they are the equivalent of raw data in an observational study such as this. Rather, it was necessary to devise a methodology for integrating the findings, particularly the observations, which would lead towards discovering human/system mismatches.

However, it became apparent that the observations listed were those which occurred to the analysts during system observation and subsequent analysis. A more comprehensive way was required for detecting mismatches. It was decided to use a schema for classifying errors which was initially developed to aid the STPG process, and which has been further developed as part of the second year of the GSC/NAARP endeavor. This consisted of expanding each of the task steps given in the generic Task Description (*Table 3.1*) into its logically-necessary substeps, and for each substep to list all of the failure modes, similar in concept to those of Failure Modes and Effects Analysis (FMEA), for example Hammer, 1985. The current list is shown as *Table 3.3*.

This list formed the basis for classifying each observation by how it could cause a failure of the inspection system. What was found, when these were counted, was that many of them involved factors which would tend to increase the probability of errors, rather than strictly leading to an error in a single step. *Table 3.4* shows how these observations were classified.

**TASK**: Isotope (Gamma Ray) Inspection **LOCATION**: Second Stage Nozzle Guide Vane Area, JT9D-7/7A

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **SEARCH** | | | | | | | | | | |
| For each vane, search for the following indications:<br>1. Trailing edge burning<br>2. Trailing edge bowing<br>3. Airfoil bulging<br>4. Missing vane inner rear foot<br>5. Broken vane mounting bolt<br>6. Tilt, measured between lines A and F | X | X | X | | X | | | | | •Nos. 1,2,3,4,6 illustrated in NDT manual. No. 5 described, not illustrated.<br>•No. 4 is called "missing are a inner lug" on diagram in NDT manual.<br>•No "perfect" vane shown in NDT manual illustration.<br>•If film does not cover area completely then high level of glare from open area of screen.<br>•Some films may be slightly misaligned, masking vane trailing edges.<br>•All defects have low contrast. |
| **DECISION** | | | | | | | | | | |
| 1.0 Measure trailing edge width for widest and narrowest on each film using calipers. Difference determines time to remove engine from service | X | X | X | X | X | X | | | | Edges not perfectly sharp, making measurement difficult.<br>No specific decision rule for No. 1 trailing edge burning.<br>Twisted inner lug defect shown on figure in NDT manual but no reference in text and no decision rule. |
| 2.0 Measure Line A to F distance to get tilt (calipers). Tilt limit determines time to remove engine | X | X | X | X | X | X | | | | Reading calipers may be difficult in darkened room. |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feedback **P**: Posture

**Figure 3.1 Example of Task Analysis**

| AREA INSPECTED | VISUAL INSPECTION | NDI INSPECTION |
|---|---|---|
| Fuselage: Internal | 1. Left fuselage skin longitudinal lap splice, B-747<br>2. Lower lobe body skin longitudinal lap joint, B-747<br>3. Cabin area inspection, B-727<br>4. Tail compartment inspection, DC-9 | |
| Fuselage: External | 1. RH fuselage area inspection, B-747<br>2. Fuselage skin longitudinal lap splice, B-747<br>3. Fuselage skin lower panel inspection, B-737 | 1. Pressure bulkhead skin splice, eddy current inspection, DC-9 |
| Fuselage: Apartures | 1. Passenger cabin aft entry door, B-727<br>2. Lower cargo door, B-727<br>3. RH co-pilot's window replacement buy-back, B-737<br>4. RH window #9, crazed window replacement, B-737 | |
| Wings | 1. Right hand wing landing gear, B-747<br>2. RH wing inboard/outboard flap track #6, ultrasonic, B-747<br>3. LH/RH wing honeycomb pane, B-747<br>4. Right wing, DC-9<br>5. Left handling gear and well, DC-9<br>6. Engine pylon fuse pin-bush migration, B-727<br>7. RH OTBD wing edge and controls, B-727<br>8. Right wing and leading edge, B-727 | 1. RH slat closing rib - borescope, B-727<br>2. RH wing inboard/outboard flap track #6, ultrasonic, B-747<br>3. Right inboard elevator actuator, radiographic isotope, DC-10 |
| Empennage | 1. LH/RH horizontal stabilizer and elevator, LH/RH vertical fin and rudder, DC-9<br>2. Vertical fin tip/tension/horizontal attachment and elevator, B-727<br>3. Empennage inspection, B-727 | |
| Power Plant | | 1. Diffuser case rear rail, eddy current inspection, B-747<br>2. Combustion chamber, borescope (enhanced visual), B-737<br>3. JT9D-7/7A isotope, B-727 |
| **TOTAL** | **23** | **8** |

**TABLE 3.2 Workcard Followed for Detailed Task Analysis**

**Task:** Wing and Leading Edge Inspection **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **INITIATE** | | | | | | | | | | |
| 1.0 Supervisor briefs the inspectors. | | | | | | | | | | |
| 2.0 Assign specific tasks. | | | | | | | | | | |
| 3.0 Collect workcard from card rack. | | | | | | | | | | |
| 4.0 Read workcard. | | | | | | | X | | | o No feedforward regarding the tasks. |
| 4.1 Read instructions. | | | X | | | | | | | o Key points missing. |
| 4.2 Identify area to be inspected. | | | X | | X | | X | | | o Figures inadequate to aid in locating the area. |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

Figure 3.2 Task Analysis of Visual Inspection Procedure

**Task:** Wing and Leading Edge Inspedtion **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **ACCESS** | | | | | | | | | | |
| 1.0 Ensure that elevators and spoilers are in raised position. | | | | | | | X | | | o No prior information to inspector inspector regarding the opening of panels. |
| 2.0 Ensure the opening of panels by maintenance. | | | | | | | | | | |
| 3.0 Ensure availability of ladder platform. | | | | | | | | | X | o Availability of ladder a problem. |
| 4.0 Carry the ladder to the area and adjust the height. | X | | | | | | | | X | o Stability of ladder poor. |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feed-back **P**: Posture

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

**Task:** Wing and Leading Edge Inspedtion **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **SEARCH** | | | | | | | | | | |
| 1.0 Inspect slat structure, wiring and installation. | | | | | | | | | | |
| 1.1 Check wear on male duct of telescopic shaft duct. | | | | | | | | | | |
| 1.1.1 Check wear by moving it and seeing if it is loose. | | | X | | X | | | | | o No prescribed force. |
| 1.2 Inspect slatwell area for corrosion and cracks. | | | | | | | | X | | o No standards for wear. |
| 1.2.1 Hold flashlight such that light falls perpendicular to the surface. | | | | | | | | X | | o Holding flashlight for a long period at odd positions - strenuous. |
| 1.2.2 Visually look for cracks or corrosion. | | | X | X | X | | | | | o Lack of information on type of cracks and figures. |
| 1.2.3 The visual indication confirmed by tactile and move scrutinized inspection. | | | X | X | X | | | | | |
| 1.3 Look for play in slat actuator nut. | | | | | | | | | | |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3-2 Task Analysis of Visual Inspection Procedure**

**Task:** Wing and Leading Edge Inspedtion **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **SEARCH (Cont'd)** | | | | | | | | | | |
| 1.3.1 Move it by applying force and see | | | | | | | | | X | o No gauges provided. |
| If there is play. | | | X | | | | | | | o No recommended force. |
| | | | X | X | X | | | | | o No limits for acceptable play given. |
| 2.0 Inspect fueling bay and instaliations. | | | | | | | | | | |
| 2.1 Open fueling bay door. | | | | | | | | | | |
| 2.2 Perform intensified inspection of fueling . adapter flange | | | | | | | | | | |
| 2.2.I Hold flashlight at an angle (grazing incidence). | | | X | | | | X | | | o The inspector was not very clear about what he was actually looking for. |
| 2.2.2 Look for evidence of bending or other deformation. | | | X | | | | | X | | o No specific diagrams to aid him in this. |
| 2.3 Re-install cover. | | | | | | | | | | |
| 3.0 Visually inspect wing span. | | | | | | | | | | |
| 3.1 Manually check the clamps. | | | | | | | | | | |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feedback **P**: Posture

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

**Task:** Wing and Leading Edge Inspection **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | OBSERVATIONS |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | |
| **SEARCH (Cont'd)** | | | | | | | | | | |
| 3.1.1 Shake the clamps by applying force. | | | X | | | | | | | o Very subjective task. |
| | | | X | X | | | | | | o No standards or procedure. |
| | | | | | | | | X | | o Very cramped position. |
| 3.2 Check for corrosion on fuel shutoff cable. | | | | | | | | | | |
| 3.2.1 Hold flashlight perpendicular to the area. | | | | | | | | | | |
| 3.2.2 Look (feel) for signs of corrosion. | | | | | | | | | | |
| 3.3 Look (feel) for softness in the panels. | | | | | | | | | | |
| 3.3.1 Tap the panel using a coin. | | | | | | | | | | |
| 3.3.2 Look for change in sound. | | | | X | | | | | X | o No training of inspector to look for change of sound. |
| 4.0 Inspect upper side of wing. | | | | | | | | | | |
| 4.1 Mount the wing using belt attachment. | | | | | | | | | | o Made the inspector free from safety hazard. |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

Task: Wing and Leading Edge Inspection  Location: Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **SEARCH (Cont'd)** | | | | | | | | | | |
| 4.2 Visually look for loose rivets or cracks. | | | | | | | | | | |
| 4.2.1 Hold flashlight at grazing or angular incidence. | | | X | | | | | | X | o No prescribed method on workcard. |
| 4.2.2 Feel for loose rivets. | | | X | X | | | | | | o No prescribed force. |
| 4.2.3 Look for missing rivets. | | | | | | | | | X | o All this resulted in a cursory check. |
| 4.3 Look for signs of erosion due to contact between slat and the upper wing. | | | | | | | | | | |
| 4.4 Check for faults in the honeycomb panel. | | | | | | | | | | |
| 4.4.1 Tap using a coin. | | | | | | | | | | |
| 4.4.2 Look for change in sound. | | | | | | | | | X | o External noise made listening difficult and inspector had to listen very carefully. |
| 5.0 Inspect leading edge flap and flapwell structure. | | | | | | | | | | |

A: Attention  S: Senses  P: Perception  D: Decision  M: Memory  C: Control  F: Feedback  P: Posture

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

**Task:** Wing and Leading Edge Inspection **Location:** Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **SEARCH (Cont'd)** | | | | | | | | | | |
| 5.1 Visually check for signs of corrosion in flap hinge fitting. | | | | | | | | | | |
| 5.2 Check for cracks in hinge attachment and torque tiffes. | | | | | | | | | | |
| 5.2.1 Hold the flashlight such that area . is well lit | | | | | | | | X | | o The space was very cramped. The inspector had difficulty in holding the flashlight. |
| 5.2.2 Perform a tactile and visual inspection. | | | | | | | | | X | o This resulted in a very cursory inspection. |
| 5.3 Visually check for leakage in hydraulic lines. | | X | X | X | | | | | | o No prescribed method on the workcard. |
| 5.4 Look for signs of deterioration of switch wiring. | | | | | | | | | | |
| 5.4.1 Use a scale to reach the wiring. | | | | | | | | | | |
| 5.4.2 Look for signs of looseness by pulling. | | | | | | | | | X | o This was not mentioned. |
| 5.4.3 Look for frays visually and with hand. | | | | | | | | | X | o This was not mentioned on the workcard. |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

Task: Wing and Leading Edge Inspection  Location: Right Wing

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **DECISION** | | | | | | | | | | |
| 1.1.1 Decide if wear exists. | | | X | X | X | | | | | |
| 1.2.2, 1.2.3 Decide if cracks or corrosion exists. | | | X | X | X | | | | | |
| 1.3.1 Decide if play exists. | | | X | X | | | | | | |
| 3.1.2 Decide if looseness or wear is unacceptable. | | | X | X | X | | | | | |
| 4.2.2 Decide if the rivet is loose. | | | X | X | | | | | | |
| 4.4.2 Decide if there is a change in the sound. | | | X | X | X | | | | X | |
| 5.4 Decide if wiring has any signs of deterioration. | | X | X | X | X | | | | | |

A: Attention  S: Senses  P: Perception  D: Decision  M: Memory  C: Control  F: Feedback  P: Posture

Figure 3.2 Task Analysis of Visual Inspection Procedure

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | OBSERVATIONS |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | |
| **ACTION AFTER** | | | | | | | | | | |
| 1.0 Mark all the faults, fault by fault with a stickerhaving a discrepancy card number. | | | | | | | | | | |
| 2.0 At the end, fill out the discrepancy workcard using stickers as memory aids. | | | | | X | | | | | o Memory call since the inspector had a tendency to forget about the exact nature of fault. |
| | | | | | | | | | X | o A lot of time was spent in phrasing the discrepancy card. The inspector was uncomfortable with the filling out of the discrepancy workcard (training issue). |
| 3.0 If the task was not completed fill out the work interrupt card giving the status of items started but not signed off. | | | | | | | | | X | o The next person does not get a copy of the workcard / discrepancy card of the previous inspector. |
| 4.0 Close workcard. | | | | | | | | | | |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3.2 Task Analysis of Visual Inspection Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **INITIATE** | | | | | | | | | | |
| 1.0 Collect workcard from the supervisor. | | | | | | | X | | | o Workcard did not provide any feedforward information (i.e. whether earlier defects had been found on this engine). |
| 2.0 Read workcard. | | X | X | | | | | | | o Inspector did not refer to workcard at this stage.<br>o Inspector was experienced and did not feel it was necessary to consult the workcard. |
| 3.0 Collect equipment necessary to perform inspection in the workcard. | | | | | | | | | | |
| 4.0 Calibrate the instrument. | | | | | | | | | | |
| 4.1 Apply a layer of tape to the surface of the probe. | | | | | | | | | | |
| 4.2 Connect the probe to the instrument and switch the instrument on. | | | | | | | | | | |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feedback **P**: Posture

**Figure 3.3 Task Analysis of NDI Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **INITIATE (Cont'd)** | | | | | | | | | | |
| 4.3 Set the operation mode on the instrument to FE (material of rail). | | | | X | | | | | | o Workcard calls for a sufficient (does not specify exact time) warm-up period after instrument is switched on. This procedure was not followed by the inspector in this case. |
| 4.4 Place the probe on the standard template and lift off the compensate probe on the areaaway from the Elox slot (simulated defect). | | | | | | | | | | |
| 4.5 Move the probe over the standard. | | | | | | | | | | |
| 4.6 Observe the deflection of the meter. | | | | | | | | | | |
| 4.7 Adjust sensitivity to give a 40% of full scale deflection. | | | | | | | | | | |
| 4.8 Observe the deflection as probe passes overthe simulated defect. | | | | | | | | | | |
| 4.9 Observe the defelction for sensors "A" and "B"by passing over the Elox slot. | | | | | | | | | | |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3.3 Task Analysis of NDI Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **ACCESS** | | | | | | | | | | |
| 1.0 Verify with supervisor that engine is cool. | | | | | | | | | | |
| 2.0 Go to inspection site. | | | | | | | | | | |
| 2.1 Check engine covers are open. | | | | | | | | | X | o The engine covers had to be opened by maintenance. |
| 2.2 Verify no interferring parallel work in progress. | | | | | | | | | X | o Parallel work in progress delayed inspection and also caused interruptions that disrupted continuity. |
| 3.0 Inspector climbs on to the construction at site. | | | | | | | | | | |
| 4.0 Transfer NDT equipment to site on to the platform by the engine. | | | | | | | | | | |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feedback **P**: Posture

**Figure 3.3 Task Analysis of NDI Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | OBSERVATIONS |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | |
| **INSPECT** | | | | | | | | | | |
| 1.0 Recalibrate the instrument to take into account the material difference between thestandard and the rail. | | | | | | | | | X | o Recalibration procedure not documented in the workcard.<br>o (Inspector perceived that there was a material difference between the standard and the rail.) |
| 1.1 Move probe over rail edge (simulating a crack). | | | | | | | | | | |
| 1.2 Adjust deflectometer to get a 40% deflection. | | | | | | | | | | |
| 2.0 Insert flexible rod through the external just aft of the rear rail. | | | | | | | | | | |
| 3.0 Feed the rod clockwise around the engineuntil rod end visible at location "B". | | | | | | | | X | | o Inspector's work hampered due to difficulty in reaching the rear rail.<br>o Poor lighting conditions. |
| 4.0 Disconnect patch cord from the probe and attach the longest end of the probe cable to the rod. | | | | | | | | X | | o The task demands inspector to adopt uncomfortable work postures. |

**Attention:** Number of time-shared tasks **Memory:** STSS, Working, Long-term **Senses:** Visual, Tactile, Auditory **Control:** Continuous, Discret
**Perception:** **Feedback:** Quality, Amount, Timing **Decision:** Sensitivity, Criterion, Timing **Posture:** Reading, Forces, Balance, Extreme Angles

**Figure 3.3 Task Analysis of NDI Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **INSPECT (Cont'd)** | | | | | | | | | | |
| 5.0 Move the rod in counterclock-wise directions until the cable end was seen at location "A". | | | | | | X | | | | o Lot of coordination is required on the port of the inspection to prevent it slipping from the groove. |
| 6.0 Disconnect the cable from the rod and attach to the spring connector to complete wrap around. | | | | | | | | | | |
| 7.0 Assume that matching contours of probe are in contact with core by feeling probe movement. | | | | | | | | | | |
| 8.0 Attach patch core to probe and lift off the compensate probe. | | | | | | | | | | |
| 9.0 Slide probe clockwise traversing the rail to the rear of port #8. | | | | | | | | | | |
| 10.0 Monitor the meter for rapid needle movements. | X | | | | | | | X | | o Meter placed by the side of the inspector (rail is straight up front) making it difficult . for the inspector to monitor the meter continuously for deflections (attention problem) |
| 11.0 Inspect similar area of port #9 and remaining eight ports. | | | | | | | | | | |
| 12.0 Rotate Probe assembly counter-clockwise up to the original location of wrap around. | | | | | | | | | | |
| 13.0 Check for meter defections. | | | | | | | | | | |

A: Attention S: Senses P: Perception D: Decision M: Memory C: Control F: Feedback P: Posture

**Figure 3.3 Task Analysis of NDI Procedure**

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | |
| | A | S | P | D | M | C | F | P | O | OBSERVATIONS |
| **DECISION** | | | | | | | | | | |
| 1.0 If crack present indicated by rapid full scale deflection of the meter,move probe back and forth over this area. | X | | | | X | | | | | o Possibility of inspector making an error is increased as he has to time share between the two activities:<br>1. Motor control of probe movements.<br>2. Monitoring of display for deflections. |
| 2.0 Rules for decisions.<br>2.1 One full scale deflection is an"A"crack. | | | | | | X | | | | o Speed with which the probe is moved over the rail is critical. |
| 2.2 Two full scale deflection is a"B"crack. | | | | | | | | | | o Possibility of missing a crack if the movement speeds exceeds critical speed and inspector fails to fixate at that instant. |
| 2.3 Three full scale deflections is a"C"crack. | | | | X | | | | | | o No storage of deflections.<br>o High cost of FA for "C". cracks makes holding of a proper payoff matrix for decision making critical. |

A: Attention S: Senses P: Perception D: Decision M: Memory C: Control F: Feedback P: Posture

Figure 3.3 Task Analysis of NDI Procedure

**Task:** Diffuser Case Rear Rail Eddy Current Inspection **Location:** Engine Number One

| TASK DESCRIPTION | TASK ANALYSIS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SUB-SYSTEMS | | | | | | | | | OBSERVATIONS |
| | A | S | P | D | M | C | F | P | O | |
| **ACTION AFTER** | | | | | | | | | | |
| 1.0 Disconnect patch cord and cable attachment at the spring and probe. | | | | | | | X | | | o If there is a "C" crack present the inspector gets immediate feedback.<br>o No feedback provided in case of "A" and "B" crack. |
| 2.0 Extract rod from rear rail by pulling cable clockwise. | | | | | | | | | | |
| 3.1 If fault detected is "C" crack notify supervisor and maintenance immediatelyfill out discrepancy workcard. | | | | | | | | | | |
| 3.2 If fault detected is a "B" crack notify supervisor and mention this in the workcard. | | | | | | | | | | |
| 3.3 If fault detected is a "A" crack mention this in the workcard. | | | | | | | | | | |

**A**: Attention **S**: Senses **P**: Perception **D**: Decision **M**: Memory **C**: Control **F**: Feedback **P**: Posture

**Figure 3.3 Task Analysis of NDI Procedure**

### 3.4.1 Potential Human/System Mismatches

The most obvious way was to form a data base of all of these observations, so that they could be counted and listed in various ways. Such a data base was indeed constructed using the REFLEX package, and is available upon request.

Note the large numbers of postural and other (mainly environmental) implications for Access, and the high numbers of cognitive implications for Initiate, Search, and Decision. For Access, the implications mainly concern the *physical difficulties of reaching and viewing the inspection site*. Inadequate work platforms, limited space inside aircraft structures, the awkward postures required to hold a mirror and a flashlight for visual access, and the often non-optimal levels of glare, temperature/humidity, and ambient noise all contribute. For Initiate, the major difficulties are with the content and layout of the workcards, calibration standards for the NDI equipment, NDI equipment *human/machine interface inadequacies*, and coordination of inspection activities with other aspects of maintenance. Search implications were largely visual (for sensing) due to inadequate lighting at the workpoint, but also included omissions of specific feedforward and directive information on the workcard, and lack of memory aids for Search. For Decision, the major difficulties were in obtaining and applying standards at the inspection point for each defect found.

While it provides evidence for opportunities for error, *Table 3.4* naturally misses some of the ergonomic detail required if Human Factors expertise is to contribute to improved inspection. However, it does serve to emphasize

| | HUMAN SUBSYSTEM | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TASK | A | S | P | D | M | C | F | Ps | O |
| 1. INITIATE | 1 | 4 | 39 | 12 | 34 | 0 | 12 | 0 | 6 |
| 2. ACCESS | 0 | 11 | 4 | 0 | 3 | 0 | 0 | 32 | 27 |
| 3. SEARCH | 10 | 45 | 47 | 36 | 31 | 3 | 1 | 8 | 1 |
| 4. DECISION | 0 | 86 | 105 | 118 | 79 | 0 | 0 | 0 | 0 |
| 5. RESPOND | 0 | 6 | 0 | 0 | 5 | 0 | 0 | 6 | 5 |
| (6. REPAIR) | — | — | — | — | — | — | — | — | — |
| 7. BUY-BACK | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 |

**Table 3.4 Number of Instances of Human Factors Implications From Task Analysis**

**(Note: A single task step may generate more than one human factors implication.)**

that not all errors lead to failure to detect a defect. Three types of errors are possible in an inspection system (e.g. Drury, 1984).

1. Type 1 error: a non-defect is classified as a defect and unnecessary repairs are thus undertaken.

2. Type 2 error: a defect is not recorded, so that necessary repairs are not undertaken.

3. Delays: the inspection process is delayed or interrupted, leading to longer inspection/repair periods.

Although only Type 2 errors have a direct impact upon airworthiness, the other two errors can have an indirect effect, both by frustrating the inspector, and by directing resources away from the critical tasks. It needs to be pointed out that Type 2 errors can occur in multiple ways. Indeed, a Type 2 error will only not occur if all of the steps in the Task Descriptions are carried out correctly. That is, the correct initial actions must be undertaken, the correct area accessed, the search must locate the indication, the correct decision that the indication is indeed a defect must be made, the correct response of writing up and marking the defect must occur, repair must be carried out correctly, and the buy-back decision must be correct. For Type 2 errors, the inspection/repair system is a parallel system,

which naturally increases the probability of a Type 2 error. If $P^2_1$ through $P^2_7$ represent the probabilities of correct performance at each of the seven stages in the presence of a defect, then the probability of Type 2 errors is:

$$e_2 = 1 - \prod_{i=1}^{7} P^2_i$$

For Type 1 errors and delays, error recovery is possible at each step, so that the only way in which an error can be made is if all steps are performed incorrectly. Thus, the probability of a type 1 error delay is:

$$e_1 = \prod_{i=1}^{7} (1 - P^1_i)$$

where $P^1_i$ is the probability of correct performance of each step in the absence of a defect. Clearly, no matter how rare Type 2 errors are, decreasing them further means improving the reliability of each step in the inspection process.

Against these three possible errors, the role of human factors is to change the human/machine system so as to reduce the error incidence, that is to make the system more reliable. These are only two possible interventions: changing the system to fit the human inspector, or changing the human inspector to fit the system. The former has long been the province of ergonomics/human factors, with interface design receiving a prominent place. The latter, primarily selection, placement and training, has also been a concern of human factors engineers, but other disciplines (such as industrial psychology and educational psychology) have contributed. A more reasonable view than the advocacy of either as an alternative is to consider both as complementary aspects of achieving enhanced human/system fit. This fit is necessary both to ensure performance and to reduce the stresses on the human due to mismatches (Drury, 1989). Human stresses can, in turn, effect human performance in inspection tasks (Drury, 1986). Thus, the goal of the human factors effort in NAARP can be restated as choosing the optimum intervention strategy (changing the system or the human) to minimize human/system mismatches at each task step, so that the incidence of error is reduced.

### 3.4.2 Choice of Intervention Strategies

A major review of the field of human factors in inspection (Drury, 1990b) concludes that the practical potential for improvement due to selection and placement of inspectors is low, but that training and system redesign are particularly effective. With this in mind, *Table 3.5* was produced part way through the current project, showing potential interaction strategies for improving inspection performance. As can be seen, only the first five steps of the inspection task are included, and potential improvements rather than specific prescriptions are given. There is, however, enough detail to compile lists of human factors interactions which can proceed rapidly based on existing human factors knowledge, and those interaction strategies which require more research before detailed prescriptive advice can be given. It should be noted that even in the absence of direct human factors advice, many system improvements have been, and will continue to be, implemented by inspection organizations. Improvement is a continuous process in an industry with a long record of innovation, so that it should not be surprising that there are few improvements which can be implemented with no additional effort. For example, there is an urgent need (recognized both in this study and the (Lock and Strutt study) for improved portable task lighting. However, without at least a short study, it will not be possible to give the make and model number of the best flashlight currently on the market. Some interventions can be immediate, for example replacing workcards which are entirely written in capital letters with ones using both upper case and lower case fonts. Still other interventions require major studies, for example designing an integrated information environment for the inspector.

Key areas requiring intervention are those listed in *Section 3.4.1* and in *Table 3.5*. It is possible to use the human factors knowledge of inspection processes to help generate and classify interventions. For example, Drury, Prabhu and Gramopadhye (1990) used earlier knowledge of search and decision-making (Drury, 1984) to list the following interventions aimed at system (rather than human) changes:

1. Increasing visual lobe size in search-lighting, contrast, target enhancement, optical aids, false colors on video.

2. Improving search strategy-briefing/feedforward, aids to encourage systematic search.

3. Enhancing fault discriminability-standards at the workplace, rapid feedback.

4. Maintaining correct criterion-recognition of pressures on inspection decisions, organization support system, feedback.

The list can be extended to include redesign of the system for better access and improved inspectability (Drury, 1990c).

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **TASK 1 — INITIATE** | | |
| 1.1 Correct instructions written. | 1.1.1 Incorrect instructions.<br>1.1.2 Incomplete instructions.<br>1.1.3 No instructions available. | Inspector has correct and correctly working equipment, and understands instructions. |
| 1.2 Correct equipment procured. | 1.2.1 Incorrect equipment.<br>1.2.2 Equipment not procured. | |
| 1.3 Inspector gets instructions. | 1.3.1 Fails to get instructions. | |
| 1.4 Inspector reads instructions. | 1.4.1 Fails to read instructions.<br>1.4.2 Partially reads instructions. | |
| 1.5 Inspector understands instructions. | 1.5.1 Fails to understand instructions.<br>1.5.2 Misinterprets instructions.<br>1.5.3 Does not act on instructions. | |
| 1.6 Correct equipment available. | 1.6.1 Correct equipment not available.<br>1.6.2 Equipment is incomplete.<br>1.6.3 Equipment is not working. | |
| 1.7 Inspector gets equipment. | 1.7.1 Gets wrong equipment.<br>1.7.2 Gets incomplete equipment.<br>1.7.3 Gets non-working equipment. | |
| 1.8 Inspector checks/calibrates equipment. | 1.8.1 Fails to check/calibrate.<br>1.8.2 Checks/calibrates incorrectly. | |

**TABLE 3.3 Task and Error Taxonomy for Inspection**

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **TASK 2 — ACCESS** | | |
| 2.1 Locate area to inspect | 2.1.1 Locate wrong aircraft.<br>2.1.2 Locate wrong area on aircraft.<br>2.1.3 Mis-locate boundaries of area. | Inspector with correct equipment at correct inspection site, is ready to begin inspection. |
| 2.2 Area is ready to inspect. | 2.2.1 Cleaning work is not completed.<br>2.2.2 Cleaning work is incorrect.<br>2.2.3 Maintenance access tasks area not completed.<br>2.2.4 Maintenance access tasks are incorrect.<br>2.2.5 Parallel work prevents access.<br>2.2.6 Parallel work impedes inspection. | |
| 2.3 Access area to inspect. | 2.3.1 Access equipment is not available.<br>2.3.2 Incorrect access equipment.<br>2.3.3 Access equipment is poorly designed.<br>2.3.4 Access is not physically possible.<br>2.3.5 Access is discouragingly difficult.<br>2.3.6 Access is dangerous to inspection. | |

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **TASK 3 — SEARCH*** | | |
| 3.1 Move to next lobe. | 3.1.1 Misses parts of access area.<br>3.1.2 Multiple searches of parts.<br>3.1.3 It is too close or far between lobes.<br>3.1.4 Move to non-required area. | All indications located in all access areas. |
| 3.2 Enhance lobe (e.g. illuminate, magnify for vision, use dye penetrant, tap for auditory inspection). | 3.2.1 Enhance wrong area.<br>3.2.2 Enhance area inadequately.<br>3.2.3 Fail to use enhancing equipment. | |
| 3.3 Examine lobe. | 3.3.1 Fail to examine lobe.<br>3.3.2 Examine for too short or long a time.<br>3.3.3 Incorrect depth of examination.<br>3.3.4 Incomplete examination of lobe.<br>3.3.5 Fatigue from a fixed posture. | |
| 3.4 Sense indication in lobe. | 3.4.1 Fail to attend to lobe.<br>3.4.2 Fail to use cues present.<br>3.4.3 Fail to sense indication.<br>3.4.4 Sense wrong indication. | |

***Note**: Search proceeds by successively examining each small area, called here a LOBE, within a single area accessible without performing a new access, called here an ACCESS AREA. When all lobes have been examined in that access area, a new access is performed followed by a new search. The concept of a lobe comes from visual search where it is called a VISUAL LOBE. Here it is generalized to include the area felt by a tactile inspection, the area probed by tapping in an auditory inspection, and the area covered by the probe of an eddy current or ultrasonic device and seen on its screen.

**TABLE 3.3 Task and Error Taxonomy for Inspection**

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **Task 3 (cont'd)** | | |
| 3.5 Match indication against list. | 3.5.1 Match against faults not listed.<br>3.5.2 Fail to match against full list.<br>3.5.3 Incorrect match. | |
| 3.6 Remember matched indication. | 3.6.1 Fail to record matched indication.<br>3.6.2 Forget matched indication. | |
| 3.7 Remember lobe location. | 3.7.1 Fail to record lobe location.<br>3.7.2 Forget lobe location. | |
| 3.8 Remember access area location. | 3.8.1 Fail to record access area location.<br>3.8.2 Forget access area location. | |
| 3.9 Move to next access area. | 3.9.1 Miss parts of area.<br>3.9.2 Multiple searches of parts.<br>3.9.3 Move to non-required area. | |
| **TASK 4 — DECISION** | | |
| 4.1 Interpret indication | 4.1.1 Classify as wrong fault type. | All indications located are correctly classified, correctly labelled as fault or no fault, and actions correctly planned for each indication. |

**TABLE 3.3 Task and Error Taxonomy for Inspection**

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **Task 4 (cont'd)** | | |
| 4.2 Access measuring equipment. | 4.2.1 Choose wrong measurement equipment.<br>4.2.2 Measurement equipment is not available.<br>4.2.3 Measurement equipment is not working.<br>4.2.4 Measurement equipment is not calibrated.<br>4.2.5 Measurement equipment is wrong calibration.<br>4.2.6 Does not use measurement equipment. | |
| 4.3 Access comparison standard. | 4.3.1 Choose wrong comparison standard.<br>4.3.2 Comparison standard is not available.<br>4.3.3 Comparison standard is not correct.<br>4.3.4 Comparison standard is incomplete.<br>4.3.5 Does not use comparison standard. | |
| 4.4 Decide on if it is a fault. | 4.4.1 Type 1 error, false alarm.<br>4.4.2 Type 2 error, missed fault. | |

TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **Task 4 (cont'd)** | | |
| 4.5 Decide on action. | 4.5.1 Choose wrong action.<br>4.5.2 Second opinion if not needed.<br>4.5.3 No second opinion if needed.<br>4.5.4 Call for buy-back when not required.<br>4.5.5 Fail to call for required buy-back. | |
| 4.6 Remember decision/action. | 4.6.1 Forget decision/action.<br>4.6.2 Fail to record decision/action. | |
| **TASK 5 — RESPOND*** | | |
| 5.1 Mark fault on aircraft. | 5.1.1 Fail to mark fault.<br>5.1.2 Mark non-fault.<br>5.1.3 Mark fault in wrong place.<br>5.1.4 Mark fault with wrong tag.<br>5.1.5 Mark fault with wrong marker. | All faults and repair items are correctly recorded. |

*Note: In some contexts, the only record of a fault is in the repair action. Both 5.2 and 5.3 have been included above to indicate that there may be some faults which should be recorded even though no repair action is needed at that inspection period.

**TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)**

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **Task 5 (cont'd)** | | |
| 5.2 Record fault. | 5.2.1 Fail to error fault.<br>5.2.2 Record non-fault.<br>5.2.3 Record fault in wrong place.<br>5.2.4 Record fault incorrectly. | |
| 5.3 Write repair action. | 5.3.1 Fail to write repair action.<br>5.3.2 Write repair action for non-fault.<br>5.3.3 Write repair action for wrong place.<br>5.3.4 Mis-write repair action.<br>5.3.5 Specify buy-back if not needed.<br>5.3.6 Fail to specify needed buy-back. | |
| **TASK 6 — REPAIR** | | |
| 6.1 Repair fault. | 6.1.1 Fail to repair fault.<br>6.1.2 Repair non-fault.<br>6.1.3 Mis-repair fault.<br>6.1.4 Prevent access for buy-back. | All recorded faults correctly repaired and accessible for buy-back inspection. |

**TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)**

| TASK | ERRORS | OUTCOME |
|---|---|---|
| **TASK 7 — BUY-BACK** | | |
| 7.1 Initiate. | 7.1.1 Fail to call inspector.<br>7.1.2 Call inspector when not needed.<br>7.1.3 Inspector fails to initiate, see (1).<br>7.1.4 Initiates buy-back out of sequence.<br>7.1.5 Misreads record of fault. | All repaired items correctly assessed at buy-back, and results recorded correctly. |
| 7.2 Access. | 7.2.1 Inspector fails to access, see (2). | |
| 7.3 Search. | 7.3.1 Inspector fails to locate, see (3). | |
| 7.4 Decision. | 7.4.1 Inspector accepts faulty repair.<br>7.4.2 Inspector rejects good repair.<br>7.4.3 Inspector fails to get second opinion. | |
| 7.5 Respond. | 7.5.1 Fails to record buy-back.<br>7.5.2 Records wrong buy-back.<br>7.5.3 Records buy-back incorrectly. | |

**TABLE 3.3 Task and Error Taxonomy for Inspection (cont'd)**

| STRATEGY | | |
|---|---|---|
| **TASK STEP** | **CHANGING INSPECTOR** | **CHANGING SYSTEM** |
| **Initiate** | - Training in NDI calibration (procedures training) | - Redesign of job cards<br>- Calibration of NDI equipment<br>- Feedforward of expected flaws |
| **Access** | - Training in area location (knowledge and recognition training) | - Better support stands<br>- Better area location system<br>- Location for NDI equipment |
| **Search** | - Training in visual search (cueing, progressive-part) | - Task lighting<br>- Optical aids<br>- Improved NDI templates |
| **Decision** | - Decision training (cueing feedback, understanding of standards) | - Standards at the work poing<br>- Pattern recognition job aids<br>- Improved feedback to inspection |
| **Action** | - Training writing skills | - Improved fault marking<br>- Hands-free fault recording |

**Table 3.5 Potential Stratagies for Improving Inspection**

### 3.4.3 Short-Term Interventions

From all of these ways of generating and classifying interventions, the following can be listed as short-term interventions to overcome stated mismatches. Note that *the two major issues of the information environment and* training design are given more complete treatments later, taken from (Drury 1990a) and Drury and Gramopadhye (1990), respectively.

#### 3.4.3.1 Initiate

##### 3.4.3.1.1 Design of Worksheets

Even within this relatively homogeneous sample of major air carriers, there was considerable variability in Workcards, or Job Cards. Many were now computer-printed, reducing earlier problems of copy legibility, but some were generated by computer systems lacking graphics capabilities. For these, the graphics necessary for location and inspection were attached from other sources, often with *imperfect matching of nomenclature for parts and defects* between workcard and secondary source material. These additional cards were often from microfiche, which has poor copy quality and a shiny surface, making reading on the job difficult. Other cards were all in capitals, a known violation of human factors principles. Still others did not call out particular faults using the latest information on that aircraft type. There were differences in level and depth between different workcard systems, and none attempted to provide layered information, so that those familiar with a particular inspection could use more of a checklist, while back-up information would be available to those who had not performed that particular inspection recently. Some systems did, however, have an integrated "Inspector's Clipboard" which had a place for the workcard, Non-Routine Repair cards and other necessary paperwork, in a package convenient for carrying at the worksite.

Short-term interventions for workcards thus include:

1. Changing the format and font to improve ease of use and legibility.
2. Ensuring that visual material is incorporated into the workcard.
3. Consistent naming of parts, directions, defects, and indications between all documents used by inspectors.
4. Multi-level workcard systems, usable by inspectors with different levels of immediate familiarity with the worksheet content.
5. A better physical integration between the workcard and the inspector's other documents and tools needed at the worksite.

#### 3.4.3.1.2 NDI Equipment Calibration

The calibration procedures used for NDI equipment involve a human/machine interface on the equipment, one or more calibration standards, and a knowledgeable inspector. Potential mismatches were seen in all three areas. The following are recommended in the short term:

1. Better labelling and control of all calibration standards, as is common in manufacturing industry. An inspector must know which standard is being used and be assured that the standard is still valid. Procedures are available for standards control: most (but not all) inspection systems in the sample appeared to follow them.

2. Improved human/NDI instrument interface designs standard texts on human factors (e.g. Salvendy, 1987) have considerable information on interface design to reduce error: this information needs to be used. As NDI equipment incorporates more computer functions, the data on human-computer interaction (e.g. Helander, 1988) becomes crucial to design. Any design improvements in the human interface will also benefit the Search and Decision tasks.

3. Design the NDI interface for multiple levels of inspector familiarity. In many organizations, NDI is not a full-time job, so that many inspectors have considerable time periods between repetitions of a particular NDI procedure. They obviously require a different level of guidance from the interface than inspectors who perform the same calibration each day. Multiple levels of user need to be considered, as at present there is a marked tendency for the inspector to rely on knowledge of other inspectors to perform the calibration.

### 3.4.3.2 Access

#### 3.4.3.2.1 Provide better support stands

Custom-made stands for each area of each aircraft type are expensive and difficult to store when not in use, but they do provide a security for the inspector, and optimum accessibility for each task. In large facilities dedicated to a homogeneous fleet, such stands are almost always provided, but there are exceptions. Cherrypickers are used for some surfaces, despite their control difficulties (poor control/display relationships) and their unsteady working platforms. Scaffolding and stairs are used (at times) which would not be allowed by safety departments in most manufacturing industries. Without adequate support stands, access is jeopardized and pressures are placed on the inspector to minimize the time spent inspecting. Both can directly cause inspection errors. For each worksheet, there should be an optimally-designed support stand specified and available.

#### 3.4.3.2.2 Better area location system

Much time is wasted, and occasionally errors are caused, because the inspector cannot positively locate parts of the area to be inspected. Some task cards have no diagrams, and rely on written instructions: others have diagrams that can mislead the inspector when searching for the area to be inspected. The inspector needs clear instructions to reach the area, and clear confirmation that the correct area has indeed been reached. These can be provided simply in the worksheets, but for aircraft which are always precisely located in the maintenance hangar, more elaborate electronic or optical location systems are possible.

#### 3.4.3.2.3 Better locations for NDI equipment

When the inspector needs to use NDI equipment, there is often no convenient place to put the equipment during the inspection process. The inspector must frequently place the equipment (with its associated display) out of convenient sight lines. This makes it particularly difficult to perform the inspection and simultaneously read the display: errors are to be expected in such situations. Design of stands (*Section 3.4.3.2.1* above) should include provision for location of NDI equipment as part of the workstand.

### 3.4.3.3 Search

#### 3.4.3.3.1 Improved lighting

The factors affecting the conspicuity of a defect are defect size, defect/background contrast, and lighting intensity. The latter two are functions of the lighting and can be improved without changing the aircraft design. Defect/background contrast is a function of the angles between the inspector's eye, the defect, and any light sources. In general, an adequate level of illumination needs to be provided at the inspection point, with levels of 500–1000 lux being typically recommended. However, the distribution of the light is at least as important as its intensity. For example, glare drastically reduces visual performance, and can be caused by any objects or areas in the visual field higher in luminance than the area immediately surrounding the defect. Thus, open hangar doors, roof lights, or even reflections off the worksheet can cause glare. Of particular concern is that in inspecting partially-hidden

areas (e.g. inside door panels), the lighting used to illuminate the defect may cause glare from surrounding surfaces. Carefully designed combinations of general area lighting, portable area task lighting, and localized spotlighting need to be produced. At least as an interim measure, the flashlights used by inspectors need to be standardized within an organization, and training is needed in how to use the flashlight correctly.

#### 3.4.3.3.2 Optical enhancement

Any device which increases the conspicuity of the defect can be classified as an optical enhancement. Thus, dye penetrant and magnetic particular inspection techniques fall under this heading. However, it is now possible to use the control inherent in video cameras and monitors to enhance luminance contrast, and to optimize color contrast. With a computer between the camera and the monitor, it should be routinely possible in the future to use false colors in the image presented to the inspector to increase defect conspicuity. Borescopes with video monitors are currently available to begin this process, but research will be needed to optimize such systems for defect detection.

#### 3.4.3.3.3 Improved NDI templates

With NDI techniques such as Eddy Current or Ultrasonics inspection, location of a probe on the inspected surface is critical. At present, some use is made of what would be termed jigs or fixtures in manufacturing industry to aid this accurate positioning process. An example is the use of circular hole templates to guide the Eddy Current probe ground, the heads of rivets in lap splice inspection. With such a device, the need for the inspector to perform an accurate control task at the same time as attending to the display is removed, with an attendant reduction in the opportunity for error. Note that the template should not require a second hand to keep it in place, as the inspector may not be able to maintain balance or reset the equipment if both hands are occupied.

### 3.4.3.4 Decision

#### 3.4.3.4.1 Standards at the work point

It has been known for many years that if comparison standards are available at the work point, more accurate inspection will result. Yet in many cases such standards are not available to the aircraft inspector. If the maximum allowable depth of a wear mark is given as 0.010 inches, there is neither a convenient way to measure this, nor a readily available standard for comparison. Other examples are play in bearings and cable runs, areas of corrosion, or looseness of rivets. All are considered to be "judgement calls" by the inspector, but simple job aids, perhaps as part of the worksheet, or standard inspection tools, would remove a source of uncertainty. Leaving standards to unaided human memory may be expeditious, but it is also unreliable.

#### 3.4.3.4.2 Pattern-recognition job aids

Wherever a complex pattern must be recognized by the inspector, such as in the appearance of corrosion on a painted surface, or the shape of an oscilloscope trace in NDI, it is possible to provide job aids which will increase the inspector's ability to discriminate a true defect from visual noise. For visual inspection, these job aids can be simply an extension of *Section 3.4.3.4.1* standards at the work point. Visually-presented standards were found to be very effective in the notoriously difficult task of judging solder joints in electronic assembly (Chaney and Teel, 1969). For NDI equipment, some pattern-recognition capability is now being incorporated into the software, but more can be done. More flexibility is required, the interface with the user should be improved, and the allocation of final decision between human and machine should be made more flexible.

### 3.4.3.5 Respond

#### 3.4.3.5.1 Improved defect indicating system

Even as simple a task as marking the aircraft to show the point of repair needs to be improved. Methods observed have included "chinagraph" pencils in various colors, soft pens, and stick-on paper tags. Marking systems can be difficult to remove completely when the repair is completed, leading to unsightly marks which can impair the confidence of the travelling public. Tags can also be left on the aircraft, or leave behind a residue which impairs the finish. One site had moved to a marker system so pale that it was difficult for the repair personnel to see. The requirements for a marking system are relatively simple to write: a wholly satisfactory system now needs to be devised to meet these requirements so that an error-free communication from the inspector to the repair personnel can result.

#### 3.4.3.5.2 Hands-free defect recording

When the inspector discovers a defect, both hands are typically occupied, and the Non-routine repairs (NRR) forms may not be close enough to use. The inspector will often "remember" one or more defects until there is a convenient time to record them. This is a potentially

error-prone procedure. Not all of the data on the NRR form needs to be recorded at this time (e.g. inspector and aircraft identifications, date), but some temporary information storage is required to aid human memory. Some inspectors do record each defect as it is found, accepting the inconvenience of leaving and re-accessing the inspection point as a necessary step. However, there is no guarantee that search will resume at the correct point following recording. Others use miniature tape recorders to provide a voice-input information storage. The recorder (e.g. dictation machine) is often taped to the flashlight, or clipped to the inspector's clothing. Tapes are transcribed later onto NRR forms. Although errors of transcription are possible, the system appears to work well. Improvements would be voice-actuated recorders built into headsets for true hands-free recording, and training in a standardized procedure for what to record. A review of all such systems is needed to determine how best to meet operational requirements.

#### 3.4.3.5.3 Prevention of "serial responding"

In some systems, the inspectors will record a minimum of information at the inspection site (see *Section 3.4.3.5.2* above), and complete the data recording as part of the "paperwork" at a later time. This may involve filling in all of the "constant" parts of the NRR forms (e.g. aircraft ID), and signing/stamping each task step on the worksheet. There is a tendency to wait until all paperwork is completed before signing/stamping the whole sequence of tasks. Such "serial responding" can lead to inadvertent signing-off on a task step which was not, in fact, completed. While such errors are presumably rare, the written record is the only permanent recording of inspection/repair information, and is relied upon by regulatory bodies. There are Quality Assurance checks of the paper record against the condition of the aircraft, but only on a sampling basis, and only if the indication is visible, i.e. a repair or very obvious defect. While it is difficult to provide a perfect procedure to prevent "serial response" it should be noted as a possible error mode and improved systems investigated.

### 3.4.3.6 Repair

(Repair was not considered as part of this study.)

### 3.4.3.7 Buy-Back Inspection

#### 3.4.3.7.1 Integrated inspect/repair/buy-back system

Final disposition of a defect depends critically upon the communication between the original inspector, the repairing technician(s), and the buy-back inspector. In most current systems it is entirely possible for different inspectors to be involved in the initial inspection, in consultation at critical points in repair, and in final buy-back. The only communications between these inspectors are those between the initial inspector and the repair technician, i.e., the NRR form and any markings on the aircraft. Because of this, there are opportunities for error at each interaction in the process. Hence, these two forms of communication need to be highly error-resistant, or lines of verbal communication between the participants need to be opened. In other countries' systems, e.g. United Kingdom, one inspector remains with the repair team throughout all stages, thus reducing these problems. However, the potential for multiple independent assessment is lost with such a system. The solution to this integration problem is not simple, but many steps to improve participant communication can be taken. Examples are communication training, standard practices for writing and marking, and even the use of voice or video to supplement written communications.

## 3.4.4 Long-Term Interventions

While many of the short-term interventions listed in *Section 3.4.2* have some long-term implications, four major areas are recommended for more detailed study:

### 3.4.4.1 Error Control

In order to control errors in the aircraft inspection process, it is necessary to be able to define these errors accurately and unambiguously. With properly defined errors, they can be identified, recorded, collected and analyzed, as the first step towards control. Systems safety emphasizes such error identification and control for all complex systems, including civil aircraft. There is a need to apply the same techniques to the human/machine system of aviation inspection, the necessary first step in any program of maintenance to ensure safety of the travelling public.

A first step has been taken towards a classification system for inspection (and to a lesser extent, repair) errors in the error taxonomy presented here as *Table 3.3*. For each subtask, the logically-possible errors are listed to form an error

taxonomy. Each error is unique, but the same effects may be caused by several different errors. Thus, a fault may be missed because of failure to calibrate equipment, failure to reach the correct inspection point, failure to examine the area and so on. This concept needs to be refined and expanded if it is to form the basis for an error control system. For example, in *Table 3.3*, Visual Inspection (VI) and Non-Destructive Inspection (NDI) are covered by the same task and error taxonomy. This has meant expanding some of the concepts, such as the visual lobe in VI, to cover other NDI situations. In this way, separate error taxonomies are not required for VI and NDI, although in practice it may be easier to produce separate but related taxonomies, and merge the data from each at the analysis stage.

A second expansion is also needed. Errors in *Table 3.3* are classified by their immediate causes (e.g. "1 6 1 Correct Equipment not available"). However, this does not lead to more distant causes. Why was correct equipment not available? Was it poor scheduling or was the equipment being repaired? For more obviously human functions, such as "1.5 Inspector understands instructions", the failure modes (errors) need further classification as to **why** instructions were not understood, misinterpreted, or not acted upon. Were the instructions illegible, was the illumination poor, was confusing language used, etc.? A matrix rather than the long list of *Table 3.3* is eventually required if we are to proceed from the necessary first step of counting errors to the ultimate goal of selecting interventions to control or eliminate these errors.

### 3.4.4.2 Integrated Information Environment

While many of the interventions listed under *Section 3.4.3* were concerned with aspects of the information flow between the inspector and the rest of the inspection/repair system, there is an urgent need to devise information systems which are integrated rather than piecemeal. This section, based on Drury (1990a), is aimed at integration. A unified view of the inspection process as a closed-loop control system will be used to introduce some of the relevant inspection/information literature, and to demonstrate inspection needs at each step in the inspection task.

Any system involving a human is typically closed loop (e.g. Sheridan and Ferrell, 1977). Obvious examples are in flying an aircraft or driving a car, but the concept applies equally to inspection tasks. As shown in *Figure 3.4*, the human in the task receives some instruction, or command input to use systems terminology. The operator and any associated machinery transform this command input into a system output. To ensure stable performance, the system output is fed back to the input side of the system, where it is compared against the command input. If there is any difference (command minus output) the system responds to reduce this difference to zero. A closed-loop model of the inspector (*Figure 3.4*) can be applied to the generic task description of inspection (*Table 3.1*) to locate and evaluate the sources of input (command) and output (feedback) information.

#### 3.4.4.2.1 Information in Inspection

While it is not obvious from *Figure 3.4*, the command input may be complex, and include both what needs to be accomplished and help in the accomplishment; i.e. directive and feedforward information. For example, a workcard may contain "detailed inspection of upper lap joint" in a specified area (directive) and "check particularly for corrosion between stations 2800 and 2840" (feedforward). Thus, there are really three potential parts to the information environment: directive information, feedforward information and feedback information. All are known to

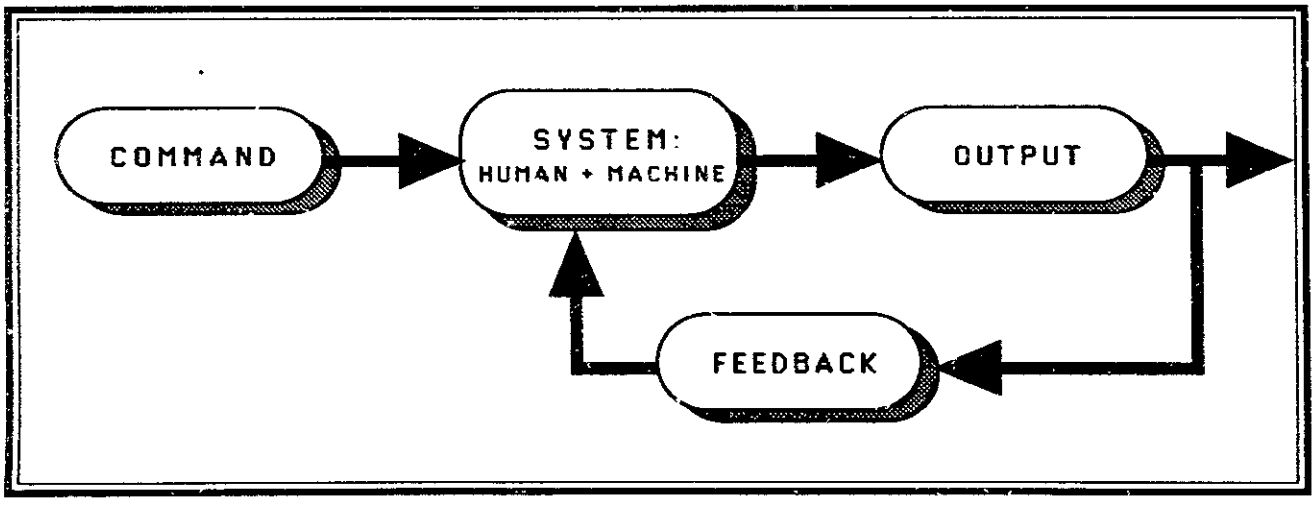


**Figure 3.4 Closed-Loop Control**

have a large effect on manufacturing inspection performance.

***Directive Information*** involves the presentation of information in a form suitable for the human, the basis of good human factors. An example from inspection is the work of Chaney and Teel (1967) who used simplified machinery drawings as an aid to inspectors. These drawings, of machined metal parts, were optimized for inspection rather than manufacture, with dimensions and tolerances in the correct placement and format, and with similar characteristics grouped together to encourage systematic inspection. Compared to a control group with the original drawings, inspectors using the optimized drawings found 42% more true errors in a test-batch.

***Feedforward Information*** can consist of two parts: telling the inspector what defects are expected and providing the probability of the defects. Because there are typically a large number of potential defects, any information made available to the inspector is valuable in focussing the search subtask in particular. Many investigators (e.g. Gallwey and Drury, 1985) have found that looking for more than one type of defect simultaneously can degrade detection performance, so that focussing on likely defects can be expected to result in more detections. Drury and Sheehan (1969) gave feedforward information on fault type to six inspectors of steel hooks. Missed defects were reduced from 17% to 7.5%, while false alarms were simultaneously reduced from 5.5% to 1.5%. Information to the inspectors on the probabilities of a defect being present has not led to such clear-cut results (e.g. Embrey, 1975), and indeed a recent experiment (McKernan, 1989) showed that probability information was only useful to inspectors for the most difficult-to-detect defects.

***Feedback Information*** has had consistent positive results in all fields of human performance (e.g. Smith and Smith, 1987), provided it is given in a timely and appropriate manner. Wiener (1975) has reviewed feedback in training for inspection and vigilance, and found it universally beneficial. Outside of the training context, feedback of results has had a powerful effect on the inspector's ability to detect defects. Embry's laboratory studies (1975) showed a large effect, but so did Gillies (1975) in a study in the glass industry where missed defects were reduced 20% when feedback was implemented. Drury and Addison (1973), another glass industry study lasting almost a year showed a reduction in missed defects from 15% to 8.8% after rapid feedback was introduced. More recently, Micalizzi and Goldberg (1989) have shown that feedback improved the discriminability of defects in a task requiring judgment of defect severity.

With the background of the effectiveness in manipulating the information environment, each task in inspection will be considered in turn.

**Task 1:** ***Initiate*** Here, the command information predominates. The workcard gives the location type of inspection to be performed, and at times also feedforward information of use in the Search and Decision phases. Typically, however, this information is embedded in a mass of other necessary, but not immediately useful, information. Often the information contains attached pages, for example with diagrams of parts to be inspected. While laser printers making a new copy for each workcard have helped diagram quality, inspectors still find some difficulties in interpreting this information. Supplemental (feedforward) information is available in manufacturers manuals, FAA communications, and company memos/messages, but these sources are typically not used at inspection time. This can place a burden on the inspector's memory, suggesting an integrated system is appropriate.

Feedback from the initiate task is obvious in many cases because it comes from Task 2 - Access. An exception is feedback for NDI calibration, which must be provided during the calibration process or there will be no assurance that Search and Decision can be performed correctly.

**Task 2:** ***Access*** In order to access an area of an aircraft the area must first be opened and cleaned, neither of which are under the control of the inspector. Thus, scheduling information required for access is the assurance that the area is ready to inspect. Work scheduling systems typically assure this, but wrong information does get to the inspector at times, giving time loss and frustration. It is at Access that confusions in location from Task 1 should become apparent. Improved information systems for locating an area on an aircraft unequivocally are needed, and need to be integrated with other information system components.

It should be noted that feedback on access can be given in any system by incorporating unique landmarks so that the inspector can be assured that the correct area has been reached.

**Task 3:** ***Search.*** It is in the tasks of Search and Decision-making that information has the largest potential impact. In visual search the inspector must closely examine each area for a list of potential faults. Which areas are searched is a matter of prior information—either from training, experience or the workcard. The relative effort expended in each area is similarly a matter of both directive and feedforward information. If the area of main effort is reduced, the inspector will be able to give more thorough coverage in the time available. An information system can be used to overcome the prior biases of training and experience, if indeed these biases need to be overridden in

a particular instance. The fault list which the inspector uses to define the targets of search comes from the same three sources. This fault list must be realistic, and consistent. In many industrial inspection tasks, developing a *consistent list and definition of fault* names to be used by all involved is a major contribution to improving inspection performance (e.g. Drury and Sinclair, 1983). Faults often go by different names to inspection personnel, manufacturers, and writers of worksheets, causing misdirected search and subsequent errors in decision and responding. Probabilities of the different targets or defects are rarely presented. Again, system integration can help.

Feedback of search success only comes from Task 4 - Decision Making, and only then if an indication was found. If the indication was missed, then feedback awaits the next inspection or audit of that area, presumably before the fault affects safe operation. Note that if an indication is found, feedback is immediate, but if missed, feedback is much delayed. Delayed feedback is often no better than no feedback.

Task 4: ***Decision Making***. The information required to make a correct decision on an indication is in the form of a standard against which to compare the indication. Such standards at the working point can be extremely effective, for example McKennel (1958) found that they reduced the average error of a trained inspector to 64% of its magnitude without such standards. The need for these comparison standards has been noted earlier (***Section 3.4.3.4.1***), *but the recommendation here is to incorporate* such a standard within a unified system.

Feedback to the inspector in the Decision Making task is not rapid or obvious. If an inspector marks a defect (and writes it up), it will be repaired and go to a buy-back inspection. Currently (***Section 3.4.3.5.3***), because of scheduling constraints and shiftwork, it will rarely be the same inspector who gets to re-inspect that repair. Thus, *an opportunity for feedback is being missed. In addition,* some repairs will destroy the defect without confirming it, e.g. drilling an oversize hole to take a larger rivet when Eddy Current inspection has indicated a small crack in the skin by that rivet.

Task 5: ***Response***. The physical response made by the inspector represents the output information from the inspector to the system. It is as much a part of the information environment as input and feedback. As noted earlier (***Section 3.4.3.5.2***), recording currently places a memory load on the inspector, or means that interruptions occur in the inspection job. Other interruptions come from scheduling (e.g. an extra inspector is required on another job), from unscheduled events such as more cleaning being required before an inspector can complete a workcard, and from maintenance operators interrupting the inspector to buy-back any repairs which have been completed.

Feedback as a result of the Response is rare. Only a small sample of work is audited, and any feedback from this is typically negative rather than positive. If a defect is reported, then feedback to the inspector who reported it can be arranged. However if the inspector does not report the defect (either search failure or a wrong decision) only an audit or subsequent inspection will give feedback.

For many defect types, a defect may only be an indication, not required to be reported, and hence not reported. *Unfortunately, the fact that the inspector found it is then* lost forever, as the chance of the same inspector being assigned to the same part of the same aircraft on subsequent checks is small. Capture of some of these indications may be a way to provide more detailed feedforward for subsequent inspections and once more, an integrated system will be required.

Task 6: ***Repair***. From the inspector's point of view, *information is flowing outward at this task, i.e. to the* repair technician. Potential difficulties of the recording and marking system for other participants have already been noted (***Section 3.4.3.7.1***).

Task 7: ***Buy-Back***. Both command and feedforward information to the buy-back inspector come from the NRR form and any markings in the aircraft. Feedback to the buy-back inspector is, like that to the original inspector *in Task 5 only, from audit or subsequent inspection.*

In all of the above tasks, information needs can be seen, and be seen to be met less than perfectly by current systems. Although ***Section 3.4.3*** provides suggestions for specific improvements, the opportunity needs to be taken to devise more integrated solutions. The coming of powerful, but portable, computers with networking capabilities, can aid this systems integration. Already prototype *systems exist for aiding fault diagnosis in aircraft systems* (Johnson, 1990), so that the practicality of aiding the airframe inspector is real. The challenge is to understand what information needs to be given, and captured, by such a system, and to understand how information technology can be applied to fault detection rather than fault diagnosis.

Research is needed to provide more detail of how much of each type of information (command, feedforward, feedback) needs to be provided for optimum inspection performance in each task step. In parallel, the technology of information capture, interface design and hardware functioning needs more research to make it applicable to the specific needs of aircraft inspection.

### 3.4.4.3 Training Design and Implementation

An obvious intervention in improving inspection performance is to call for improvements in training. As will be shown, training has a powerful effect on inspection performance, even when applied to experienced personnel. Also, a basic Task Description of inspection, the first step in any training scheme design, is available (*Table 3.1*). From this task description, it is seen that both manual/procedural tasks (Initiate, Access, Respond) and cognitive tasks (Search, Decision) are represented. While training for procedural tasks is relatively straightforward (e.g. Johnson, 1981), most of the opportunities for error occur in the cognitive aspects of inspection (Drury, 1984).

The current state of aircraft inspection training is that much emphasis is placed on both procedural aspects of the task (e.g. how to set up for an X-ray inspection of an aileron), and on diagnosis of the causes of problems from symptoms (e.g. trouble shooting an elevator control circuit). However, the inspectors we have studied in our task analysis work have been less well-trained in the cognitive aspects of visual inspection itself. How do you search an array of rivets—by columns, by rows, by blocks? How do you judge whether corrosion is severe enough to be reported?

Most inspectors receive their training in these cognitive aspects on the job, by working with an experienced inspector. This is highly realistic, but uncontrolled. Experience in training inspectors in manufacturing industry (Kleiner, 1983) has shown that a more controlled training environment produces better inspectors. If training is entirely on-the-job, then two of the main determinants of the training program, what the trainee sees and what feedback is given, are a matter of chance, i.e. of which particular defects are present in the particular aircraft inspected. There is a large difference between training and practice. *Figure 3.5* (Parker and Perry, 1982) shows how the effective discriminability of a target changed between two periods of practice, compared with periods before and after training. There was a highly significant improvement with training but not with practice. The challenge is to apply what is known about human learning of cognitive tasks so as to maximize the effectiveness of training for the aviation inspector.

A basic principle of training is to determine whether the activity is indeed trainable. Studies of visual search (Parkes, 1967; Bloomfield, 1975) have shown that both speed and accuracy improve with controlled practice. Embrey (1979) has shown that for decision-making, discriminability can be trained. Thus, both cognitive factors (Search, Decision) can be trained.

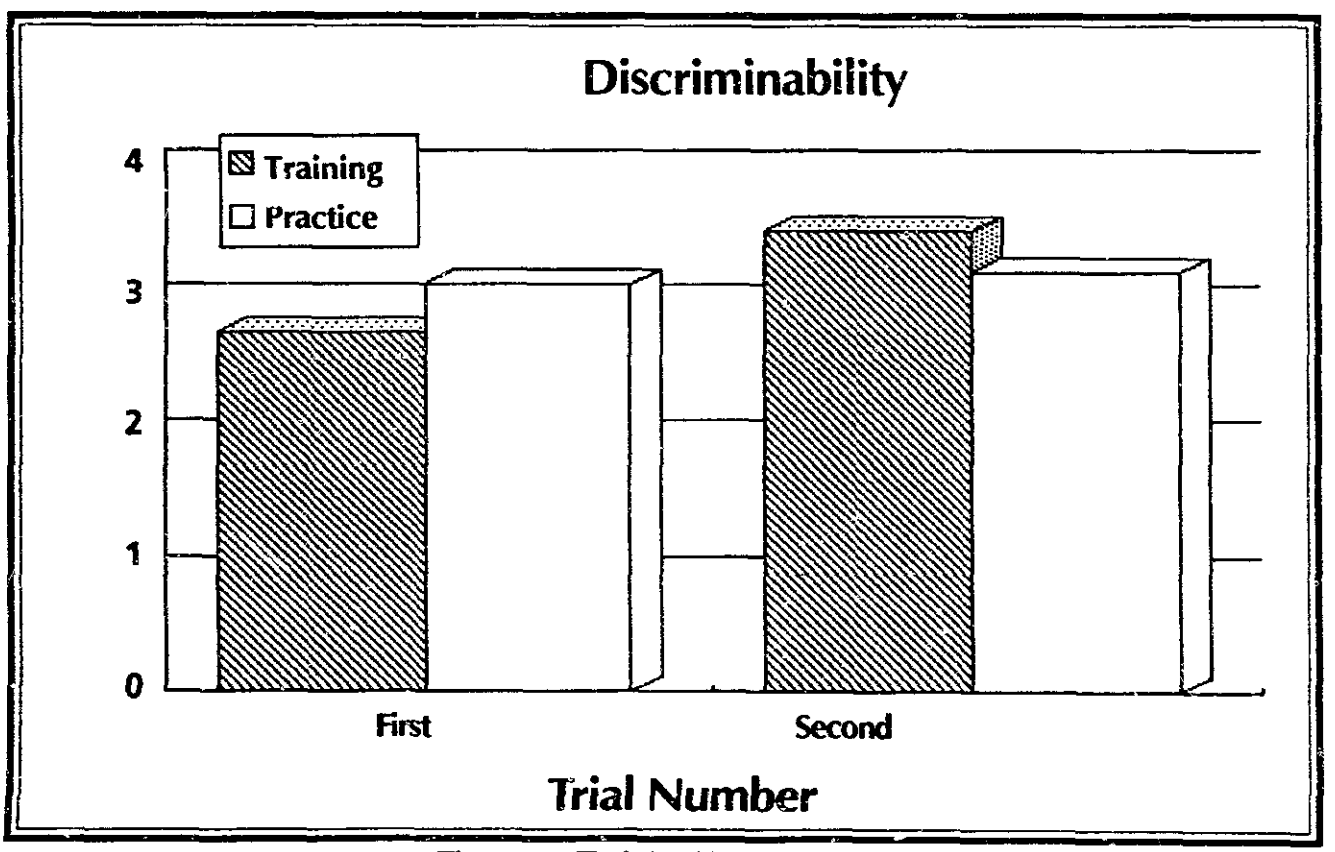


**Figure 3.5 Training Versus Practice**

The principles on which training should be based are relatively well known, and can be summarized (Goldstein, 1974):

1. Develop and maintain attention, i.e. focus the trainee.
2. Present expected outcomes, i.e. present objectives.
3. Stimulate recall of prerequisites, i.e. get ready to learn.
4. Present underlying stimuli, i.e. form prototype patterns.
5. Guide the trainee, i.e. build up skills progressively.
6. Give knowledge of results, i.e. rapid feedback.
7. Appraise performance, i.e. test against objectives.
8. Aim for transfer, i.e. help trainee generalize.
9. Aim for retention, i.e. provide regular practice after training.

Control is important, e.g. 4, 5 and 6 above all require the trainee to receive a carefully-tailored experience to obtain maximum benefit. Some particular ways in which these principles have been applied are:

1. **Cueing.** It is often necessary to cue the trainee as to what to perceive. When a novice first tries to find defective vanes in an engine, the indications are not obvious. The trainee must know what to look for in each X-ray. Many organizations have files of X-ray film with known indications for just this purpose. Specific techniques within cueing include match-to-sample and delayed-match-to-sample.

2. **Feedback.** The trainee needs rapid, accurate feedback in order to correctly classify a defect or to know whether a search pattern was effective. However, when training is completed, feedback is rare. The training program should start with rapid, frequent feedback, and gradually delay this until the "working" level is reached. More feedback beyond the end of the training program will help to keep the inspector calibrated (e.g. Drury, 1990a).

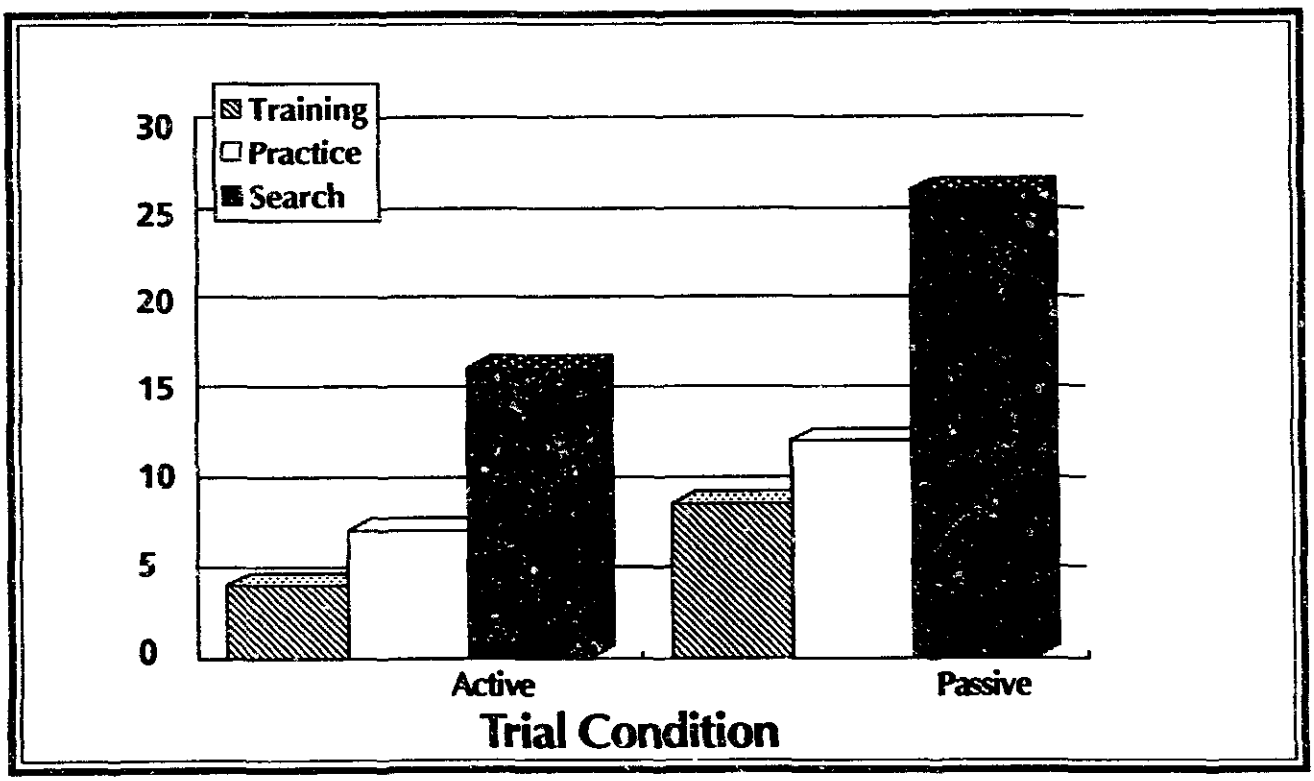


**Figure 3.6 Training Condition**

3. **Active Training.** In order to keep the trainee involved and aid in internalizing the material, an active approach is preferred (Belbin and Downs, 1964). In this method, the trainee makes an active response after each new piece of material is present, e.g. naming a fault, waiting a discrepancy card. Czaja and Drury (1981) showed that an active training program was much more effective than the equipment passive program (*Figure 3.6*) for a complex inspection task.

4. **Progressive Part.** A standard methodology in industrial skills training (e.g. Salvendy and Seymour, 1973) is to teach parts of the job to criterion, and then successively larger sequences of parts. Thus, if four task elements were $E_1$, $E_2$, $E_3$ and $E_4$ we would have

   - Train $E_1$, $E_2$, $E_3E_4$ separately to criterion.
   - Train $E_1$ and $E_2$, $E_3$ and $E_4$ to criterion.
   - Train $E_1$ and $E_2$ and $E_3$, $E_2$ and $E_3$ and $E_4$ to criterion.
   - Train whole task $E_1$ and $E_2$ and $E_3$ and $E_4$ to criterion.

   This technique enables the trainee to understand task elements separately and also the links between them which represent a higher level of skill. Czaja and Drury (1981) and Kleiner (1983) used progressive part training very effectively.

5. **Develop Schema.** The trainee must eventually be able to generalize the training experience to new situations. For example, to train for every possible site and extent of corrosion is clearly impossible, so that the trainee must be able to detect and classify corrosion wherever it occurs. Here, the trainee will have developed a "schema" for corrosion which will allow the correct response to be made in novel situations which are recognizable instances of the schema. The key to development of schema is to expose the trainee to controlled variability in training (e.g. Kleiner and Catalano, 1983).

Not all of these techniques are appropriate to all aspects of training aircraft inspectors, but there are some industrial examples of their use, which can lead to recommendations for aircraft inspection training.

#### 3.4.4.3.1 Examples of Inspection Training in Manufacturing

*Table 3.6*, modified from Czaja and Drury (1981), shows the results achieved by industrial users of the training principles given above. In each case, the inspectors were experienced, but the results from new training programs were dramatic. To provide a flavor of one of these successful programs, the final one by Kleiner and Drury will be illustrated. The company-manufactured precision roller bearings for aircraft, and the training scheme was aimed at improving the performance of the inspection function for the rollers. All inspectors were experienced, from 2 to 14 years, but measurements of performance (Drury and Sinclair, 1983) showed much room for improvement. Based on a detailed Task Analysis, a two-day training program was developed. Inspectors were taught using a task card-based system. Each card had a color-coded task section.

- Naming of defects (flaws)
- Naming of parts (surfaces)
- Handling methods (handling)
- Visual search (search)
- Decision making (standards, decision making)
- Process interface.

For each section, there were a progressive set of cards with information, possible physical examples or test procedures, and a sequence indication. Each card required an active response.

This training program was evaluated in two ways. First, two new recruits were able to achieve perfect scores on the test batch at the completion of the program. Second, the quality of feedback from inspection to manufacturing increased so much that scrap was halved between the six months before the training and the six months after. The whole program was replicated for the inner and outer races of the bearings, entirely by company personnel using the roller training program as an example.

Such a training program in the cognitive skills underlying fault detection is needed for aircraft inspectors. Drury and Gramopadhye (1990) show how it can be applied to one aircraft inspection task, but a more complete design is needed if an impact is to be made. It is recommended that, in addition to the training in fault diagnosis in avionics systems being undertaken by Johnson (1990), more effort be made to use the task analysis data already collected to devise improved training programs for airframe inspectors using the above principles. The training programs for the cognitive and manual skills of fault detection then need to

| INVESTIGATORS | TRAINING TECHNIQUE | TYPE OF TASK | RESULTS |
|---|---|---|---|
| Tiffin, J. and Rodgers, H.B. (1941) | Knowledge of results (K of R)and training sessions which included lectures and demonstrations | Inspection of tin plates | General improvements in inspection performance; greater detection of faults |
| Evans (1951) | 30 min class instruction; 11 tests with K of R over 2 weeks | Micrometer inspection of blocks | 50% reduction in average error, but no effect on retention |
| Martineck, H. and Sadacca, R. (1965) | Knowledge of results using and error key | Photointerpretation | Decrease in errors of commission |
| Chaney, F.B. and Teel, K. S. (1967) | Four, 1-hr sessions which included lectures, demonstrations, and K of R from a question and answer period | Inspection of machine parts | Training resulted in a 32% increase in defects detected |
| Cockrell, J. T. and Sadacca, R. (1971) | Knowledge of results and group discussion | Photointerpretation | Significant improvement in inspection performance and a decrease in false alarms |
| Parker, G. C. and Perry G. (1972) | Demonstrations, use of photographs simulating items and faults, examples of faulty items, practice with K of R | Inspection of glass bowls | 50% increase in faulty detection, 50% increase in false rejections |
| Duncan, K. D. and Gray, M. J. (1975) | Gradual approach to the task (diagnosis of faults then verification) using programmed instruction | Fault detection in a petroleum refinery process | Training resulted in an increase in faults detected, decrease in detection time, and decrease in false rejection |
| Houghton, S. (1982) | Product knowledge, standards, search training, practice with K of R, progressive part | Solder joint, inspection | Efficiency up from 33-67% to 89-97% |
| Kleiner (1983) | Progressive part, cueing, K of R, active | Aircraft bearing inspection | Rest error reduced to zero, 50% scrap reduction |

**TABLE 3.6 Summary Table of Practical Applications of Inspector Training Programs**

be evaluated to demonstrate their effectiveness, as was done for the studies in Table 6. From these demonstrations, a standard methodology needs to be developed so that aircraft repair sites can apply the same principles on a routine basis to all existing and new inspection tasks.

### 3.4.4.4 Selection/Placement Procedures

Throughout manufacturing industry, a major emphasis has traditionally been placed by management on finding the right person for the right job. Aircraft inspection appears to be no exception. If there are individual differences in performance, then it appears reasonable to select initially those applicants who have a higher probability of achieving high job performance, and placing individuals throughout their career into jobs which in some way match their abilities. Unfortunately, the evidence in inspection tasks does not support this common sense approach at all strongly. A major review by Wiener (1975) concluded that emphasis on training and job/equipment design would yield much higher benefits than pursuing the search for good selection/placement tests. For the specific job of aircraft inspection, a study is needed to make a definitive decision, so that resources can be applied to devising such tests, or the whole concept can be put aside.

Wiener raised the issue of test validity. If the inspector's task is to detect true defects, while ignoring non-defects, then any potential tests should correlate with these measures, rather than with less-related measures such as supervisor ratings. Harris and Chaney (1969) devised a well-validated selection test for electronic inspectors, using the criteria of detection ability to establish validity. However, the test was found to be not valid for mechanical inspectors. A large study of selection tests for inspectors in general (Gallwey, 1983) showed that general tests such as intelligence or cognitive style were not strongly correlated with performance. A simplified version of the actual inspection task was the only selection device to show reasonable correlations with performance. Further study by Wang and Drury (1989) found that using a task analytic approach allowed tests of somewhat higher validity to be chosen, but the power of such tests to discriminate between successful and unsuccessful inspectors was not high.

Analysis of the same data (Drury and Wang, 1986) determined that inspection performance was highly task-specific. Good inspectors on one inspection task may be poor on other tasks. This fact would explain why Harris and Chaney's test only worked for the electronic inspectors for whom it was originally designed.

Aircraft inspection tasks are diverse, as was found clearly in the current study. They range from visual detection of many discrete defects, though kinesthetic detection of play in bearings or cables, to tactile inspection for loose rivets. NDI tasks represent another spectrum of required inspection skills. If inspection ability is indeed task specific, the prospects for a single "inspection test" are not good. However, it is worth recommending a definitive study of individual differences in aircraft inspection because the payoff for establishing a reliable and valid inspection test would be large. This recommendation has thus a low probability of success but a high value if it does succeed, and on balance is probably worth performing. It should have the lowest priority of the four recommended long-term studies.

## 3.5 CONCLUSIONS

The work reported here represents the results of the first year of a process designed to use the known results of human factors in manufacturing inspection to aid in improving the reliability of aircraft inspection. As such, it has concentrated on detailed observation of the current aircraft inspection system, and the analysis of that system in terms of models found useful in improving manufacturing inspection. The sample was restricted initially to major national carriers, and all methodology had to be devised specially for aircraft inspection by analogy. Despite these inevitable limitations of any starting endeavor, solid conclusions can be drawn.

1. Task Analysis of aircraft inspection is possible, and has proven useful in locating human/system mismatches which can cause inspection errors. The principles and models derived from human factors in manufacturing inspection have been readily adapted to aircraft inspection. This effort needs to continue with a more diverse sample.
2. A set of short-term and long-term interventions has been generated, to guide both relatively rapid implementation and the search for new data and techniques (Sections 4.3 and 4.4). Implementation can only be achieved by the organizations whose mission is aircraft inspection and maintenance. The research team and the FAA should work closely with these organizations both to implement changes, and to measure the effectiveness of these changes.

3. A firm conclusion must be that the current system is good. Major improvements have been made over the years (e.g. NDI equipment), and all participants encountered during this study have shown a keen commitment to system safety. The improvements which now need to be made are not always obvious or easy: if they were they would probably already have been made. Recommended improvements are the result of bringing new expertise (human factors) to bear on an already error-resistant system.

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## APPENDIX A

The following is a list of papers written for and presented with Federal Aviation Administration/Galaxy Scientific Corporation during the first year of the contract #891014SC03:

1. Drury, C.G., 1989. The Information Environment in Aircraft Inspection, In *Proceedings of* the Second International Conference on Human Factors in Ageing Aircraft, Biotechnology, Inc. Falls Church, Virginia.
2. Drury, C.G. and Gramopadhye, A., 1990. Training for Visual Inspection, In *Proceedings of* the Third Federal Aviation Administration Meeting on Human Factors in Aircraft *Maintenance and Inspection: Training Issues.* Atlantic City, New Jersey.
3. Drury, C.G., 1990. Design for Inspectability, In *Proceedings of the IEA Human Factors in Design for Manufacturability and Process Planning,* Honolulu, Hawaii.
4. Drury, C.G., Prabhu, P. and Gramopadhye, A., 1990. Task Analysis of Aircraft Inspection Activities: Methods and Findings, In *Proceedings of the Human Factors Society Annual Conference.*
5. Drury, C.G., 1990. Exploring Search Strategies in Aircraft Inspection, In *Proceedings of the Second International Conference on Visual Search,* University of Durham, England.

The following publications were written in conjunction with, but not funded by, the Galaxy Scientific Corporation/Federal Aviation Administration contract:

1. Drury, C.G., 1990. Inspection Performance. In *Handbook of Industrial Engineering (2nd Edition),* edited by G. Salvendy, New York: John Wiley and Sons.
2. Drury, C.G. and Kleiner, B.M., 1990. Training in Industrial Environments. In *Proceedings of the Human Factors Association of Canada Meeting,* Ottawa, Canada.

# Chapter Four
# Advanced Technology Training for Aviation Maintenance

This chapter reports the status of a project to support the application of advanced technology systems for aircraft maintenance training. The first phase of the research was to assess the current use of such technology in airlines, manufacturers, and approved aviation maintenance technician schools. The findings of the assessment are reported here. The second phase of the research is building a prototype intelligent tutoring system for aircraft maintenance training. The chapter defines intelligent tutoring system technology and presents the specifications for the prototype. This chapter also describes example constraints to the rapid design, development, and implementation of advanced technology for maintenance training.

## 4.0 INTRODUCTION

The human is an important component in the commercial aviation system that provides safe and affordable public air transportation. Much attention to the "Human Factor" in the aviation industry has focused on the cockpit crew. However, the FAA and the airlines recognize that aircraft maintenance technicians (AMTs) are equal partners with pilots to insure reliable, safe dispatch. The job of the AMT is becoming increasingly difficult, as discussed in *Chapter 1*. This is a result of the fact that there are increasing maintenance tasks to support continuing airworthiness of the aging aircraft fleet while, at the same time, new technology aircraft are presenting complex digital systems that must be understood and maintained. Sheet metal and mechanical instruments have given way to composite materials and glass cockpits. These new technologies have placed an increased training burden on the mechanic and the airline training organizations.

The FAA Office of Aviation Medicine, as a part of the National Aging Aircraft Research Program and the National Plan for Aviation Human Factors, is studying a number of Human Factors related issues that affect aviation maintenance. As described in *Chapter 1*, examples of the projects under investigation include the following: a study of job aiding for maintenance tasks (Berninger, 1990); design and development of a handbook of Human Factors principles related to maintenance; a task analysis of aviation inspection practices (Drury, 1989 and 1990); a study of maintenance organizations (Taylor, 1989 and 1990); and the assessment and specification/demonstration of advanced technology for maintenance training. The advanced technology training research, reported here, is exploring alternatives for the effective and efficient delivery of a variety of aircraft maintenance training.

## 4.1 RESEARCH PHASES

The training technology research is divided into three phases that will be conducted over a three year period. The work began in January of 1990.

In the first six months the status of training technology for maintenance technicians was assessed. This was done with a series of telephone interviews and site visits to manufacturers, airlines, and schools operating under Federal Aviation Regulation Part 147 (FAR 147). Currently the research team is designing and building a prototype intelligent tutoring system (ITS) that can be used as a demonstration of the application of expert system technology to maintenance training. ITSs are described in Section 4.2. The prototype will also be used to help finalize the specifications for a fully operational intelligent tutoring system that will be completed in the second year for a full scale evaluation in year three.

The operational intelligent tutoring system will be built in conjunction with a school and airline that were identified during the first six months of the project. The intelligent tutoring software will be generic in design so that it can be modified for a variety of aircraft maintenance training applications. The product will be a turn-key training system for maintenance. The important by-product will be a field-tested approach to develop, efficiently, subsequent ITSs for aircraft maintenance training.

The third phase will be dedicated to evaluation of the intelligent tutoring system for maintenance training. The system will be integrated into a training program at a school or airline. User acceptance and training effectiveness of the intelligent tutoring system for maintenance training will be evaluated. In addition, there will be an analysis of the cost effectiveness of such training technology. *Table 4.1* is a summary of the three phases.

## 4.2 DEFINITIONS OF ADVANCED TECHNOLOGY AND ITSs

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 applied to a variety of technical training applications. Examples of such technology include computer-based simulation, interactive videodisc,

| | | |
|---|---|---|
| **Phase 1** | 1990 | Technology Assessment and Prototype |
| **Phase 2** | 1991 | Build Complete Intelligent Tutoring System |
| **Phase 3** | 1992 | Conduct System Evaluation |

**Table 4.1**
**Phases of Research Plan**

and other derivatives of computer-based instruction. Compact disc read only memory (CDROM) and Digital Video Interactive (DVI) are two additional technologies that will offer the "multi-media" training systems of the future.

The application of artificial intelligence (AI) to training captivated the instructional technology literature of the eighties (Sleeman and Brown, 1983, Wenger, 1987, Keansley, 1987). The AI-based training systems are called intelligent tutoring systems (Polson and Richardson, 1988, Psotka, et al, 1988). This section will define the ITS technology as it exists today. The section will show examples of systems that are currently in use and/or development. The examples are those for which the author has responsibility. There are many other excellent ITSs in development today. Intelligent tutoring systems are usually described with some version of the diagram in *Figure 4.1* (Johnson et al, 1989; Mitchell and Govindaraj, 1989; Yazdani, 1987).

At the center of the diagram is the instructional environment. It can include any of the techniques that have been available with conventional computer-based instruction (CBI). This could include the following: simple tutorials, drill and practice, problem solving, simulation, and others. It can be argued that the design of the instructional environment is the most critical element in a training system. However, an ITS is only as strong as its weakest module.

Between the instructional environment and the student is the user interface. The interface permits the student to communicate with the instructional environment. The interface can be as simple as text with a keyboard. However, today's interfaces are more likely to include sophisticated color graphics, animation, audio, and video disc. Example input devices are keyboards, touch screens, mice, trackballs, voice, and other such hardware.

The software that differentiates ITSs from conventional CBI are the models of the expert, student, and instructor. The expert model contains an understanding of the technical domain represented in the instructional environment. There are numerous ways to encode this expert understanding. The most common is with production rules. When the instructional environment is a simulation, a portion of the expert model is often embedded in the simulation. This is true with Microcomputer Intelligence for Technical Training (MITT) (Johnson et al, 1988 & 1989) and with the Intelligent Maintenance Training System (IMTS) (Towne and Munro, 1989).

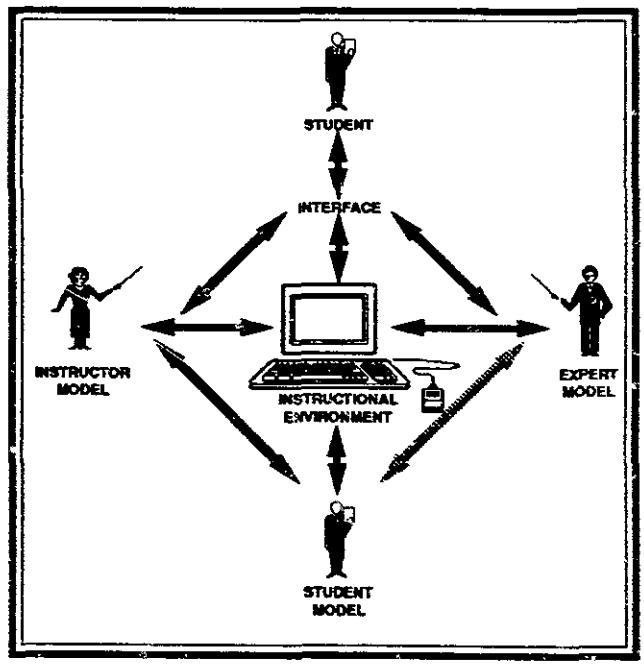


**Figure 4.1 Intelligent Tutoring System**

The student model is a dynamic accounting of student performance within a given problem. Most student models also contain a historical record of previous student

performance. The final model, the instructor, compares the student model to the expert model to assess student performance. The instructor model, sometimes called the pedagogical expert, offers appropriate feedback and/or suggestions for remediation. The instructor model also sequences subsequent instruction based on perceived level of competence of the student. The instructor model is an expert system with production rules about training and feedback. This model does not necessarily know anything about the content matter within the instructional domain.

### 4.2.1 Example Systems

Research on artificial intelligence in training has been going on for quite some time (Carbonell and Collins, 1973). However, few systems have made a successful transition from the laboratory to real training environments (Polson, 1989, Johnson, 1988b). Johnson has offered a number of the reasons that the transition has been difficult. He also described how to build ITSs for real applications (Johnson, 1988a, 1988b, 1988c).

Flowcharts and diagrams, like the one in *Figure 4.1*, are helpful to gain a broad understanding of the ITS concept. Examples of operational ITSs are a better way to understand and appreciate their potential for technical training. MITT, MITT Writer (citation), and Advanced Learning for MSE (ALM) (Coonan, et al, 1990) are examples of such systems.

### 4.2.2 Summary of Examples

MITT, MITT Writer, and ALM are but a few examples of ITSs that have transitioned from the laboratory to the operational training environment. This transition was possible because the systems were designed to meet the hardware, software, and budget constraints associated with real training. These systems operate on hardware that is available, in place, today. If intelligent tutoring systems are to become a part of technical training they must be sensitive to these constraints. Each will be briefly discussed here.

Hardware is the first constraint. Most of the early ITSs were developed on dedicated artificial intelligence workstations. Such hardware is considered to be obsolete and impractical by most developers. However the early ITS development on the Xerox and Symbolics workstations permitted the initial design principles for today's systems.

The hardware problem is history. Today's computers, the IBM-AT, compatibles and the Macintosh, have the capability for ITSs. The faster 80386 and 80486 processors are providing significant capability to deliver intelligent training. Such hardware is becoming increasingly affordable and reasonable for training applications.

Software has also evolved to become more suitable for ITS. The new operating systems, with new hardware, permit parallel processing and direct access to unlimited memory. These two changes, by themselves, will have a major impact on new training software. In addition to these advances are a variety of software tools that facilitate the development of interactive graphics, as an example.

Budget considerations are a third constraint to the development and implementation of ITS in technical training environments. The advent of ITSs on available microcomputers is driving down such costs. The development of authoring systems, like MITT Writer, will also bring down the cost of ITSs.

## 4.3 ADVANCED TECHNOLOGY FOR AIRCRAFT MAINTENANCE TRAINING

The goal of Phase 1 was to identify the extent to which advanced technology was being applied to aviation maintenance training. To accomplish this goal, a sample of the population of airlines, schools, and manufacturers was either visited or interviewed by telephone or personal discussion. The organizations that had major input to the survey are shown in *Table 4.2*.

Each interview began with a discussion of the perceived status quo of maintenance training. *Table 4.3* summarizes the preconceptions that served as a basis for initial discussions.

The interviews confirmed that the initial perceptions were accurate. However, there were noteworthy exceptions. Perhaps the most significant of the incorrect assumptions was the FAA position on advanced technology for maintenance training. The discussions with FAA personnel and training personnel throughout the industry confirm that advanced technology training systems have the potential to substitute for real equipment in certain laboratory tasks. For example, an AMT trainee can learn to start and troubleshoot a turbine engine using a simulation rather than the real engine. Advanced technology cannot substitute for many psychomotor activities but is especially useful where students must practice the integration of knowledge and skill for problem solving, decision making, and other such diagnostic activities. It appears, therefore, that simulators and other advanced technology are becoming an important component of maintenance training curricula. Proposed changes to FAR 147 have suggested that "the curriculum may be presented utilizing currently accepted educational materials and equipment, including, but not limited to: calculators, computers, and audio-visual equipment."

| | |
|---|---|
| **AIRLINES:** | American Airlines Maintenance Academy<br>British Airways<br>Continental Airlines<br>Delta Airlines<br>Northwest Airlines<br>United Airlines<br>ATA Maintenance Training Committee |
| **SCHOOLS:** | Clayton State College<br>Embry-Riddle Aeronautical University<br>The University of Ilinios |
| **MANUFACTURERS:** | West Los Angeles College<br>Boeing Commercial Airplanes<br>Douglas Aircraft<br>Airbus/Aeroformation<br>ATA Maintenance Training Committee |

**Table 4.2 Sources of Information for Technology Survey**

### 4.3.1 A Discussion of Hardware for Advanced Technology Training

All of the interviews resulted in a discussion about the appropriate hardware systems for advanced technology training. While there is not unanimous agreement, the current favorite is the 80286 or 80386 operating in the DOS environment. VGA seems to be the acceptable video hardware standard. Many airline managers were outspoken about their dissatisfaction with the lack of standards among the various CBI vendors. The Air Transport Association (ATA) Maintenance Training Committee (ATA, 1989) has strongly recommended that all manufacturer-produced courseware be designed for a common non-proprietary system like the IBM-AT and compatible

- Maintenance training is traditional.
- Training personnel do not have time to develop advanced technology training systems.
- FAA has not encouraged the use of advanced technology as a substitute for laboratory practice.
- Advanced technology is an effective maintenance training alternative.
- There are few vendors of advanced technology for maintenance training.
- Most CBI systems require proprietary hardware.
- Training personnel want advanced technology training systems.

**Table 4.3 The Perceived Situation for Interview Discussions**

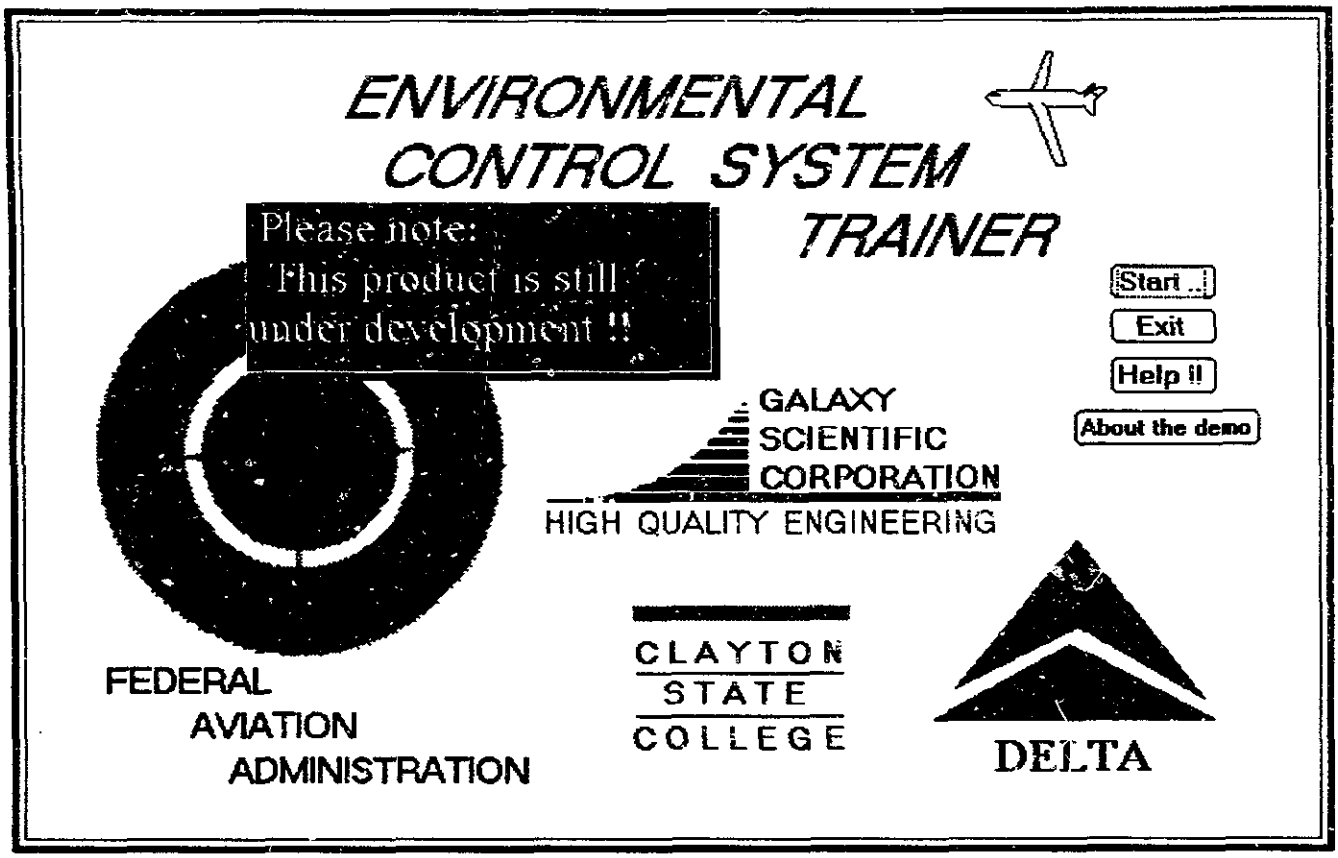


**Figure 4.2 Advanced Technology Training Prototype**

computers. That is not currently the case, although the trends are in that direction. Software developers who meet the ATA standards are more likely to succeed in the new marketplace.

The two largest producers of CBI for aviation maintenance are Aeroformation (for Airbus) and Boeing Commercial Airplane Company. Both systems require some proprietary hardware but are somewhat compatible within the 80286/386 family. Douglas Aircraft is also developing CBI that will be compatible with the ATA standard. Another committee that is promoting standards is the Aviation Industry Computing Committee (AICC). They have published hardware guidelines and a catalog of current and planned CBI developments by its members (AICC, 1990).

Among the major airlines there is some hardware variance. Delta Airlines, one of the few to have a significant CBI development staff, is using a large number of 80386 processors with advanced graphical displays. The Delta systems are also DOS-compatible in order to maximize applications.

The majority of Boeing training software is for the 747-400. The Boeing software was developed under contract to a large CBI company. The Advanced Technology training development group at Boeing are cooperating with United Airlines and Apple Computer Company to explore the concept of "Instructor led CBT." Using MacIntosh computers and a variety of color graphics and hypermedia tools, they have created a variety of dynamic displays to be used for group training. Boeing calls the development "Instructor-led CBT." Eventually this approach should find its way to individualized CBI.

## 4.4 ADVANCED TECHNOLOGY TRAINING PROTOTYPE

As described in *Section 4.1*, the first phase of the project would establish the current status of advanced technology for maintenance training, and then would build a prototype ITS. The prototype can be used as a demonstration of the application of expert system technology to maintenance training. The prototype (see *Figure 4.2*) will be used as a model for the fully operational ITSs to be completed in phase two and evaluated in phase three.

The prototype was developed with two major areas of concern in mind, the interface and simulation. An intuitive, easy-to-use interface was essential for user acceptance of advanced technology training. A correct and realistic simulation of the instructional domain was also crucial. An iterative design approach involving subject matter experts, technical instructors, educational technologists, and computer scientists was used to ensure that both of these goals were achieved.

### 4.4.1 The Prototype Specifications

The prototype was developed on hardware that is aligned with the ATA-recommended standards. The specifications are listed in *Table 4.4*. This hardware insures that the prototype will be of value for demonstration on available computers. It does not require special hardware.

| | | |
|---|---|---|
| • 80286 or 80386 Processor | • Mouse | • C++ Programming Language |
| • 1 Mb of Memory | • MS-DOS | • MS Windows |
| • VGA Display | • Off-the-shelf software for graphics and windows | |
| • Hard Disk Storage | | |

**Table 4.4 Hardware and Software for Prototype**

The instructional and pedagogical design is a more important consideration than hardware. While the design is hardware and software dependent, it must be emphasized that robust and expensive hardware does not make up for poor design of the instruction. An incomplete listing of the instructional specifications is shown in *Table 4.5*. These specifications evolved with the software.

- Extensive Freeplay and Interaction
- Problem Solving and Simulation
- Explanation, Advice, and Coaching
- Orientation Towards Maintenance Tasks
- Adaptable to Student Skill Level

**Table 4.5 Instructional Specifications for Prototype**

### 4.4.2 The Instructional Domain

The primary criteria for selection of the instructional domain for the prototype was that the finished ITS be of immediate value to airlines and to FAR 147 schools. In order to accomplish this goal, the domain had to be a complex system that is prone to failure. In addition, the system had to have an effect on passenger safety and/or comfort. Candidate systems that were considered included the following: hydraulics, auxiliary power unit (APU), engine information and crew alerting system (EICAS), electric power distribution, fuel distribution, and environmental control system (ECS).

ECS was chosen for the prototype system. This system is ideal for many reasons. On the ECS, diagnostic information and maintenance checks occur throughout the aircraft. The system is integrated with the APU and the main engines. The ECS is critical to passenger safety and comfort. Further, the ECS principles can be generalized to many aircraft. Therefore, currently, the ECS is the prototype domain.

### 4.4.3 Prototype Development Partners

At the outset of this research, the intent was to elicit participation from at least one FAR 147 school and at least one major air carrier. A large number of schools and airlines offered to participate. That is encouraging to the research team and to the FAA sponsor.

The development partners are Clayton State College and Delta Airlines, both in Atlanta, Georgia. The combination of a major airline and an approved FAR 147 school will insure that the ITSs will meet the instructional needs across a wide spectrum of AMT personnel. The combination will insure that the training system is technically correct and instructionally sound. Further the airline/school combination will be ideal to conduct evaluations of training effectiveness and cost efficiency during phase three.

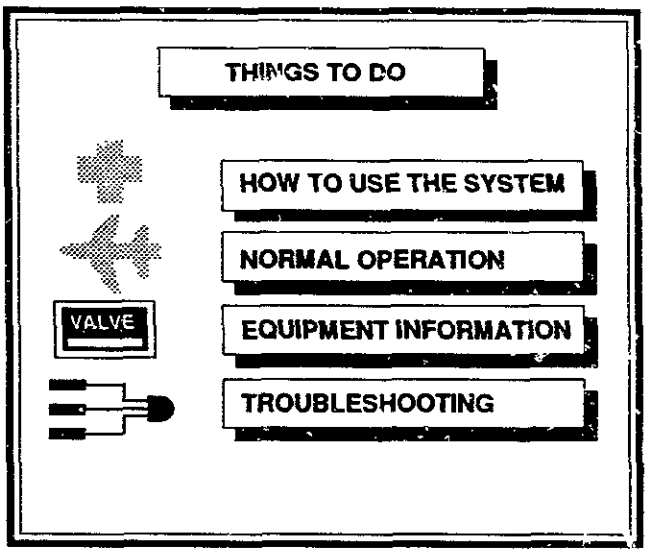


**Figure 4.3 Menu Options**

### 4.4.4 Prototype Development Environment

The development environment for the prototype was chosen in accordance with the prototype specifications outlined in *Section 4.4.1*. The prototype was developed with Asymetrix Toolbook under Microsoft Windows 3.0. Both of these products allowed access to extra memory, when available.

Toolbook is a software construction set with a graphical user interface and object-oriented programming features (Toolbook is not a programming language). These features allowed for the rapid development of an interface prototype and accompanying simulation.

The Toolbook development environment was excellent for development of an interface prototype. However, as the system grew, Toolbook ran into memory limitations. Also, because Toolbook was not a programming language, there were inherent limitations on flexibility. This inflexibility was highlighted during the development of the simulation.

While adequate for the prototype, Toolbook will not be acceptable for the ITS that will be developed in the second phase. Therefore, different options are being explored for the next phase. A combination of a programming language and an interface development package (still under Windows 3.0) will be used for the next phase. This will allow for a more flexible and more powerful development environment.

### 4.4.5 Iterative Design Approach

After discussions with subject matter experts, an initial interface prototype was developed. This interface prototype was presented to the development partners for evaluation and critique. Changes were made to the prototype based on these comments. The modified system was again presented to the development partners. This iterative process continued throughout development of the prototype.

As the user interface evolved, work also began on the simulation that works behind the interface. Once again, the simulation development was an iterative process. The subject matter experts ensured both correctness and completeness of the simulation.

### 4.4.6 Prototype Description

The prototype addressed the following three major areas: Equipment Information, Normal Operation, and Troubleshooting (see *Figure 4.3*). Help is also available to the student at any time. Each of the major areas is described below.

#### 4.4.6.1 Equipment Information

The "Equipment Information" mode allows the user to get information about the different components of the ECS. This information describes various switchlights, knobs, buttons, video displays, and warning lights for the equipment used to troubleshoot the ECS.

The equipment that is available to the student includes the following: ECS Overhead Panel, Bleed Air Supply Panel (See *Figure 4.4*), BITE Boxes, EICAS display, and Cooling Pack Schematic. The approach used to implement Equipment Information is very modular to support the addition of any new equipment in the future.

#### 4.4.6.2 Normal Operation

The "Normal Operation" mode simulates how the ECS responds under normal operating conditions. This mode will provide the students with a baseline against which they can compare a malfunction. The student has access to all of the equipment described in Equipment Information. The student can change knob and switch positions just as in the "real" world. In this mode it would not make sense for the student to replace components because every component is good. Part replacement is reserved for Troubleshooting.

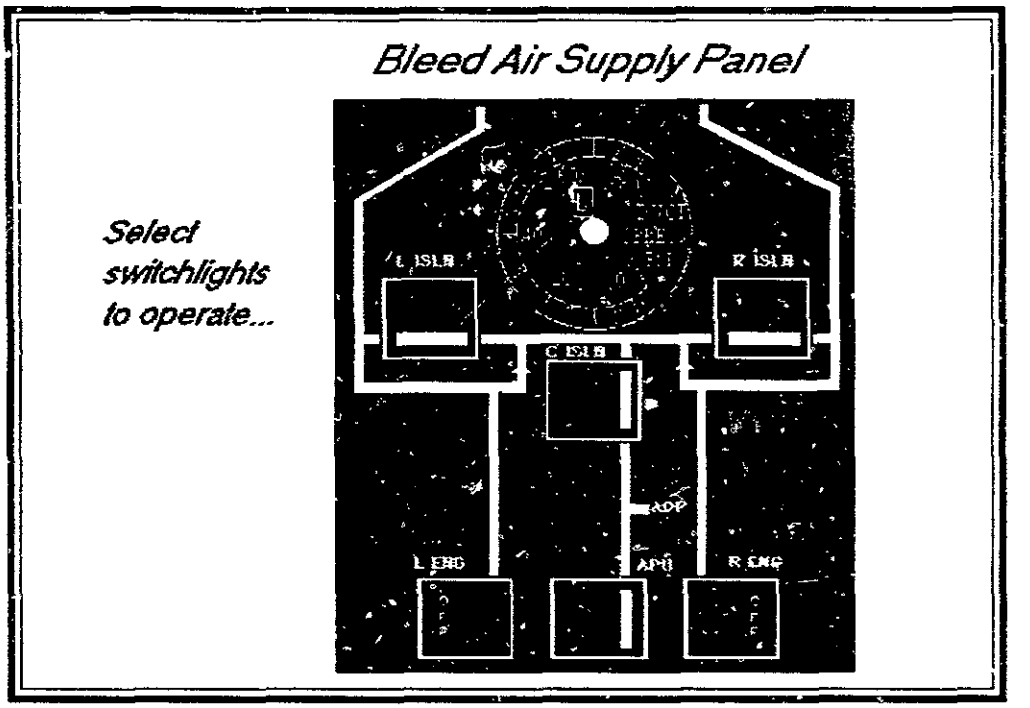


**Figure 4.4 Bleed Air Supply Panel**

### 4.4.6.3 Troubleshooting

The "Troubleshooting" mode simulates how the ECS operates when a component has failed. As in "Normal Operation", the student can change switch positions. Changes in switch positions will affect the operation of the Cooling Pack as in the "real" world. Also, the student has access to a variety of diagnostic tests (Built-in Test Equipment) and tools to aid in troubleshooting.

The prototype also supports the manufacturer's Fault Isolation Maintenance Manual (FIMM). The FIMM, as shown in *Figure 4.5*, represents the decision tree that the student may follow to troubleshoot the aircraft. The student chooses the Fault Code to indicate the suspected malfunction. The simulation knows about the current malfunction and notifies the student of any logical errors in the selection. If the correct fault code is selected, then the student sees the specific troubleshooting instructions for that fault code.

Even though the system supports use of the FIMM, it is not required. The students may troubleshoot in any order that they choose. The student may also swap circuit cards, use a voltmeter to check continuity and voltages (see *Figure 4.6*), and replace components. Eventually, the student will be able to replace a component and then verify that the replacement corrected the malfunction.

## 4.5 PLANS FOR PHASE II

During Phase I the prototype was completed and reviewed by the cooperating airline a . Part 147 school. The overall design and technical accuracy of the environmental control system simulation was acceptable. During Phase II the prototype will be converted to a turn-key intelligent simulation.

The Phase I prototype was developed with software tools designed for rapid prototyping. While the tools were easy to use they lacked the robust capability that can be derived from a programming language. During Phase II the simulation will be written in a programming language (C++). The graphics will be developed in a manner that will provide higher resolution and more color with less memory requirements than the prototype.

During Pnase II a robust evaluation plan will be designed. The evaluation is likely to involve a design with experimental treatment and control groups. The plan will include methods to assess training effectiveness and cost effectiveness. The experiment will be conducted with the cooperating airline and Part 147 school during Phase III.

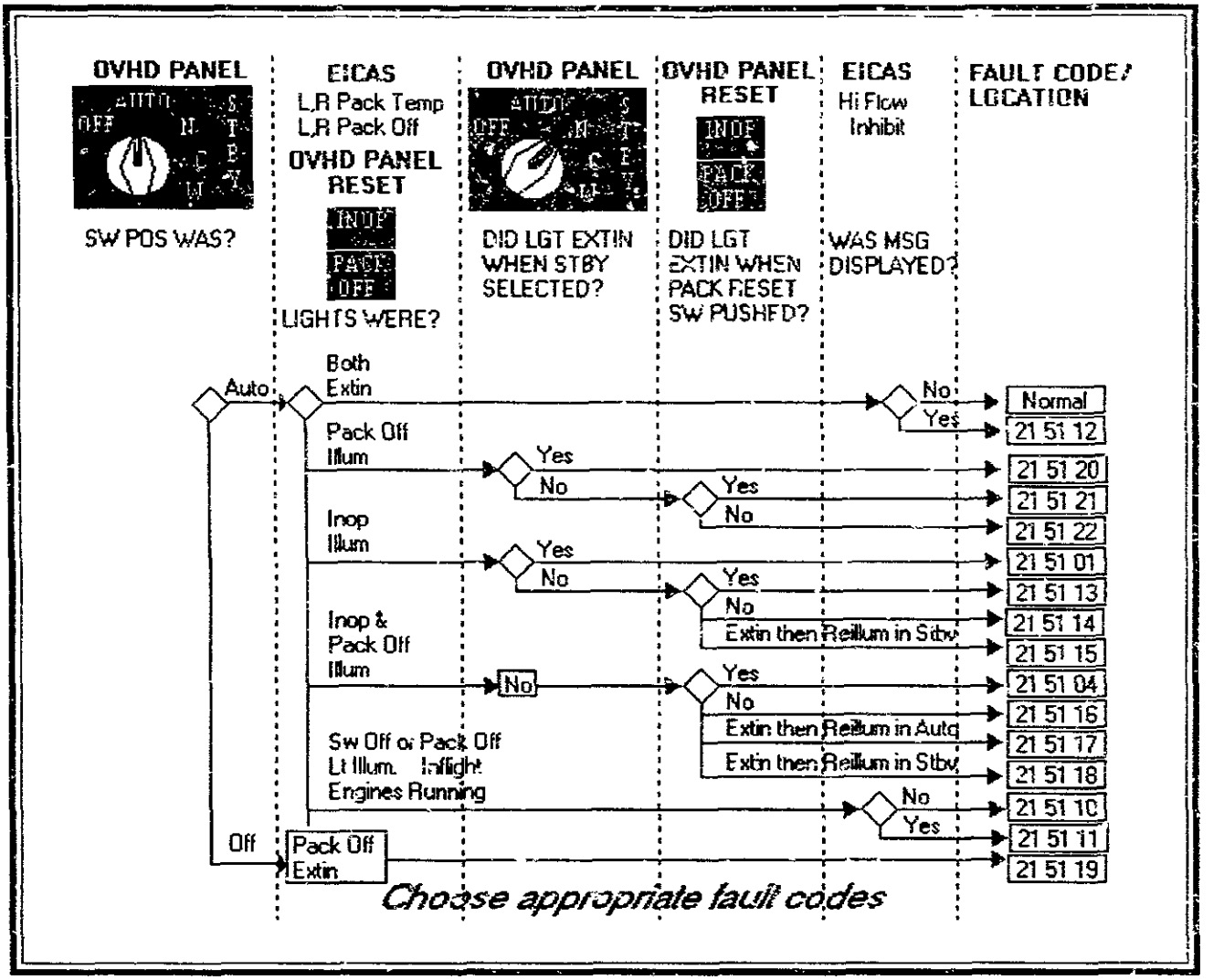


Figure 4.5 Fault Isolation Maintenance Manual

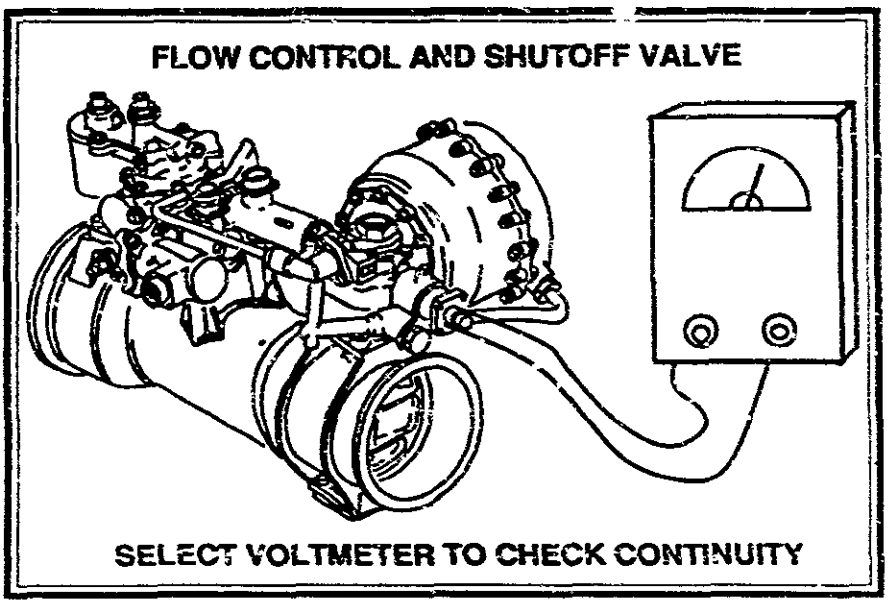


Figure 4.6 Example of ECS Trainer Tools

## 4.6 SUMMARY

This chapter has described the ongoing research and development related to the application of advanced technology to aircraft maintenance training. The research has characterized current use of advanced technology for maintenance personnel. Subsequent phases of the research will design, develop, and evaluate an intelligent tutoring system for aircraft maintenance training.

Training humans to learn new skills and to maintain current skills and knowledge is critical to the safe operation and maintenance of manufacturing, power production, and transportation systems. As the U.S. labor force changes, the criticality of such training becomes even more eminent. Intelligent tutoring systems, combined with human technical instructors, offer a cost-effective, reasonable alternative that can impact training immediately and into the future.

## 4.7 ACKNOWLEDGMENTS

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# Chapter Five
# Job Performance Aids

## 5.1 INTRODUCTION

This research is designed to provide information that will enable maintenance managers in government and industry to more effectively manage the integration of technology into the work place. The information in this chapter will aid in assessing the capability of technologies and possible applications. It will provide a basis to judge various approaches of implementing technology. The information will contribute to efforts for estimating the time, expense, and utility of fielding Job Performance Aids (JPAs) and technology in maintenance operations. Principally, the information will help determine the return that can be expected from an investment in technology. A primary focus is on developing approaches for technology implementation that complement human capabilities. This is accomplished through research in two areas.

The first area seeks a commercial maintenance perspective of the issues. The research investigates current approaches to computerization and job aiding in aircraft maintenance. This includes a review of the relative level of automation at major airlines. The structure of completed systems is observed and work force reactions to the systems are determined. Trends are identified. The needs of the maintenance technician are assessed, and an overall understanding of the maintenance process is acquired.

The second area focuses on technologies. A survey was conducted to determine the capability of existing JPA systems. The state-of-the-art in computers and related technologies are assessed. The complexity and pragmatic considerations of designing databases, expert systems, and computer user interfaces are evaluated through experiments. Current approaches to system integration are identified. Expert assessments were obtained on the capabilities and limitations of various technological approaches.

## 5.2 PROBLEM DEFINITION

Research on Advanced Technology Job Performance Aids is included in a human factors research program in response to the concern that humans will not be able to meet the growing challenges of aircraft maintenance without the proper application of technology. The word "technology" is used broadly in this report to identify the tools available in science and engineering that may be applied to aviation maintenance. The growing challenges in commercial aviation maintenance are well documented (Parker and Shepherd, 1989, 1990 a. and b.). The challenges include aging aircraft, retiring work force, increasing maintenance capacity requirements, increasing aircraft complexity, increasing fleet diversity and size, diminishing pool of new technicians, and limited financial resources.

Table 5.2 summarizes the researcher's understanding of the problem that originally motivated the research. Table 5.3 is the researcher's understanding of the problem at the completion of Phase I research.

If technology is to be used to meet new challenges it must complement existing human resources. Motivation to introduce technology might come from any of the areas

**Summary of Research Objectives**

| Rank | Description |
|---|---|
| 1. | Provide information to enable informed decisions on the intergration of humans and technology. |
| 2. | Provide information to increase the understanding of the capabilities and limitations of technology. |
| 3. | Provide information that will stimulate thought and awareness of avenues for increasing human performance through Human Factors considerations. |

Table 5.1 Summary of Research Objectives

described in *Table 5.2.* The relationship of technology and humans must be carefully planned.

The process of implementing Job Performance Aids is not straight-forward. It has proven difficult to predict the duration and costs of development. Development requires complete communication between the application experts (eventual users) and the system developers (who know what technology can do). This close working relationship is difficult due to the disparate backgrounds and languages of the two groups. The development process is a long series of trade-offs between reducing functionality to make development more feasible and adding functionality to make the system more useful. The final system is the system developer's interpretation of user needs, tempered by what is feasible.

Some JPAs are already in place, such as built-in test equipment (BITE). The fielding of these technologies is on-going, but guidelines that work in many environments are unsuccessful in aviation. For example, initial BITE systems fielded by Airbus had accuracy levels in the range of 90%. In the perspective of the design team this is a very successful system, but to a maintenance technician this was a very frustrating system. Repairs and component replacement in aviation are almost universally time consuming, so even one misguided recommendation in ten can waste an entire shift with some frequency. The BITE systems are improving and are now generally accepted as useful tools, but their implementation took time and considerable resources.

**Initial Motivation for Research**

| Rank | Description |
|---|---|
| 1. | Technology is needed to help humans cope with growing challenges. |
| 2. | Technology is needed to overcome the potential for human error. |
| 3. | Technology is needed to overcome human limitations. (i.e. accuracy) |
| 4. | Technology can make maintenance operations more efficient. |
| 5. | Maintenance Technology should keep pace with aircraft technology. |

**Table 5.2 Initial Understanding of the Problem**

**Final Motivation for Research**

| Rank | Description |
|---|---|
| 1. | Avenues for achieving peak human performance are under utilized. |
| 2. | Implementing technology is more complex and expensive than accepted |
| 3. | The human factors of achieving user acceptance are not will understood |
| 4. | The human factors of system development (i.e. Developer/User communication are not well understood |

**Table 5.3 Understanding of the Problem at the End of the Phase 1 Research**

### 5.2.1 Computerization

The trend toward increased automation through computerization is well under way. Computers are already deployed in most of the "deterministic" tasks of maintenance operations such as tracking, scheduling, budgeting, and status reporting. Starting with mainframes in the 70's, most major airlines are now working on their second or third generation systems. While the mark of computers on maintenance operations is apparent and permanent, the implementation of the systems has not always been well received and their cost effectiveness is not always clear. Aviation maintenance is not necessarily an ideal application for computers, but during the 80's, as operations grew in complexity, computers seemed to be a solution for many problems. Computers in aviation maintenance usually achieved functional requirements, but sometimes failed to live up to the expectations of the user. This was due in part to the difficulty of fielding new technologies, and in part to the user's difficulty in specifying needs clearly. All involved are now sensitized to the criticality of assessing the user's needs, but it is not clear how this can be achieved satisfactorily. In any case, there is much more awareness of the difficulty of achieving objectives when humans are an integral part of the system (which is almost always the case.)

Computers solved some problems and created some new ones. Many difficulties had to be overcome to fit existing approaches to the nature of computer solutions. For example, many problems arose from the computer's affinity for numbers and the human affinity for symbols. Early on, technical considerations dominated and parts numbering, for example, became driven by computer requirements rather than maintenance requirements. One airline reported an air-turn-back when similar (but non-interchangeable) parts with like numbers were interchanged. This example and others highlight why the enthusiasm for computers diminished as workers lost control to the demands of the computer system.

Implementation of technology is an expensive, and to some extent experimental (trial and error) process. The Department of Defense expends enormous resources to bring ideas from concept to reality. Airlines rarely have the resources to carry out the same process. Maintenance operations are faced with mostly fixed expenses such as facilities, spares, and labor. Labor is not entirely fixed, but nearly so, given union agreements and the disruptions caused by layoffs. The volatility of repairs required in the fleet during any year are not reflected in the flexibility of annual budgets under which maintenance managers work. Financial resources are focused on the many expenditures encountered in maintenance, for example, in the process of swapping out or replacing parts in the aircraft. As a result, a very low percentage of the budget, if any, is available for computerization.

Computers will continue to become more adept at performing existing tasks, but the remaining avenues for computerization are more challenging. For example, communication of maintenance information is a central concern for every maintenance worker. Some technicians reported spending as much as 75% of their time obtaining the information needed to perform their duties. The problem is that this information is difficult to quantify. It is not simply a matter of having technical manuals available on-line. Subtle information such as the fact that a battery needs charging can make the difference between a successful engine run up or a wasted shift. Aircraft maintenance depends on a large number of interdependent events. The resulting complexity challenges the humans involved, and makes the process of computerization arduous.

### 5.2.2 Human Error

At the technician level there are consistent calls to automate elements of maintenance programs which are prone to human error. The heavy demands placed on inspectors to detect structural problems with aging aircraft motivate the pursuit of new Non-Destructive Inspection (NDI) equipment. The National Transportation Safety Board accident report on the Sioux City accident contains the following recommendation (NTSB, 1990):

"Intensify research in the nondestructive inspection field to identify emerging technologies that can serve to simplify, automate, or otherwise improve the reliability of the inspection process."

### 5.2.3 Human Limitations

Labor costs are a common concern of managers; thus the idea of tireless, efficient, and precise robots is appealing. JPAs are sought to overcome human limitations of attention span, endurance, and accuracy. This propensity is also motivated by the expectation that there will not be enough technicians available in the future, and the ones that are available will have difficulty working with increasingly complex aircraft.

### 5.2.4 Maintenance 2020

In the 40's and 50's it was likely that the aircraft mechanic was familiar with most aircraft systems, with the possible exception of the radio equipment. Today, only the most experienced aircraft technicians are familiar with a majority of the systems, and radio has been joined by a growing set of avionics equipment. The complexity of aircraft maintenance is expected to continue to increase. It is likely that computers and technology will play a larger role in the

maintenance effort, but what are the characteristics of the role? How large will the role be, which technologies will be used, and when will they be used? If these questions could be answered, many false starts and considerable wasted effort could be prevented. Integration of technology is a long process and planning must be accomplished years in advance. The maintenance process has little margin for trial and error, and few resources are available to support extensive experimentation. Technology changes so rapidly that it often seems a new approach is obsolete as soon as it is successfully fielded. There may never come a time when maintenance programs or technology will arrive at a steady state. While it is not possible to see the future in a crystal ball, a great deal can be learned from past experience.

### 5.2.5 Technology

Technology has a lure of its own. Emerging technological capabilities seem to have "potential" to improve nearly everything. Pressure for change often comes from the promises of "technologists", eager to find applications for their inventions. It seems natural that as aircraft become more sophisticated, maintenance should follow. However, bias toward new technology should be tempered by a careful assessment of user needs. Designers are usually able to field hardware and software that works functionally, but compatibility with humans is more elusive.

Clearly "manual" methods are not sufficient forever. For example, technical documentation on aircraft systems has grown exponentially and a typical narrow body aircraft now arrives with 17,000 pages of documentation. Airlines usually maintain several different types of aircraft and must use unique procedures for each. A number of technological solutions are available to make the information more accessible, but more work is needed to facilitate the assimilation of the information. The point is that finding a technological solution does not replace the need for careful consideration of human factors.

## 5.3 METHODOLOGY

The research sought to obtain a rapid high level understanding of the issues. The primary task was to assess the implications of fielding technology to aid commercial aircraft maintenance. The information contained in this chapter is targeted for a reader who has considerable knowledge of aircraft maintenance, limited knowledge of computers and technology, and very little knowledge of Human Factors.

### 5.3.1 Aviation Maintenance Assessment

The research sought a first hand understanding of the challenges facing the aviation maintenance community and the current approaches for utilizing technology to meet those challenges. Basically, this knowledge is obtained from several sources:

Aviation maintenance managers

Aviation maintenance technicians

Maintenance computerization specialists (MIS or DP)

Aviation maintenance industry representatives

FAA managers responsible for aviation maintenance

Aircraft manufacturer representatives

#### 5.3.1.1 Participation in Industry Forums

Participation in numerous industry forums from conferences to high level briefings provided access to most of the individuals listed above. Information was collected through informal unstructured interviews and discussions, as well as, through observation. The research objectives and approach were presented on these occasions, and feedback was used to focus and direct the effort.

#### 5.3.1.2 Site Visits

Site visits lasting from several hours to one week were utilized to collect information on facilities, develop an understanding of the overall maintenance process, and to further talk with the individuals listed above. Information was collected through informal interviews and observation. When possible, the researchers participated on an non-interference basis in the normal conduct of aircraft maintenance. Technicians explained what they were doing as they performed their duties. All shifts of operation were observed. Training classes and morning management briefings were observed. The researchers reviewed documentation and procedures utilized in each aircraft maintenance organization. The Quality Control Department was normally the host, but time was spent with a cross-section of the maintenance organization. The research objectives and approach were always presented to verify that the results would be useful to the maintenance community.

### 5.3.2 Technology Assessment

#### 5.3.2.1 Survey

A survey of existing JPA systems was conducted. A narrow definition of JPA was utilized, since there are existing sources of information on tooling, ATE, fixtures, and non-destructive inspection equipment. The focus of the JPA survey was on computer and microprocessor based systems utilized for information delivery, processing, or storage. In addition, a few applicable technologies, not yet incorporated in systems, were identified as part of the

survey. Systems and technologies developed outside of aviation were included if they demonstrated a technology not already used in aviation. The military was the primary sponsor. Each aircraft manufacturer and large airline, as well as several other major industrial companies, had at least one JPA in development. The goal of the survey was not to find the system that would "revolutionize" aviation maintenance (although, if we had found one, it would have been included), but to assess the overall extent and characteristics of what is feasible and possible in Job Aiding. The systems were identified through database searches and the information was supplemented by contacting the developers. In addition, some systems were identified through site visits or at industry forums.

#### 5.3.2.2 Technology Research

Research was conducted to assess the capabilities and limitations of the technologies that are most often proposed for implementation in aviation maintenance operations. Principally this effort focused on the application of computer technologies. Artificial intelligence and expert systems were given particular emphasis. Several "new" technologies were investigated in computer displays, microprocessors, storage, and input/output devices.

#### 5.3.2.3 Experiments

Limited experiments were conducted to evaluate the pragmatic considerations involved in developing expert systems, databases, and computer user interfaces. The experiment in interfaces was principally software development task, but emerging technologies in the processor, packaging, and display were also tested. Database technology was used to organize the findings from the JPA survey, and a small expert system was developed with a commercial expert system development package.

## 5.4 FINDINGS

### 5.4.1 Overview

The findings are divided into three categories:

Technological contributions

Technological obstacles

Implementation guidance

A working knowledge of each is needed to make successful decisions about applying new technologies in aviation maintenance. The findings apply to the industry, in general, but the reader can assess whether it is applies in their situation. The overall theme of the findings is the importance of a realistic assessment of the capabilities of technology. The section characterizes the present capabilities of technology and the likely capability of technology over the next ten years. The scope is limited to ten years, since predictions beyond ten years are highly speculative. In any case, few maintenance managers can afford to make decisions based on a theoretical potential 15 years in the future. Lessons learned from implementing technology over the last decade are documented throughout this section.

### 5.4.2 Technological Contributions

#### 5.4.2.1 Automation in Aviation Maintenance

For a majority of the industry, maintenance automation means computerized maintenance information systems. Virtually all maintenance organizations have systems in place or anticipate implementing systems in the near future. Information systems provide indirect support of maintenance, but computers are also directly involved in maintenance in automatic test equipment or diagnostic support systems. The latter are covered in the next section on technologies.

The amount of information maintained on each aircraft has grown exponentially, but the basic structure of the paper methods are intact in today's information systems. This was necessary to ease the transition from manual methods and avoid extensive retraining. Most airlines developed maintenance information systems internally because each had unique maintenance programs. Even so, problems surfaced because computer applications were rarely able to do everything the same as manual methods and lacked flexibility. Further, it proved difficult to predict the magnitude of effort needed to develop systems or insure user acceptance.

Most maintenance operations now use computers to track parts and aircraft status, and more organizations are moving computers into forecasting and other decision aiding functions. Systems are justified based on promises to increase aircraft, engine, and component availability, or enable more production with existing resources. However, managers reported that unless an aircraft fleet was growing, labor savings in production were usually offset by increases in planning, production control, material, and data processing. The intensity of computerization efforts has slowed somewhat; only the largest (and profitable) airlines have data processing departments actively developing major new systems. All airlines continue to absorb and become accustomed to existing systems.

##### 5.4.2.1.1 Why Automate?

The growth that airlines experienced in the post deregulation era provided motivation for most automation efforts. Tasks such as aircraft routing became too cumbersome as fleet size increased. Computerization offered

increased capacity, faster turnaround without the need to develop an entirely new approach. Tangible and intangible benefits are achieved with automation. The intangible benefits out number the tangible ones.

The intangible benefits were often promoted as more important than the tangible benefits. The information needed by management to streamline operations is mostly intangible. Automation systems provide many more avenues than manual systems for tracking the technical performance of the organization. Management needs this information to recognize problems before they become critical. Automation systems make it easier to identify trends. The result is a more accurate control of resources and the efficiencies achieved can lead to increased maintenance capacity.

Cost control was frequently given as a reason for implementing automation systems. The computerization enables faster customer billing and closer tracking of costs. Detailed histories of existing costs improve forecasting and planning. In addition, comprehensive reliability information enables prompt acknowledgment of performance difficulties. The effectiveness of individual management decisions can be determined more readily with the additional information provided by the automation systems.

Tangible benefits are primarily found in increased aircraft (or engine or component) availability and additional capacity. The information from maintenance automation systems provides efficiencies that reduce turnaround times. Reduced turnaround time leads to increased aircraft revenue hours, fewer labor and material dollars for each service, and shorter AOG's. The information processing capability of the systems augment condition monitoring and enable more efficient stocking of spares. Stricter control of inventory and resulting efficiencies can lead to savings.

A couple of benefits that were sighted in the early years of automation never became reality. One area is manpower saving, as mentioned earlier. The other was the goal of a "paperless" system. There are a number of reasons for this failure including the fact that humans prefer to read hard copies and that computer information is updated so frequently. Combining these with the proliferation of copy machines and a visit to most maintenance facilities demonstrates that the goal of a "paperless" system has not been achieved.

#### 5.4.2.1.2 What Can be Automated?

Computers are involved in most aspects of information management for maintenance, engineering, and materials. Airlines incrementally developed their systems over a number of years. Functionality and enhancements were added to a core capability. The difficulties not withstanding, the presumption is that each new piece or type of information added provides a more accurate and complete picture of the maintenance operation. As an example of the complexity involved, consider service scheduling. Scheduling depends on multiple constraints and has many ramifications. The service schedule has implications for labor, facilities, and materials requirements. The objective is to make efficient use of the first two and minimize the last element. In any case, in order to ensure all are available in sufficient quantity (and not in excess quantity) the service schedule must be carefully planned. The schedule is based on forecasts of expected demand. The unscheduled service requirements are anticipated from reliability information and the time condition of the aircraft. Rotable requirements, modification requirements, and deferred work all figure into the equation. The schedule requirements are meshed with resource availability to determine aircraft arrival and work scheduling.

Planning might utilize the computer for maintaining aircraft maintenance history, development of work packages, and work card generation. In addition, planners need access to service forecasting, service scheduling, and aircraft routing information. Computer support of work cards is increasingly common. Most organizations have computerized work card indexes and some systems generate the cards on demand.

Other than tracking parts, status information is one of the most widely implemented functions and represents a significant level of complexity on its own. The hours and cycles of every aircraft in the inventory must be known for tracking time limited parts and complying with regulations. The configuration of each aircraft is tracked for modifications and component serial numbers. Maintenance status includes pilot reports, discrepancies, deferrals, and history. Information necessary to support warranty claims is maintained, such as manufacturers requirements, time tracking, and flight history. Aircraft modifications might be tracked separately for the fleet, aircraft, and individual components.

Varying degrees of reliability information can be maintained on the fleet. A delay summary might be reviewed daily, where each delay is charged to a specific area of the airline or maintenance department. Unscheduled removal rate can be tracked to identify trends, perhaps from shop information. The management of materials and purchasing can be similarly information intensive, and there are several types of information of interest to manage rotables.

### 5.4.2.2 Industry Computerization

Virtually all major maintenance organizations utilize some form of computerized management information system. Relatively few utilize computer based job aiding systems for the technicians, other than tracking parts or automatic test equipment. Most of the systems were developed internally, although the current trend is to use outside consultants and off-the-shelf software. Some airlines are marketing their information systems to other maintenance organizations. It is difficult to gauge the cost benefits of the current generation of systems, but few consider it possible to go back to the old manual methods.

The following describes the level of automation at several airlines:

**Air Canada** has several types of mainframes, including Honeywell, IBM, and Unisys. They utilize networked HP and Wang mini-computers, as well as PCs. Most information utilized by management is maintained using the computers.

**Alaska Airlines** uses an Amdahl mainframe that is networked to the maintenance base. The system tracks aircraft and component history. Macintoshes are available for management reporting and other applications.

**American Airlines** has many management activities automated and is currently studying a major new automation plan.

**America West** uses a Unisys mainframe running software developed internally. The system performs tracking functions and supports planning.

**British Airways** has IBM mainframes handling all management information processing and storage requirements.

**KLM** uses several computerized systems. One is called CROCOS (computerized rotables control system) and another is called COMPASS (computerized material procurement and supply system.)

**Northwest Airlines** has an extensive automation system called SCEPTRE. It runs on IBM mainframes and was developed internally. The system addresses most management information needs, and is still growing.

**Pan Am** uses a system developed internally called AMIS (aircraft maintenance information system.) This is also a mainframe based system and performs functions such as maintenance scheduling, technical services, and retrieval of maintenance items.

**TWA** has applications running on an IBM 3090 mainframe to track aircraft status, maintenance requirements, and support reliability analysis. Capability has been added to track parts and labor using bar code technology.

**United Airlines** is one of the few airlines with a separate department devoted to developing maintenance automation systems. They review proposals received from vendors and develop systems in-house.

**US Air** uses a system developed internally called MERLIN. It is an integrated set of applications running on a IBM 3090 mainframe. Some of the details of this extensive system are included as a part of the JPA survey in the Appendix. Modules have been developed to perform numerous functions such as tracking maintenance activity, discrepancies, component times, and preparing repair shop schedules. US Air also has a robot controlled parts warehouse system.

### 5.4.2.3 JPA Survey

A survey of job performance aids was conducted to assess the application of technology in aviation maintenance over the last ten years. The focus was on computer or microprocessor based systems used to process, store, or deliver information to the maintenance technician. The systems currently in use in commercial maintenance tend to be the information systems discussed above. The survey concentrated on novel approaches to analysis, diagnosis, decision and job aiding, although a sample of other applications are included. Brief descriptions are included in the appendix, and a summary is included in the Chapter Appendix. In the interest of conserving space, the description of some systems is not included.

The survey was comprehensive, but some proprietary systems or recently announced systems might have been missed. In any case, the sample gives an overall sense of trends, typical applications, and the envelope of system capability. The findings demonstrated that application of technologies to aircraft maintenance is still an experimental process. Most of the systems identified did not survive beyond feasibility studies and prototyping. Active systems tended to be in the development cycle, and few systems were integrated into the day-to-day maintenance process. The long term impact of JPAs is unknown, but few experienced sponsors demonstrated eagerness to develop more systems or implement existing systems in critical applications.

It is difficult to generalize, but there seemed to be a 15 year lag between the time when an application is technologically feasible and when it is refined to the point of being cost effective. The process of implementing technology is a long term effort, and for now, except for a few specific applications (i.e.. engines, avionics), there is little evidence that the JPAs have had a major impact on the way aircraft maintenance is accomplished. In some cases, sponsors were withholding judgement until the completion of development. None-the-less, there are a few success stories and many lessons to be learned from past efforts.

Sixty percent of the systems identified were sponsored by the military, with the Air Force being the dominant sponsor. The remaining 40% were divided between commercial aviation and other commercial industries. Each of the aircraft manufacturers had at least one system in development, although often through their military divisions. Many airlines developed maintenance information systems internally, but only a few airlines were major players in JPA development. The dominant applications were systems that supported on-condition maintenance of aircraft engines.

Engines are a particularly good application, because maintenance involves collection and analysis of a lot of data. The analysis requires expertise, but can be computerized since it involves identifying trends in the data. Computers are particularly adept at reviewing vast quantities of numbers and comparing them to limits.

The recent generation of aircraft incorporates built-in test (BIT) for avionics. The early systems tended to generate numerous false alarms, but accuracy has increased over time. BIT seems to be here to stay since there are few alternatives given the growing complexity of avionics.

Thirty percent of the systems were used for fault diagnosis. Forty five percent of the systems were management information systems, 45% were used directly to support maintenance, and the rest were used for analysis. Some novel applications were identified. Several organizations are working on systems that have an imbedded self repair capability. One involves use of an expert system to reconfigure aircraft aerodynamics in the event of system failure or battle damage. A handful of efforts are tracking trend data on structures to anticipate maintenance needs, similar to what is already done for engines. The analysis involves reviewing the trends in vibration data collected from sensors. For example, the VSLED (vibration, structural life, and engine diagnostic) system developed for the V-22 tilt-rotor aircraft monitors data and generates reports that specify needed maintenance actions. Several voice recognition systems have been developed that could be used for data entry by inspectors. A product recently marketed by Lanier Voice Products receives voice inputs and automatically generates reports. Another application analyzes samples of engine lubricants taken at regular intervals. The levels of oxidation, sludge, viscosity, fuel dilution, dirt, glycol, water, and wear metals are recorded and tracked to predict when maintenance will be needed.

Forty percent of the systems identified incorporated expert system technology, 15% were portable and all used state-of-the-art hardware technology. Several new technologies made their debut in recent years. Fuzzy Logic is an approach to logic that incorporates characteristics of imprecise reasoning. Rather than being only "on" or "off", the Fuzzy methodology permits degrees of "on" or "off". This approach is used with some success to model human reasoning processes. It is a popular approach in Asia, but has not caught on in the United States. One technology that is receiving increasing attention is Virtual Reality (VR). VR combines three-dimensional graphics with sensors attached to the user to create an artificial environment. The sensors detect movement and modify the three-dimensional display accordingly. For example, the user wearing a set of goggles with miniature displays can walk through an environment created by the computer. The systems have potential to be the simulators of the future. CD-ROM has received a great deal of press, but the technology has not been widely implemented. It has very large information storage capabilities, but requires expensive hardware to store and retrieve the data. It reduces duplication costs, but it is not any more flexible than paper and humans are uncomfortable reading information from computer screens.

Several systems were portable, but portability did not appear to be as important as might be expected. It seems for the type of applications that are needed, it is not a problem to go to a terminal and get a hard copy. Portability is only a factor if each technician is given their own system, not a likely event, given current hardware and software costs. Even "dumb" terminals are currently too expensive to give one to everybody.

The principal criterion that separated the successful systems from others was the utility to the user. The successful systems are typically in applications where there is no alternative, such as engine monitoring or avionics testing. Overall, the most ambitious systems tended to get into the most trouble, unless the developer was very persistent and well funded. The systems developed by the automobile manufacturers, were well funded and had persistent developers, but still received slow acceptance until a manual mode was added. Further, it is very difficult to estimate development costs unless the application is very specific and the requirements are rigid. There is a tendency to make the system general in nature to spread the development costs across as many users as possible, but this

inevitably lead to failure. The systems that targeted a very specific problem with a clear set of requirements fared best.

The road blocks to system development are establishing clear user requirements, software productivity, and the input/output required. Software is the principal expense in these systems and software development has been a long and arduous process. Several enhancements in software technology are beginning to address the problem. Computer Aided Software Engineering (CASE) tools are becoming more powerful. Object oriented programming is being implemented to facilitate the reuse of software. Authoring systems have the potential to enable users to develop their own systems. Currently, developing an application requires the developer to become an expert in the domain. Developing authoring systems is a major undertaking and no one has developed a JPA authoring system yet. Progress is being made in the I/O area in terms of graphical user interfaces, voice recognition, and computer vision. However, it will be some time (more than 10 years) before information can be communicated between humans and computers as rapidly as between humans.

### 5.4.3 Technological Obstacles

#### 5.4.3.1 Technologies

The question might be asked, "What does technology have to do with human factors?" The answer is three fold. First, technology (especially "new" technology) is often sold as a solution for human factors problems. Secondly, observation shows that one of the greatest challenges of implementing technology is the human factors challenge in achieving the necessary communication between developers and users. Lastly, all systems ultimately interact with humans on some level and care must be addressed to human system interfaces.

Technology is a tool for developing systems that facilitate aircraft maintenance, but in itself does not solve any problems. For example, artificial intelligence is a tool for software development, but it is not a maintenance automation system. New technologies are developed at a rapid pace, and, in the fervor to find applications for technology, realism tends to be a casualty. Technologies are always "emerging", and industry often buys the "latest" technology. This aspect of the research seeks to diffuse this in favor of a more pragmatic assessment of the role of technology. Importantly, these findings are absent the salesmanship that often accompanies discussions of technology, as the researchers have no stake in any particular technology. A central effort in the research involved assessing the contribution already made. Comparison of past expectations and actual contributions provides insight into future contributions.

The Automated Intelligent Maintenance System (AIMS) is a typical example that illustrates the plight of many JPAs. AIMS was designed as a job aid for Army truck maintenance. It featured expert system and voice recognition technology, along with a computer screen that displayed schematic diagrams and installation drawings. It was wireless and packaged in a large briefcase. In addition to delivering technical maintenance information, AIMS was designed to track maintenance records, order parts, control inventory, maintain schedules, and support training. Over a million dollars went into development and a working prototype was fielded. However, the effort was ended when technicians were reluctant to use the prototype and the cost of updating the database was recognized. The system simply did not have the utility the technicians needed.

While not typical, the Air Force's Integrated Maintenance Information System (IMIS) serves as a model of how Job Performance Aid development efforts should proceed. It also gives a sense of the magnitude of the effort and perseverance needed to successfully implement a JPA. *Table 5.4* identifies the time frame involved. IMIS is designed to be a single source of information for Air Force technicians. Technical data, diagnostics, training, historical data, and maintenance management information normally obtained from diverse sources is integrated by IMIS. IMIS has an interface for the aircraft maintenance data bus and can process information from BITE. The aircraft is identified through the interface and IMIS automatically provides aircraft specific information. In addition, IMIS has data entry capability and helps to generate necessary reports. IMIS was initiated by a concept paper in 1979 and a full up system demonstration is expected in 1993. Constant attention to the user, from assessing needs to final acceptance, is identified as the characteristic that leads this program to be more successful than others. It has proceeded in a phased manner from concept development using off-the-shelf hardware to field tests using custom hardware. The program has continually evaluated and enhanced the man-machine interface. The IMIS program is working on a complete set of specifications that could be adapted by others with similar objectives. The lessons learned by the Air Force during the development of IMIS can be utilized by the commercial industry. However, commercial and military approaches to maintenance are not the same, and IMIS technology may not transfer directly to commercial maintenance.

Clearly maintenance will be different in thirty years and anything is possible, but the survey demonstrated that, for at least the next ten years, there is little evidence that technician job performance aids will be widely used in commercial aviation maintenance. The research reveals twelve reasons for this conclusion:

1) The Department of Defense is not planning to field systems until the middle of the decade. Commercial maintenance applications are at least five years behind the military in development.

2) Development of the systems in the automobile industry took nearly a decade and the application is more well defined. User acceptance has improved, but the cost effectiveness of the automobile systems are not clear.

3) Commercial aviation maintenance is performed by the users. Airlines and repair stations do not have the resources to undertake major development projects. Manufacturers have resources but insufficient motivation since they are not the primary maintainer of aircraft. Built-in Test systems are an exception and BIT will continue to be enhanced by manufacturers.

4) The per user cost of hardware stands at $3-5K. Although it is somewhat a function of utility, the margins in maintenance operations are not likely to support systems for every technician until system costs are under $100 per user. Acceptable costs are somewhat more at the supervisor level, but not more than $1000 per supervisor. Expensive equipment is often purchased to comply with regulations, but there seems to be no reason to regulate the use of JPAs.

5) Benefits of JPAs are primarily intangible.

6) Experience shows that user acceptance is difficult to achieve. The reasons vary from poor man-machine interface to a lack of utility. Contrary to conventional wisdom, distaste for technology was not a major reason for lack of user acceptance. Systems that did not facilitate the maintenance effort were not supported.

7) Hardware and software technologies advance so rapidly that fielded systems become obsolete over a relatively short period of time. Once an organization commits to using the systems, it is very difficult to avoid the expensive temptation to track technology changes.

8) Maintenance operations are still trying to integrate and justify automation systems implemented in the last decade. There seems to be little eagerness to start a new phase.

9) There are at least a dozen systems now looking for commercial maintenance sponsorship, none have found one.

10) The current approach to maintenance is working. As long as JPAs are not mandated by regulation or warranted due to a lack of capacity or manpower, there is little reason to try something new.

11) The utility of the systems is not clear. The types of information needed in maintenance are diverse and difficult to quantify. In the time it takes to enter a query into a computer, most questions can be resolved by talking with an experienced co-worker.

12) There are still enhancements possible in aviation maintenance through more effective use of existing resources, in particular human resources. Thus, there is little motivation to introduce new systems with new unknowns.

A few applications did seem to have potential. One was the use of expert systems to document the knowledge of experienced technicians that are retiring. These systems can be feasible if they are done for very specific applications. There are also opportunities to field technologies that give technicians better knowledge of the "big picture." Knowledge about the performance of the organization, priorities, successes, and anticipated workload does not always reach the people who actually work on the aircraft. This information, which is already used by management to assess the overall operation of the maintenance organization, would be useful to a technician on the floor.

### 5.4.3 Computers and Microprocessors

The enthusiasm about technological solutions to human factors problems revolves around the growing capability of information processing technologies. The fact that computers are becoming more powerful, smaller, and less expensive is widely covered. Computer processing speed, often measured in millions of instructions per second (MIPS), has doubled every three years for over twenty years. The price of each MIPS falls as more and more circuitry can be integrated on a single chip. The computer industry, in a very short time, has become one of the few trillion dollar industries that exist. It is safe to say the capabilities of computers will continue to increase, but additional considerations are necessary before it can be concluded that aviation maintenance needs more computers.

A basic understanding of how computers operate is useful in assessing where they can be applied. While the processing power of computers has increased many orders of magnitude, the architecture and the basic operation of computers has seen little change since 1946 when mathematician John von Neumann proposed a "Logical Design of an Electronic Computing System". He introduced

**Example Development Cycle**

| Rank | Description | % Total Time |
|---|---|---|
| 1. | Identification of need | - |
| 2. | Feasibility study | 3% |
| 3. | Development plan and schedule | 2% |
| 4. | Definition of user requirements | 15% |
| 5. | Definition of user requirements | 10% |
| 6. | Initial system development | 3% |
| 7. | Small scale demonstration | 2% |
| 8. | Small scale test and evaluation | 3% |
| 9. | Final system development | 22% |
| 10. | Installation | 10% |
| 11. | Final integration- making changes to obtain user acceptance | 30% |

Note: Steps are in order, but are largely iterative

**Table 5.4 Development Time Frame for IMIS**

the concept of stored programs and an architectural structure that remains the basis of computers today. This architecture has some basic features:

- Single Memory
  - sequentially addressed
  - common storage of data and program
  - unidimensional
- No hardware distinction between data and instructions
- No hardware meaning of data

When von Neumann proposed his architecture, many hardware limitations shaped his decisions. These constraints no longer exist, but his architecture has persisted. There is considerable momentum building in the area of parallel computing, but even this effort is based on parallel von Neumann architectures. The principal reason for the persistence of this architecture is the need for backward compatibility. In other words, the need for old programs to run on new computers. During any given generation of computers, there is a considerable investment in software. It is undesirable to lose this investment every time a new computer is fielded.

The reason for raising this issue is that a computer's architecture drives its inherent functionality and the amount of software effort necessary to achieve other functions (i.e.. not processing speed). A primary characteristic of the von Neumann architecture is its generality. All application characteristics must be specified in the software. This is true no matter how many MIPS a particular generation of computers can claim. One example is the constraints related to memory allocation. Computer programs must explicitly account for all anticipated memory needs. If a description is going to be associated with parts in a parts tracking application, a field must be defined for the description. The length of the field is fixed in the software, for example, perhaps 20 characters. Once this is done, 20 characters worth of memory will be allocated for every description. Even if a part has a short description, it will be stored with 20 characters worth of memory. If a part has a particularly long description (perhaps longer than anticipated during software design), its description still has to be limited to 20 characters. Additional flexibility could be achieved by setting aside 40 characters of memory, but memory is expensive in terms of purchase price and slowing down processing rates.

Even more important than memory allocation is the processing limitations associated with the Von Neumann architecture. It is often noted that computers process 1's and 0's, but what does this really mean? The 1's and 0's represent numbers in binary format (i.e.. 0101 is equivalent to 5). All of the processing done by the computer revolves around manipulating binary numbers. There are only a few ways in which numbers can be manipulated by computers. 1's and 0's can be added together, compared,

decremented (or incremented), shifted (left or right), transferred and accessed from memory. Other arithmetic or logical functions can be achieved by adding several flavors of memory and instructions for combining the basic operations. Using these basic functions, computer programs can carry out an enormous variety of applications. However, the point is that computers only work with numbers, and there are inherent limitations to the non-numerical capabilities of computers. The numbers being manipulated might represent "numbers", but normally they represent various elements in the application. Computers do not inherently "know" anything except the meaning of numbers, as a result, everything else needs to be explicitly predefined in the software. For example, computers might represent an aircraft with the number 37889 and a wing by 98843. If the application requires knowledge about the relationship of aircraft and a wing, this must be explicitly stated in the software by other numbers. In contrast, the representation of aircraft and wings utilized by humans inherently represents their relationships. Once a human understands the meaning of "aircraft", they inherently understand wings. Therein lies the fundamental weakness of computers: everything and all relationships must be explicitly defined. This is not to say that all relationships cannot be defined, but that doing so is very often an enormous undertaking.

The result is that less expensive, more powerful computer hardware does not necessarily warrant application of more computers in aviation maintenance. The largest task involved in applying computers is independent of processing speed, it is explicitly understanding and documenting all of the information needed to accomplish the application. New techniques being are identified to facilitate this process. Standards are increasingly being established to facilitate the reuse and portability of software. Computer Aided Software Engineering (CASE) tools are further increasing the productivity of programmers. Artificial Intelligence is an example of a software technology that makes efforts to develop human reasoning applications more productive and well defined. Expert System and Database technologies also fall into the category of approaches to make the software process more productive. None-the-less these technologies do not change the fundamental need to define all application elements and relationships explicitly.

Solutions based on computer technology must also address security, configuration, and the threat of computer viruses. Passwords usually provide sufficient security, but configuration can be a major challenge. The primary issue is that, once a program is written and distributed to different locations, each location can make changes in the software. The result is a variety of versions of the software and some confusion. As a result, it is normally necessary to have a configuration manager to track the integrity of the code. Computer viruses are more of an unknown. These are software programs that can sabotage applications and stored information. Viruses are primarily a problem for computers that communicate with remote locations, but the possibility of overt or accidental contamination is always possible. Techniques and expertise exist to address these issues, but all of these issues represent additional considerations involved in computer applications.

### 5.4.3.3 Artificial Intelligence

Artificial Intelligence (AI) has achieved "buzz word" status, and is frequently advocated as the heart of automation systems of the future. Although AI has not produced a machine that can think, the field has developed several new software development techniques. Expert Systems are the most successful example of these techniques. The aim of research in AI still includes the pursuit of machine intelligence, but for practical purposes, few believe this will be achieved any time soon. AI does have some applications in aviation maintenance, but it is important that these efforts are initiated without any illusions about machines becoming intelligent. AI is warranted if an application would benefit from "human-like" reasoning. AI provides a structured methodology for incorporating this reasoning into programs. Remember, however, that all elements and relationships must be specified, computers do not have intuition. It is helpful to keep this in mind when assessing the feasibility of a particular activity. The more information (knowledge) necessary to carry out the application, the more complicated, time consuming, and expensive the project will be. This includes knowledge that seems obvious to humans, such as the relationship between an airplane and a wing. Nothing is obvious to computers!

The field of Artificial Intelligence has developed structured methodologies for accomplishing several types of capabilities. There are techniques for voice recognition, speech understanding, computer vision, text understanding, robotics, and decision aiding. Researchers continue to work on automatic programming and learning. All have capabilities far short of humans and require major development efforts. For the most part, it will remain economical to utilize humans for applications that require human capabilities.

### 5.4.3.4 Expert Systems

Expert Systems now enjoy wide popularity. Expert Systems achieve intelligent functionality in a straight forward manner. They are based on "if-then" rules. For example, "if the object is a 747, then it has wings". The heart of expert systems are rules that address every relation-

ship of interest in the application. While the concept sounds simple, developing an effective approach to implementing these systems took considerable time.

The process is now facilitated by the use of software packages called "expert system shells". Developers no longer need to spend large amounts of time coding the structure of the expert system. These packages normally contain development environments that facilitate building the knowledge base and designing a user interface. There are many shells on the market to suit different needs, but large complicated expert systems are often customized. Shells have limitations of functionality and flexibility, but there are few (if any) aviation maintenance applications that can be implemented cost effectively by a custom expert system.

When a shell is utilized, roughly 50% of the effort is planning and documenting the knowledge to be represented by the expert system. *Figure 5.1* shows the overall structure of an expert system. This process requires two kinds of people, one is frequently labeled the "knowledge engineer" and the other is the domain expert. It is the knowledge engineer's job to develop the rules that will be the basis of the expert system. This is as much of an art as a science, since it is never possible to be sure the knowledge is complete. Domain experts do not readily think in terms of explicit rules so these need to be drawn from answers to questions. Expert systems can not be developed from technical manuals, live experts are needed. Much of the power of an expert's knowledge is in terms of nuances that are not contained in manuals.

The process starts by assessing the types of issues that will be encountered by the final product. Likely scenarios are identified, and the expert is asked how they might respond to a given scenario and why. The difficulty is that there is no way of knowing for sure if all scenarios the operational expert system will experience have been addressed. Thus, it is never possible to know if the rules obtained from the expert are sufficient. Unfortunately, as with most computer applications, changes once the system is operational are not easy. The reason is that rules entered into the program are written in terms of models of the system and possible interaction between the elements of the system. Adding to the existing rules is not a major undertaking but, if the model must be changed, it can have implications for many rules.

It is not possible to know how the system will respond in an operational environment because only known scenarios can be tested. This uncertainty leads to a critical criterion for determining the feasibility of an expert system. The problem has to be very well defined. The success of the project will be further jeopardized if the problem is not rigid and changes during the project cycle.

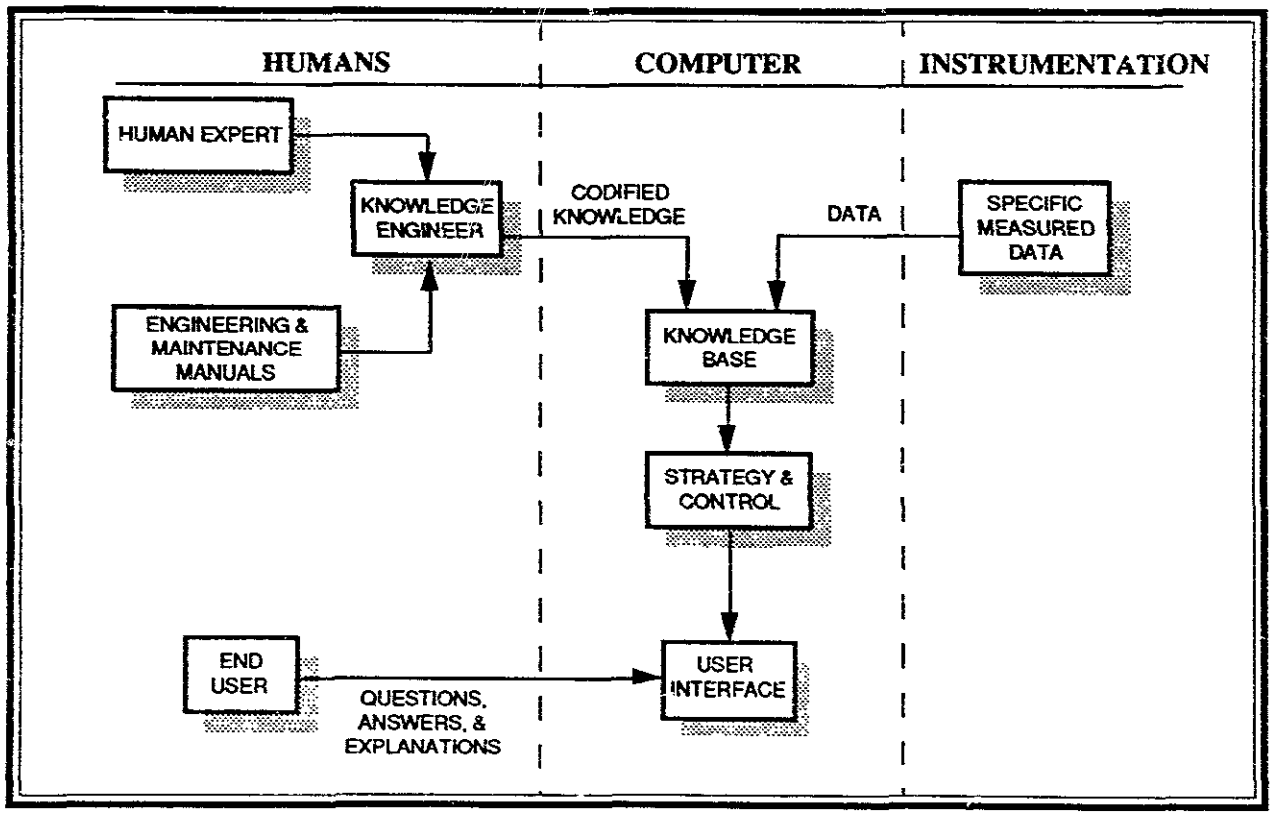


**Figure 5.1 Expert System Diagram**

The final expert system is usually implemented with a menu interface. The user navigates through the system by selecting items on menus. Data is entered in a similar manner by selecting one of several possibilities offered by the computer. The interfaces are becoming more graphical and intuitive, but the computer still only understands numbers. The software associates each element in the menu with a number. For example, if the observation to be considered is that there is a "blue stain on the fuselage" it would be too difficult for the software to associate a number with each of the words. In addition, there are numerous ways in which the same message can be conveyed in natural language. This problem is avoided by creating menus of options, each of which is assigned a number. This is an additional limiting factor, since it may not be possible to know ahead of time all of the possible conditions that should be addressed in menus.

Once an initial question is asked by the user, the expert system will prompt the user with questions until it has the information necessary to satisfy the rules. The rules in the expert system are normally given associated confidence factors. For example, if two conditions exist there is some amount of confidence that a third condition exists. This information is presented to the user along with conclusions and the list of rules that were applied to reach the conclusion.

One of the steps of expert system development is the thorough documentation of knowledge in a particular area. This can be a useful product in itself if an expert is nearing retirement. This is not an unusual situation, since the expertise we value most is that gained over a life time. The aviation maintenance industry is facing the retirement of a large percentage of its work force over the next decade. Expert systems might be warranted in some specific, well defined areas.

### 5.4.3.5 Databases

There is a science to collecting and maintaining information with computers. The primary task is to ensure that information will be readily accessible when it is needed. Numerous software packages are available to facilitate this process for most applications, including packages specifically designed for aircraft maintenance. The task of database development involves three steps. The steps and percentage of total time required are listed below:

| | |
|---|---|
| Planning | 30% |
| Implementation | 60% |
| Data entry | 10% |

The most deterministic step is the data entry effort. If you can assess how long the data entry will take, it gives you some idea of the magnitude of effort involved in the other steps. The implementation stage is a matter of learning the particular software package involved and carrying out the steps required. The planning stage is the most critical and the least defined. Databases are essentially made up of numerous small databases with links between them. The planning process involves predicting the characteristics of all of the types of information that are to be included in the database. In addition, all the possible uses of the information need to be known ahead of time. This is usually done by developing input screens and reports with the help of the user.

The person that enters information into the database, enters information into one or more fields. These fields correspond to the possible classifications of the information. The fields explicitly link the new information to information already in the database. For example, a maintenance database might have a field for part number, aircraft type, part description, quantity available, or other designations. The number of ways information can be accessed is a function of the number of fields, but each field takes data entry time and the number of fields should be minimized. The final database is the developer's interpretation of the user's needs. For the interpretation to be accurate, developing a database requires careful communication between the user and the developer.

As with other efforts to implement technological solutions, it makes sense to start small. A demonstration database should be built to test assumptions and obtain additional input from the user. Databases can not be easily modified once they are complete, so it is important that the process not get too far ahead of the user (i.e.. entering vast amounts of data without obtaining user acceptance of the approach).

There are other considerations once the database is complete. Data entry should be carefully controlled to maintain the integrity of the information (i.e.. two people entering different versions of the same information). Once again, major applications are likely to need a specialist to support and maintain the database.

### 5.4.3.6 Peripheral and Supporting Technologies

**Storage media.** Data storage is currently accomplished with magnetic and optical technologies. The vast majority of memory devices use magnetic technology, for example floppy disks, hard disks, tape, cassette, and most mainframe memory peripherals. The major advantages lie in its cost, physical size, power requirements, and speed in accessing data. Industry manufacturers such as Conner Peripherals, Seagate, and Toshiba continuously identify enhancements.

Optical Technology, which is used in compact disk read-only memory (CD-ROM) and write once read many (WORM) systems, is relatively new. The major advantages of optical storage technology is its large capacity and the reliability of the data (i.e.. it is not as susceptible to magnetic fields or physical contamination). The major disadvantages are in data access times which are long due to data file format and the lack of standardization found in WORM technology. In addition, the hardware is more expensive than that used with magnetic storage mediums. The advent of rewriteable optical storage based on magneto-optical technology, may increase the utility of optical systems.

**Input methods.** The keyboard remains the primary input device for computers, however, a number of other options are becoming available. These include touch-screen, voice recognition, mouse, bar code readers, stylus and handwriting recognition software. Touch-screen is currently used in applications such as manufacturing environments where keyboard input is not feasible. It is mainly integrated in CRT displays with some use in flat-panel displays. Voice recognition systems have made considerable progress to the point where vocabularies of 60,000 words have been achieved. The systems are probably still not practical for the maintenance environment for cost reasons, their tendency to require words to be repeated, and the problems caused by extraneous noises. Data entry by mouse or joy stick is relatively routine. Bar code readers are finding increasing application. TWA uses bar code technology to track labor and parts. The first commercial portable computer to accept handwritten input is expected in December 1991. The hardware for this system will cost around $5000 and there are a numerous constraints about how the handwritten inputs are made; however, handwritten input may eventually be useful for specific maintenance activities.

**Output methods.** There are several display technologies, including Cathode Ray Tube (CRT), Flat-panel, and miniature displays. CRT display technology has progressed from monochrome, low resolution displays to multi-colored, high resolution systems as the industry standard. Current trends indicate resolutions will continue to improve for greater picture quality. Flat-panel displays offer a low-profile alternative to the CRT. The three major technologies offered in flat-panel displays are the liquid crystal display (LCD), the gas plasma display, and the electro-luminescent (EL) display. The major challenge in developing these displays is to make the screen readable in virtually all lighting conditions, at high resolutions, and produce it at reasonable costs. Currently this flexibility is still elusive. This is complicated even further if a color screen is desired. Currently, displays are being produced in all three technologies with the LCD technology dominating most of the flat-panel market (i.e.. for PC laptops.)

A flat-panel display technology currently under development is called field-emission displays. They take advantage of the basic principle of the CRT, but rather than using a bulky, high voltage electron gun, it uses a micron-size cone-shaped structure called a "field-emission cathode" which can produce the same results as a CRT, at much lower voltages.

A display developed by Reflection Technology called the "Private Eye" is worn by the user on a headset. It is a miniature display (1x1 inch) that is placed in front of the users dominant eye, and creates the illusion of a full (10x12 inch) display. It costs around $600, but it is not yet practical for aviation maintenance. Use of the system demonstrated that the head set is awkward and keeping the display in the right location for viewing requires constant attention. In addition, looking at the display for any length of time becomes uncomfortable.

Printers increase in quality and become less expensive each year. Printers remain the principal form of computer output. Voice synthesis as output has found some applications in telecommunication systems, but are as yet too expensive and inflexible to be applied in more than a few aviation maintenance activities.

### 5.4.4 Implementation Guidance

#### 5.4.4.1 System Integration

This section relates lessons learned from a decade of implementing technology in aviation maintenance and other applications. Technical functionality is normally the focus of development efforts, but experience demonstrates that Human Factors issues are the principal barrier to success. Humans remain the engine for most complex systems. For example, even automatic test equipment (ATE) is dependent on humans for planning, design, manufacturer, installation, and maintenance. Aircraft maintenance in thirty years will be different than today, and automation will certainly have a larger role. The question is how do we get to that future system with a minimum of trial and error? The answer seems to favor the "tortoise" over the "hare". Development efforts in the 1980's demonstrated that implementing new technologies is an expensive and largely experimental process.

Overall, the findings indicate that unless an organization has the resources to experiment with technology, it should wait for others to work out the "bugs". If a system

development project is undertaken, it should be done with "eyes wide open" and not based the fact that it is "technologically feasible". There are numerous lessons to be learned from past efforts on this account. Finally, it our finding that for the foreseeable future, humans will remain central to maintenance, and implementation of technology should be centered on supporting human activities.

#### 5.4.4.1.1 Planning an Automation System

There are numerous reasons for needing a system and even more functions the system can perform, but once management recognizes the need for a system more details need to be considered. *Table 5.5* list the typical steps in a feasibility study. Many early systems were developed without sufficient input from the end user and, in some cases, the final system was rejected (or ignored) by the users. Maintenance organizations are now very sensitized to the importance of incorporating user requirements. Large airlines have internal data processing departments and some large and small airlines use consultants to help in system development. The process requires a close working relationship between user and system developer. Often user organizations are surprised to learn that system development requires the full-time involvement of one or more staff members, and the part-time involvement of many staff.

Once a team has been assembled from the two groups the planning can begin. Three types of information must be obtained during the planning process. The first is determination of system requirements and the functions the system will perform. The objective might be to computerize the current system, in which case research is probably needed to identify existing types and flow of information. Requirements might also go beyond the current system in specific areas. It was noted that ineffective manual approaches remain ineffective when done on a computer, thus existing approaches should be carefully scrutinized before they are computerized. The requirements process might also involve a number of visits to different locations to assess what others have done.

Once the requirements of the system are determined, the approach for implementing the requirements is developed. Naturally, it is desirable to build on existing systems. The approach should be divided into modules that can be developed and fielded incrementally. Benefits should not wait for the entire system, each module should add value. Anticipated screen layouts and report formats might be identified at this stage. The next step is to bring the requirements and the design concept together in an implementation plan.

This is the stage that requires the closest cooperation between user and developer. Numerous tradeoffs are

**Example Feasability Study**

| Step | Description | % Total Time |
|---|---|---|
| 1. | Rapid needs assessment | 5% |
| 2. | Survey of management support & team building | 5% |
| 3. | Airline analysis- existing verses needed resources | 10% |
| 4. | Definition of requirements | 25% |
| 5. | Definition of approach to design | 20% |
| 6. | Reassess requirements and design with users | 10% |
| 7. | Justification - benefits | 5% |
| 8. | Justification - costs | 10% |
| 9. | Overall development approach | 10% |
| 10. | Report - written and oral presentation | ongoing |

Note: The steps are listed in the order that they will be carried out, however, most steps are iterative in nature.

**Table 5.5 Steps Involved in a Feasibility Study**

always needed to make implementation feasible. Users need to ensure that priority of various functions are known by the system developer. Otherwise, facilitating hardware and software development will drive trade-offs and the result may not be acceptable to the user. Once the planning stage has been completed, it is possible to make a more realistic assessment of the advantages of automation. Cost estimates should be balanced with promised benefits.

#### 5.4.4.1.2 Human Factors

The objective may be to implement technology, but the success or failure of system integration very often comes down to Human Factors issues. The development task is basically one of reconciling the needs of two groups. The group developing the system knows what needs to be done to achieve a particular functionality. The group that will use the system knows what functions they want implemented. Unfortunately, approaches that are easier for the developers often produce unsatisfactory results for the user and vice-versa. The tradeoffs must be negotiated between the groups and there-in lies the Human Factors challenge. The groups have disparate languages and perhaps even disparate goals. The system developer is usually judged by the cost and the rate of development progress, and the user's focus is on maintaining aircraft. The process requires constant communication between these groups. The user is usually interviewed to determine his requirements, but unless there is a constant exchange of information, the final product ends up being the developers interpretation of what the user needs. Thus, a primary lesson of efforts to date is that there is a need for increasing consideration of human factors in system design. A paradigm that centers system integration on humans (end users and those that participate in system development) and not on emerging technologies is warranted. There is an enhanced awareness of the need to focus on the user, but the current paradigms still focus on technology.

#### 5.4.4.1.3 Alternatives

The least expensive approach to implementing technology is not to do it at all. Organizations can get hooked into competing based on who uses the most advanced technology, but given that the product is aircraft maintenance this can be an expensive diversion. Implementation of technology is not the only avenue for addressing the increased complexity of aircraft maintenance. The research program on ***Human Factors in Aviation Maintenance***, of which this technology study is a part, is designed to develop approaches to make more effective use of the human resources. Peak human performance is a function of a number of factors and current management techniques do not address them all. Quality Circles and similar employee involvement programs were a start, but there is a need for additional creativity in increasing worker production. Aircraft maintenance organizations focus on the factors that make humans capable of doing the job (training, tools, support equipment), but many do not adequately address factors affecting human willingness to do tasks (participation in decision making, economic incentives, recognition programs).

Alternatives should be considered before system development is attempted. The availability of new technologies is not in itself a reason to implement technology. One factor that characterizes successful use of technology is that they are in applications where there are no alternatives. Examples include systems that support on-condition maintenance of aircraft engines and tracking parts.

#### 5.4.4.1.4 System Development

If there are no alternatives and the decision is made to implement a technological solution, there are a number of things to consider:

1) **It is never easy the first time.** If an application is particularly suited to a technological solution, there will eventually be numerous off-the-shelf packages available. If the proposed application is the first of its kind, beware. Systems are built from numerous individual technologies for everything from wire to metal cabinets. The system is dependent on all of these elements working together. Failures can occur anywhere. Successful implementation of technology requires explicit consideration of every possible outcome. Once similar systems have been built, knowing all of the possible things that can go wrong is easier. One way to address this is to build a small scale version of the application and test assumptions.

2) **Use the most experienced talent available.** Nothing replaces experience when it comes to developing complex technical systems. The experienced person will cost more hourly, but the job will be completed much more thoroughly and rapidly. If experienced help seems to be too expensive, it should raise questions about whether there is sufficient resources to undertake the task at all.

3) **Whatever can go wrong will go wrong.** Canceling a project because of problems encountered can be very disappointing and expensive. The project should not be initiated without recognizing that numerous difficulties will be encountered. The difficulties will be proportional to the maturity of the technology and the experience of the individuals involved. Installing dedicated ATE from a manufacturer may have a few unexpected problems, but internal development of unique ATE

which incorporates voice recognition can expect many.

4) **Requirements should be specific and rigid.** In effect, system development requires predicting the anticipated use of equipment and the operating environment. This is nearly impossible as applications become more general. Avoid the tendency of requiring equipment to be more general in order to spread the development costs across more applications. Rigid requirements are necessary, since changes become more expensive to incorporate as development proceeds. *Figure 5.2* illustrates the increase in cost as the project proceeds.

5) **The system should be fielded incrementally.** Each element should add value, and the changes to the current approach should be made slowly. This permits an ongoing process of evaluation and enables users to provide inputs and become accustomed to the system. Waiting until all resources have been expended is not a good time to discover the success or failure of a system.

6) **Assume technology will continue to change.** The three or four year cycle needed to implement technology corresponds with the three or four year cycle in which major new technologies are developed. The result is that by the time a program to implement the last generation of technology is done, a new generation of technology will be available.

#### 5.4.4.1.5 Maintenance Automation

Automation system development is normally controlled by data processing personnel. The users will usually assign one person to act as a liaison to insure their interests are incorporated. Problems can arise in several areas. Technological considerations that simplify system design are often incompatible with features that simplify use. The computer's affinity for numbers versus human affinity for symbols is in constant conflict. Unless the design team has considerable experience in the application area, they very often underestimate the effort required. When deadlines approach, user requirements are vulnerable.

Neither group may have a strong understanding of human factors considerations, and human factors specialists are often not a part of the design team. Approaches that facilitate the incorporation of human factors exist and should be considered. The MANPRINT (manpower and personnel integration) program at the Army has developed a very specific process to incorporate human factors considerations in system integration of large systems. They have also accumulated over 70 resources that are available for addressing human factors, including the following (Booher, 1990):

- Analytic Techniques
- Computer Software
- Data Bases
- Handbooks/Guides
- Military Standards/Specifications

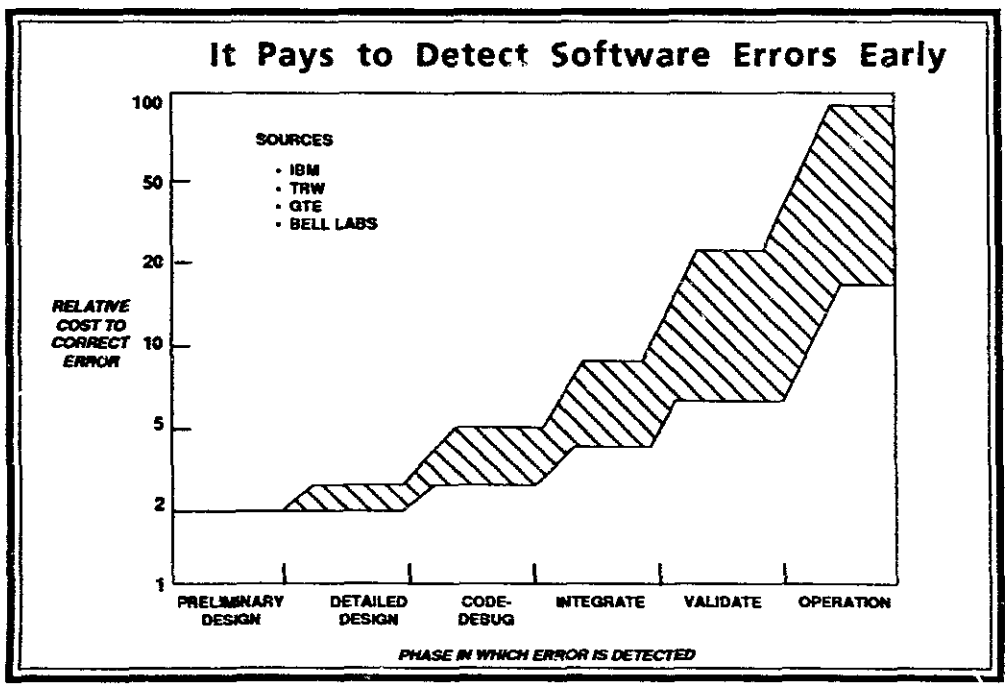


**Figure 5.2 Cost of Correcting Software**

Maintenance data processing professionals and managers learned the following from experience:

Ensure user involvement and support during all phases; there should be no surprises in the end.

It might even be necessary to ensure the users have a realistic knowledge of the challenges of the process to avoid excessive expectations.

Do not chase the latest technology, and be conservative on the number of functions automated.

The definition of the functions automated should be very precise.

Design in flexibility and anticipate future needs.

Build the system in an incremental manner where each module can return value as soon as it is complete.

Do not lose sight of the fact that maintenance is the mission of interest and computerization should not become an end in itself.

The original justification of automation systems can be lost in the "heat" of implementing the system. Evaluations and expectations should be verified on a continuous basis from proposal throughout the life of the system.

### 5.4.4.1.6 User Requirements

It has not been productive to compel humans to use automation systems, thus success depends on obtaining user acceptance. The problem does not seem to be a general reluctance to use technology, but resistance to systems that do not have adequate utility. System developers are now well sensitized to the importance of considering the user, and will always claim advocacy of user needs. The problem is that addressing the users needs is not easy, and simply asking users what they want rarely suffices. The users know and understand the current approaches for getting the job done, but not to the level of detail needed for computerization. In any case, if the most appropriate approach is different from the current approach, users may not be the best source for requirements. The criterion of "user friendly" might suffice as an objective, but is too vague to be a useful design criterion. Developing a system that addresses user requirements is difficult not only because user requirements are hard to define, but because technologies can only be implemented in a limited number of ways. Implementation must be accomplished within a long series of constraints.

Achieving user acceptance requires system developers to take a broader view of design objectives. The system must be designed to achieve functionality so that the human is capable of using the system to achieve a task, but additional considerations are necessary before humans will be willing to use the system. Much can be accomplished by simply asking, as long as the developer is willing and able to give priority to even seemingly minor considerations. The design should account for the following:

Control should remain with the user. Humans are naturally uncomfortable in situations where they do not have control over progress. In most cases this is not just when, but the frustration that results from identifying a more efficient approach and not being able to enact it.

Gaining user input should be more than a one step process at the project's beginning. Often users don't know what they really want or need and don't know what is possible. User input must be an interactive and iterative process explicitly scheduled and evaluated throughout the development stages. Involve users in the decision waiting process when considering alternatives and options. Let users test the proposed system and see if they really like the approach. Often the user does not, for reasons they were unable to predict from a concept description.

Humans should not be expected to assimilate vast quantities of data or information. Computers have the capability to keep vast amounts of information on-line, but the information should not be presented to humans all at once. The challenge of serving as a source of information is not just to provide access, but to provide rapid access to needed information and nothing more.

Single data entry should serve all parts of the system. Data entry is a "bottleneck" for computer based systems and is made worse if disparate systems can not share data. Applications that are input or output intensive should be avoided.

Systems should provide tangible benefits for the work force. It seems obvious, but there should be some clear benefit in using the system. If the benefits are in terms of greater profitability of the organization, then that should be communicated to the users. Humans are naturally reluctant to use systems that increase their workload with no clear benefits.

Computers should serve humans. Computer systems depend on humans for data entry, maintenance, and upgrades, so it can start to be confusing who is serving who. Humans usually need to adapt their approach to fit the computer. The use and benefits of computer systems should be clearly

stated and clearly demonstrated, so that humans will know why they should want to adapt.

Users should be allowed to optimize the system. System development may end with a working system, but there are always enhancements to be made. Users are the best source for identifying these enhancements.

There are several general considerations that apply to technology in commercial aircraft maintenance:

**Cost** - few maintenance organizations can afford to pay for the development of new technology applications. Some can afford to purchase systems developed by others. In any case, the vision of every technician walking around with a portable job performance aid is some time off, unless the benefits become more tangible. A system that provided access to maintenance manual information would be worth less than $100/technician in tangible benefits.

**Hostile environment** - technology is fragile, and making it durable can be expensive. While most maintenance activities are not greasy or done in the rain, things do get dirty or dropped. Experience with microfilm readers and computer terminals demonstrates durability is important.

**Information needs of technicians** - the information needed by technicians is not easily quantified. It is not simply a matter of placing technical manuals on-line. Technicians need numerous types of information:

- Location of tooling and fixtures
- Work completed on previous shift
- Location or arrival time of aircraft
- Relative urgency of repair
- History of particular aircraft
- Remote effects of local actions
- Alternative repairs
- Procedural nuances

**Portability** - given current per user costs, it is likely that systems will have to be shared between many technicians. As a result, they need only be located in a central location.

**Graphics** - Graphics are expensive to display and store, so there is some motivation to minimize them. However, illustrating what has to be done is much more effective than text instructions, so graphics are essential to user acceptance.

**Training** - All new systems will have implications for training. These should be anticipated and planned. Training will have initial and ongoing elements.

## 5.5 RECOMMENDATIONS

### 5.5.1 Overview

This research is part of a larger research program on Human Factors in Aviation Maintenance Inspection. The interest is in strategies for enhancing current practice that might not be apparent from the perspective of maintenance professionals performing their day-to-day duties. The recommendations that follow are based on the first phase of Job Performance Aid research. The last two phases of research will demonstrate, validate, and develop approaches to implement the recommendations.

### 5.5.2 Recommendation 1

Make more effective use of human resources and realistically examine the utility of technology.

#### 5.5.2.1 Description

Additional consideration should be given to approaches that use human resources more effectively before new technologies are implemented. The process of fielding technology is largely experimental, and although initially appealing, it often requires more resources and produces less satisfactory results than anticipated. Fielding technology is important for long term competitiveness, but it is a long and expensive process. It is not a practical alternative to making more effective use of human resources today. Management of human resources should use a broader perspective when considering the issues involved in attaining peak human performance. The current focus is on elements that make humans capable of performing the work, but there are other considerations such as obtaining their willingness to do the work:

- Clear and concise goals
  - ownership
  - cooperation
- Job satisfaction
  - recognition of contribution
  - realistic expectations
  - adequate working environment
- Respect, trust, and loyalty
- Competence
  - physical
  - cognitive

Few would admit to placing more faith in technology than people, but the research demonstrated that low faith in the capabilities of humans was a large part of the motivation for system development. There is some discomfort with

addressing issues such as job satisfaction, and technology appears to be more predictable. However, if humans are used more effectively and technology is viewed more realistically, a different picture arises.

Research in this area and others addressed by the ***Human Factors in Aviation Maintenance and Inspection Research*** demonstrated that there is a potential for increasing human performance in aircraft maintenance. The untapped potential of existing human resources should be utilized and existing technologies should be completely integrated before new systems are fielded. Experience demonstrates that each new system introduces unknowns into the maintenance process.

### 5.5.2.2 Interventions

Maintenance managers are often too busy meeting the demands of the day-to-day maintenance effort to have time for reflection on alternative approaches to make more effective use of human resources. Changes can not be initiated bottom up, and no one person can change the philosophy of an organization. Affecting changes will not be easy. The ***Human Factors in Aviation Maintenance*** research effort is designed to increase awareness from the top down. Once it is recognized that further consideration of human factors might provide avenues to achieving more effective use of human resources, the next step is to test the idea. A pilot program can be initiated to provide a model of how human factors can contribute to the maintenance effort. Perhaps work on a particular type of aircraft or particular shop can serve as the test case. The effort should be carefully planned and the expected benefits should be tangible to include the following:

Reduced turn-around time

Increased quality

Reduced parts costs

### 5.5.3 Recommendation 2

Avoid user acceptance and system utility problems by centering system development on humans.

### 5.5.3.1 Description

A decade of user acceptance problems has led to an enhanced sensitivity of user needs. No developer will risk being perceived as insensitive to the user. However, sensitivity does not mean developers know how to effectively incorporate user needs in system design. Implementation of technology is still easier if the user is ignored. Developers need the expertise, resources, and staying power to end up with a system that is compatible with humans. The expertise exists, but a shift in thinking is needed to insure future systems will be accepted by the user. The perspective needed is one that centers system development on humans.

Many claim to work closely with users during system development, but not all are successful. Implementation decisions still tend to be dominated by a given technology's facility for achieving a given function. For example, most on-line work card systems do not incorporate pictures of the task described, because graphics are memory intensive and much more difficult to create than text. Perhaps, work-arounds can be identified such as pasting in graphics, after the fact, but this leads to other difficulties. For example, if the graphics and text come from two sources, the terminology may not correlate sufficiently. A system development perspective centered on humans might lead to a decision to hold off putting work cards on-line until pictures can be adequately incorporated. Care should be addressed to elements that seem to be minor inconveniences. Parts are no longer tracked by their name and description, but by numbers. If two parts look similar and have similar numbers, technicians might use a part without taking the time to track down the descriptions that indicate why the parts are not interchangeable.

In other words, once the conclusion is reached that more effective utilization of humans is not sufficient for a particular problem and a technology solution is warranted, humans should not be forgotten. So far there is no structure to insure this. This process can be facilitated by establishing up front that humans (users) are more important than technology. The process should revolve around helping humans maintain aircraft, and not the existence of a particular emerging technology. Tradeoffs during the development process should carefully consider the technological alternatives for increasing the utility of the system for the human users, and should not be dominated by eliminating functionality simply because it is technically inconvenient to implement. The reverse is also true; functions should not be added because they are technologically convenient. Developers and users should have shared goals.

### 5.5.3.2 Interventions

Boeing Corporation has taken the step of assigning a maintenance expert to a leading role in the development of their next generation aircraft (Boeing 777.) This individual has the clout to insure that ease of maintenance is a primary consideration in system design. Boeing was motivated to do this to increase customer satisfaction with their product. Equivalent steps can be taken in any system development effort. It is a matter of establishing from the top down that consideration of the user is paramount. If technology has not progressed enough to provide an approach that will provide the functionality needed by

humans, the development project should not be started until it does.

The Army's MANPRINT (manpower and personnel integration) program provides the largest scale demonstration of how human factors can be incorporated in system integration Booher (1990). Their program integrates consideration of human factors into the many phases of the acquisition process (request for proposal, proposal, award, design, implementation, test, and evaluation.) Consideration of human factors is a primary component in the award of contracts. For example, a soldier's lack of skills can not be faulted for system failure during test and evaluation. Designers are aware of the soldier's skills during the entire design process, thus there is no room for this justification. The initial apprehension of contractors about a heavy focus on human factors is usually diminished by the end of the process, and the results have been excellent. For example, the tools required to maintain one type of engine was reduced from 140 specialized tools and fixtures to a little over a dozen that can be found in most homes.

## 5.6 CONCLUSION

The conclusion of the research is that Job Performance Aid Technology is less mature and more expensive than generally accepted. Developing applications for new technology is important in the long term, but in the short term it should be secondary to increasing the effectiveness of existing resources, in particular human resources. Technology should continue to be applied in areas where there is no alternative. If a technological solution is chosen, the development process should center on humans. Most implementation efforts to date were successful in achieving a promised technical functionality, but few performed satisfactorily with the human user. Additional attention should be addressed to human factors in the development effort (i.e.. communication between developers and users) and human factors in the application (i.e.. user requirements and compatibility).

This is not the conclusion anticipated when the research was initiated. It was expected that a survey of technologies and Job Performance Aids would identify numerous systems that could make important contributions to aviation maintenance. At most, it was anticipated that some additional guidance might be needed in the design of the man machine interface. The research rapidly demonstrated that while projects were initiated with great expectations, few sponsors claimed the final product would have a major impact or were actively pursuing new development efforts. This is not to say there were no bright spots, as some programs such as the Air Force's Integrated Maintenance Information System (IMIS) can serve as models for future efforts. Efforts got into trouble when they underestimated the magnitude of the undertaking or tried to implement technology in place of better utilization of human resources. Increasing the efficiency of human resources is a lot more appealing when technology is well understood and viewed realistically.

The conclusion does not reflect the lack of capability of the system development community, but respect for the magnitude of the challenge involved in implementing technological solutions. It is the complexity of technology that warrants caution in promoting it as a near term solution. It is recognized that technology will be important for long term competitiveness, however, implementing technology is a long, expensive, and largely experimental process.

The mission of maintenance organizations should remain maintenance, and managers should not be lured by the seeming excitement of implementing systems at the leading edge of technology. No one expects a better version of humans to be available in the near future, and advocates of technology can always claim something new and wonderful is "just around the corner." However, commercial maintenance organizations should be pragmatic and expect technology to be accountable in the same way humans are accountable - "what can you do for me today?" Organizations should take additional advantage of what is known about achieving peak human performance. Technology is good and important, but it is not a "silver bullet".

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| NO. | APPLICATION | FUNCTION | NOTES |
|---|---|---|---|
| 1 | Mechanical systems | Data collection | Automatic |
| 2 | Materials | Parts delivery | Electrified-monorail |
| 3 | Avionics ATE | Fault isolation | Automatic |
| 4 | Display | Remote operation | Helmet mounted |
| 5 | Avionics | Training | for AMT's |
| 6 | System Data | Data collection | Airbourne |
| 7 | Engine | Built-in -test | |
| 8 | Avionics | Data Aquis. diag. | Automatic, in-flight |
| 9 | Tracks | JPA | Portable expert system |
| 10 | Fleet Maintenance | Analysis | Quantify maintenance errors |
| 11 | Scheduling | Scheduling | Airline developed & automatic |
| 12 | APU | Detection/Isolation | Flight-line JPA |
| 13 | Maintenance | Training | |
| 14 | Hardware | Maintenance | Expert system |
| 15 | Engines | On-conditon | Airbourne system |
| 16 | Components | Maintenance | |
| 17 | ATE | Code generation | Prototype |
| 18 | Engines | Diagnosis | Software generated prog. |
| 19 | Engines | Data extraction | Vibration data |
| 20 | Electro-mechanical | JPA | |
| 21 | Maintenance | Structure | |
| 22 | Components | Maintenance | Microcomputer based |
| 23 | Technical Data | Paper transition to | Automatic |
| 24 | Electronic Cars | JPA | |
| 25 | Trains | JPA | Portable |
| 26 | Oil Analysis | Predict repair | |
| 27 | Tracks Component | Efficiency | Comm-maint,invent& sched |
| 28 | Engines | On-condition | Portable |
| 29 | Avionics | Diagnosis | Prototype |
| 30 | Systems | Data | |
| 31 | Test data collection | Fault isolation | In-flight & ground operations |
| 32 | Maintenance mgmt | Efficiency | VAX based |
| 33 | Engines | On-condition | Ground-based |
| 34 | Milling | Diagnosis | |
| 35 | Milling | Maintenance | Telecommunications -based |
| 36 | A/C emergencies | Respond to | On-board diagnosis |
| 37 | Autos | Support maintenance | On-line diagnostic tool |
| 38 | Maintenance Ops | Troubleshooting | Expert-based |
| 39 | Maintenance Ops | Organizational | COTS equipment based |
| 40 | Design | Analysis | |

**Appendix**

## Summary of Job Performance Aid Survey

| NO. | APPLICATION | FUNCTION | NOTES |
|---|---|---|---|
| 41 | Maintenance Ops | Organizational | |
| 4 2 | Engines | Diagnosis | Knowledge-based |
| 43 | Engines | Trending & | |
| 44 | Components | ATE | |
| 45 | Oil analysis | Maintenance | |
| 46 | Engines | On condition | Time & temperature |
| 47 | Battle damage | Diagnosis | |
| 48 | Data info IS/RS | Field support | CD ROM-based |
| 49 | Components | Built-in-test | On-board equipment |
| 50 | Flight control | Diagnosis | Imbedded sensors on A/C |
| 51 | APU | Data | |
| 52 | Hydraulics | Diagnosis | A/C hydraulics |
| 53 | Gates | Response | Expert system |
| 54 | Engines | Monitor | Integrated |
| 55 | Systems | Diagnosis | Expert system |
| 56 | Info | Info & diagnosis | Portable |
| 57 | Ins | Fault diagnosis | Expert system |
| 58 | ATE support | ATE | Expert system |
| 59 | Engines | Diagnosis | Integrated |
| 60 | Systems | Diagnosis | |
| 61 | Maintenance | Technique | |
| 62 | Systems | Data/ analysis | |
| 63 | Data Link | Integration | Display based |
| 64 | Engines | Diagnosis | Uses input from TEMS & |
| 65 | Logistics | Analysis | Computer model |
| 66 | Engines | Diagnosis | Automatic, real-time |
| 67 | Flight Data | Data recorder | |
| 68 | Hydraulics | Inspection | Prototype |
| 69 | Logistics | Planning | |
| 70 | Trucks | Info | CD ROM-based |
| 71 | Engines | Fault isolation | On-board |
| 72 | Maintenance | History | |
| 73 | Avionics | Troubleshoot | AI-based & portable |
| 74 | Maintenance data | Monitor | Data-buses |
| 75 | Maintenance | Control | Part of Merlin system |
| 76 | Assess fleet | Support | |
| 77 | Maintenance | JPA | Portable |
| 78 | Maintenance | Support | Software-based |
| 79 | Info | Info | Microfiche-based |
| 80 | info | Integrate data | MIS |

**Appendix**

## Summary of Job Performance Aid Survey

| NO. | APPLICATION | FUNCTION | NOTES |
|---|---|---|---|
| 81 | Maintenance | Organization | Part of Merlin system |
| 82 | Maintenance | Training | AI-based |
| 83 | Engines | Diagnosis | |
| 84 | Flight control | Fault detection | In-flight detection |
| 85 | Inertial Navigation | Diagnosis | |
| 86 | Maintenance | JPA | Portable |
| 87 | Parts | Parts Tracking | |
| 88 | Logistics | Decision Support | Software-based |
| 89 | ATE | Planning | Model |
| 90 | X-ray | Support | PC-based |
| 91 | Components | Fault diagnosis | |
| 92 | ATC | Remote | NAS system component |
| 93 | Structures | Predict &Plan | Software-based |
| 94 | Engines | Training | |
| 95 | Flight control | Intervention | |
| 96 | Maintenance | Training | |
| 97 | Cars | Diagnosis | |
| 98 | Cars | Diagnosis | utilizes hypertext |
| 99 | Maintenance | Organization | Software tool |
| 100 | Satelites | Decision aid | Prototype |
| 101 | Structural | Diagnosis | On-board |
| 102 | Multipurpose | Training | 3D-simulation |
| 103 | Engines | Diagnosis | |
| 104 | Ensines | Monitor | Early application |
| 105 | Engines | Diagnosis | Expert system-based |
| 106 | Subsystem | Training | Computer-based |
| 107 | Structure | Maintenance support | |
| 108 | Engines | Diagnosis | Interface to maint. databases |

## Appendix
## Summary of Job Performance Aid Survey

## 7.0 APPENDIX

### 1. ADE—AUTOMATIC DATA ENTRY FOR AIRCRAFT MAINTENANCE

| | |
|---|---|
| FUNCTION | Facilitate data entry |
| SPONSOR | US Air Force |
| DEVELOPER | Lockheed |
| INTIATED | 1975 |
| DESCRIPTION | An automatic data entry system which encompasses all mechanical devices. This system replaces the manual entry of data into the information system. |

### 2. AEM—AUTOMATED ELECTRIFIED MONORAIL

| | |
|---|---|
| FUNCTION | To deliver replacement parts used in maintenance at high-speed. |
| DEVELOPER | United Airlines |
| LIFE | Present. |
| DESCRIPTION | Electrified monorail parts delivery system moves product at high speed thus improving efficiency. |

### 3. AFTA—AVIONIC FAULT TREE ANALYZER

| | |
|---|---|
| FUNCTION | Performs automatic testing of avionics equipment in its' operational environment |
| SPONSOR | U.S. Navy |
| DEVELOPER | Douglas Aircraft Company, St. Louis, Mo. |
| DESCRIPTION | The Avionics Fault Tree Analyzer, AFTA, is a suit-case sized microprocessor-based computer system which performs automatic testing and fault isolation of F/A-18 avionic systems. It is capable of fault analysis to the Shop Replaceable Assembly level. The fault isolation programs are referred to as fault trees; analysis of these trees include analyzing, sorting, comparing, examining, and manipulating data from the system being tested. The effectiveness of this system is contingent upon the effectiveness of the avionics system built-in-test (BIT) equipment and the knowledge and practical expertise of the fault tree designer. In addition to the lightweight, portable computer, the AFTA requires removable magnetic tape cassette cartridges. The system connects to the aircraft MUX BUS and aircraft power. Once the program is initiated, the fault diagnosis is illuminated on the flat screen display. A hard copy can be generated. |

### 4. AGILE EYE, and AGILE EYE PLUS—HELMET MOUNTED DISPLAY BUILT IN TEST EQUIPMENT

| | |
|---|---|
| FUNCTION | Helmet-mounted display |
| SPONSOR | US Air Force |
| DEVELOPER | Kaiser Electronics |
| LIFE | 1990 |
| DESCRIPTION | This system modifies the "Private Eye" minature display, also called Agile Eye and Agile Eye Plus. The display is incorporated with a helmet in order to significantly increase a pilot's situational awareness. It is possible using this apparatus to project television monitor information or other computer information. The image is directed to the visor of the pilot's helmet, thus keeping the information in front of his eyes at all times. It is a monocular presentation to the pilot's dominate eye. It displays only information needed. The system can also be tailored by the pilot, i.e., "decluttered" so that it can include only what the pilot wants to see. |

## 5. AGTR—AVIONICS GROUND TRAINING RIG (RAF)

| | |
|---|---|
| FUNCTION | To train aircraft maintenance personnel in fault diagnosis and service of advanced avionic systems. |
| SPONSOR | United Kingdom Royal Air Force (RAF) |
| DEVELOPER | Essams |
| LIFE | 1985 |
| DESCRIPTION | The Avionic Ground Training Rig, AGTR, is a maintenance trainer and simulator designed to train ground crews in advanced avionic fault diagnosis and servicing methods. The system is composed of a life-size cock-pit and a PDP 11/55 and VAX 11/70 computer-based system. The ground crew can accurately diagnose aircrew reported system deficiencies through simulated flight. This system was developed for the UK Royal Air Force, Tornado F2 interceptors. |

## 6. AIDS—AIRBORNE INTEGRATED DATA SYSTEM

| | |
|---|---|
| FUNCTION | On-line integrated data systems for use in work areas by technical and engineering personnel. |
| SPONSOR | Trans World Airlines |
| LIFE | Operational in 1986 |
| DESCRIPTION | Satisfies the need for dedicated computers for maintenance and engineering functions.. The system uses an ARINC Communications and Reporting Systems (ACARS) data link. |

## 7. AIDAPS —AUTOMATIC INSPECTION DIAGNOSTIC AND PROGNOSTIC SYSTEM, also referred to as, UH-AIDAPS TEST BED PROGRAM

| | |
|---|---|
| FUNCTION | Engine monitoring instrument that performs automatic in-flight inspection, diagnostic and prognostic procedures to detect mechanical malfunctions and warn of failure-conditions. |
| SPONSOR | US Army Aviation Systems Command, St. Louis, MO. |
| DEVELOPER | Test Bed Program Developer: Hamilton Standard ;Analysis, Procedures and Trade-Off Concept Formulation Study, Computer Tabulations, Computer Models, Computer Output Data, Northrup Corporation. |
| LIFE | 1972. Computer modelling 1972 through 1975. |
| DESCRIPTION | Automatic data-acquisition and data analyzer systems to inspect, diagnose malfunctions, and predict failure of in-flight aircraft engines and fuel systems. AIDAPS was designed for the US Army helicopter, UH-1H. |

## 8. AIMES—AVIONICS INTEGRATED MAINTENANCE EXPERT SYSTEM

| | |
|---|---|
| FUNCTION | Monitors engine functions and performs real-time diagnostic procedures. |
| DEVELOPER | McDonnell Douglas |
| LIFE | Flight tested January 1986 |
| DESCRIPTION | In-flight, automatic test system for use in US Army F/A-18 Hornet aircraft which utilizes artificial intelligence. Data acquisition and diagnostic operations are performed while the craft is airborne which eliminates the need for maintenance personnel to re-create the conditions once on the ground. The knowledge of the mechanic is coded on the computer in the form of operating rules. |

## 9. AIMS—AUTOMATED INTELLIGENT MAINTENANCE SYSTEM

| | |
|---|---|
| FUNCTION | Portable interactive computer system used for maintenance testing and repair of US Army vehicles. |
| SPONSOR | US Army |
| DEVELOPER | Analytics Corporation, King of Prussia, PA. |
| LIFE | 1987 |
| DESCRIPTION | AIMS is a portable, light-weight, expert system for use in maintenance, repair and training arenas. It uses expert system and voice recognition technologies, and computer screen displays of schematic diagrams and installation drawings. System may also be used for inventory tracking, parts requisition and maintenance-history records of vehicles, and schedules. Interchangeable software will accommodate to other type vehicles including aircraft and rotorcraft. |

## 10. AMES—AIRCRAFT MAINTENANCE EFFECTIVENESS SIMULATION MODEL

| | |
|---|---|
| FUNCTION | Project to develop simulation of operation and maintenance of an aircraft squadron. |
| SPONSOR | Navy |
| DEVELOPER | XYZYX Information Corporation, Canoga Park, California |
| LIFE | 1977-1979. |
| DESCRIPTION | A computer-based program of Aircraft Maintenance Effectiveness Simulation (AMES) which is able to develop and test maintenance performance and operational readiness in an aircraft squadron. This program can quantify the cost of human errors and maintenance accuracy and its impact on other factors of maintenance (i.e., consumption of spares, missed gate-times, delay, aborted missions.) This information is helpful since human errors are difficult to measure and evaluate since they are interactive with other types of errors, and not easily traced by conventional analysis. |

## 11. AMICAL

| | |
|---|---|
| FUNCTION | Computer program to automate and perform economical scheduling of maintenance tasks. |
| SPONSOR | KLM Royal Dutch Airline |
| LIFE | 1986 |
| DESCRIPTION | Airline-developed computer program with applications for aircraft maintenance task scheduling, uses mini-computer based system. |

## 12. APU MAID –AUXILIARY POWER UNIT MAINTENANCE AID and MAIDEN

| | |
|---|---|
| FUNCTION | Auxiliary Power Unit Maintenance Aid (APU MAID) software assists the flightline technician in performing test, fault detection, fault isolation and repair of the C-130 APU. Software is hosted on a portable, computer called, MAIDEN, which is specifically designed for this use. |
| DEVELOPER | Allied-Signal Aerospace Co., Teterboro, NJ |
| LIFE | 1987 |
| DESCRIPTION | The APU MAID is an expert system based job performance aid which uses heuristic and logical reasoning. It was developed for the C-130 aircraft auxiliary power unit. System is designed to be useful on the maintenance flight-line in APU diagnostic, fault detection, isolation and repair. It is used in conjunction with a specifically designed computer, called MAIDEN (MaintenanceAid Engine). The computer is light-weight, portable, and battery operated. |

**13. ASMT - AIRCRAFT SIMULATION MAINTENANCE TRAINERS**

| | |
|---|---|
| FUNCTION | Computer driven simulator to train and certify C-17 maintenance personnel. |
| SPONSOR | USAF |
| DEVELOPER | ECC International Corporation |
| LIFE | 1989 |
| DESCRIPTION | Air Force Aeronautical Systems Division awarded a $138-million contract for 5 C-17 Aircraft Simulation Maintenance Trainers. These will provide computer-aided instruction to the maintenance trainee personnel. Each trainer will have twelve separate training devices that replicate the C-17's systems. |

**14. ATEOPS**

| | |
|---|---|
| FUNCTION | Expert systems used to direct automatic test equipment for testing of F-15 fighter hardware. |
| SPONSOR | USA |
| LIFE | 1985 |
| DESCRIPTION | ATEOPS, ATEFEXPERS and ATEFATLAS are three expert systems used to control Automatic Test Equipment (ATE) by troubleshooting the converter programmer power-supply card on the F-15 aircraft. Each system uses a specific knowledge base with tests particular to the specific circuit being tested and the test requirements. Each includes a constraint propagated frame system that allows enhanced control by creating code in the Atlas programming language, checking the code for good form, controlling the ATE and changing the test sequence as needed. |

**15. ASTROLOG**

| | |
|---|---|
| FUNCTION | Early demonstration to integrate ground based computers and airborne data recorders for engine maintenance. |
| SPONSOR | American Airlines, Maintenance and Engineering Center, Tulsa, OK |
| LIFE | 1967 |
| DESCRIPTION | Astrolog is an integrated system for engine maintenance. The engine maintenance recorder portion of the data system consists of four major components: airborne magnetic data recorders, conventional long distance telephone data transmission links, centralized ground based computer complex, and computer programming which permits automatic diagnosis of engine health, fault identification and measurement of the urgency of such corrective action. |

**16. ATE's for AH-64 HELICOPTERS for use at AVIM—AVIATION INTERMEDIATE MAINTENANCE UNITS.**

| | |
|---|---|
| FUNCTION | Automatic testing units designed to test and diagnose faults on components removed from Army helicopter AH-64. |
| SPONSOR | Army |
| DESCRIPTION | Computer-driven automatic test equipment designed for shop use to test and diagnose faults in Line Replaceable Units removed from the helicopter. |

### 17. AUTOMATIC TEST PROGRAM GENERATOR (ATPG)

| | |
|---|---|
| FUNCTION | Knowledge-based interactive editor |
| SPONSOR | Warner Robins Air Logistics Center (WRALC) |
| DEVELOPER | Air Force Institute of Technology, School of Engineering |
| LIFE | 1986 |
| DESCRIPTION | A prototype knowledge-based automatic test program generator (ATPG) has been developed which uses a special language to operate automatic test equipment. The ATPG is an interactive editor that will enable the software analyst to write codes effectively and efficiently. It will also aid the software development process by reducing the amount of time used in software maintenance and modification. The ATPG prototype is used in selected tests performed on a component of the F-15 aircraft. |

### 18. ATSJEA III —AUTO TEST SYSTEM FOR JET ENGINE ASSEMBLIES

| | |
|---|---|
| FUNCTION | System to test overhauled engines. |
| SPONSOR | Air Force |
| DEVELOPER | *Advanced Technology and Testing, Inc., Michigan* |
| LIFE | 1989 |
| DESCRIPTION | This system is designed to test overhauled fuel assemblies from Allison T56 turboprop engines powering USAF C-130K transports. This product, presently in its third generation includes a new software generated programming technique to perform necessary adjustment diagnostics and prompt the operator as necessary. |

### 19. AVID—AUTOMATIC VIBRATION DIAGNOSIS SYSTEMS

| | |
|---|---|
| FUNCTION | Vibration data extraction from gas turbine engines. |
| SPONSOR | USAF |
| DEVELOPER | Mechanical Technology, Inc., Latham, New York |
| LIFE | 1983 |
| DESCRIPTION | Automated vibration data extraction system was developed for jet transport overhaul centers. AVID automates trouble shooting procedures for fully assembled gas turbine engines. High frequency vibration data is extracted from existing standard instrumentation and provides input to a specialized symptom/fault matrix. Malfunctions are detected and assigned to a particular data set, with corrections detailed. |

### 20. BRAD —BRILLIANT REUSABLE ADA DIAGNOSTICIAN (REUSED SOFTWARE)

| | |
|---|---|
| FUNCTION | To assist a novice munition maintenance technician in various systems and components. |
| SPONSOR | Air Force Munitions Systems Division |
| LIFE | 1989 |
| DESCRIPTION | System in development which intends to demonstrate the applicability of model based reasoning and the concept of software reuse. The goal of the work is to enable a novice maintenance munitions technician to perform fault isolation and diagnostics in electronic, electro-mechanical, and mechanical faults using schematics and design data. |

## 21. CAD—COMPUTER AIDED DESIGN

| | |
|---|---|
| FUNCTION | To streamline aircraft maintenance and repair. |
| SPONSOR | US Naval Aviation Depot, Cherry Point, NC |
| DEVELOPER | McDonnell Aircraft |
| DESCRIPTION | This system aids US Marine personnel to troubleshoot maintenance functions by having direct access to drawings and engineering information of the builder/designer of the AV-8B HarrierII short take-off and vertical landing aircraft. Computer drawings and data for structural repairs are updated every three months, as is stress analyses and wiring diagrams. |

## 22. CADS—COMPUTER AIDED DIAGNOSTIC SYSTEM

| | |
|---|---|
| FUNCTION | Demonstration of diagnostic system application to the H-34 helicopter. |
| SPONSOR | US Navy |
| DEVELOPER | Naval Postgraduate School , Monterey, California |
| LIFE | 1987 |
| DESCRIPTION | Prototype to demonstrate feasibility of applying expert systems technology to the H-46 helicopter maintenance process. This is known as a micro computer based prototype called CADS, Computer Aided Diagnostic System. The complexity of the helicopter system diagnosis, inadequacies of the maintenance manuals often result in unnecessary removal of system components. The diagnostic system for the H-34 is proposed to add a comprehensive, stable knowledge base not dependent upon particular personnel for capable repair. |

## 23. CALS—COMPUTER ACQUISITION AND LOGISTIC SUPPORT

| | |
|---|---|
| FUNCTION | DOD and industry strategy for the transition from paper-intensive acquisition and logistic processes to a highly automated and integrated mode of operation for the weapon systems of the 90's. |
| SPONSOR | US Department of Defense and Industry |
| DEVELOPER | US Department of Defense |
| LIFE | In September 1985, Deputy Secretary of Defense approved recommendations of a DOD-industry task force on CALS. MIL-M-28001 was published February1988. In August, 1988, another memorandum was issued stating that major steps had been taken towards routine contractual implementation of CALS through out DOD and industry. The memorandum upheld the issuance of standards for digital data delivery and required technical data in digital form for weapons systems in development in FY 1989 and beyond. |
| DESCRIPTION | CALS addresses the generation, access, management, maintenance, distribution and use of technical data associated with weapon systems. This includes engineering drawings, product definition, and logistic support analysis data, technical manuals, training materials, technical plans and reports, and operational feedback data. The CALS system will facilitate data exchange and access, and reduce duplication of the data preparation effort. Additionally, CALS provides the framework for integration of other automation systems within DOD. The cornerstone standard for the interchange of textual technical in formation is MIL-M-28001. |

## 24. CAMS—COMPUTERIZED AUTOMOTIVE MAINTENANCE SYSTEM

FUNCTION: Automotive diagnostic system which can interface with a remote mainframe computer.

SPONSOR: Commercial

DEVELOPER: General Motors, Buick Division

LIFE: 1987

DESCRIPTION: A computer with diagnostic capability using the car computer, built-in sensors, and circuits. The system can retrieve and store a portion of data so that in termittent problems may be analyzed, sometimes with the aid of a small portable monitor hook-up. This system can interface with the Buick mainframe in Michigan by telephone hook-up, if required.

Locally, the CAMS machine consists of a touch screen command system, so that it may be used by persons without computer background. Buick claims that 48% of cars repaired without the system would return for the same type of repair; with the CAMS system, Buick claims that this was reduce to 8%, since the machine is particularly successful with small circuit analysis. This system is similar to Ford Motor OASIS system, and will soon be followed by Chevrolet, Pontiac, and GMC, and Oldsmobile. It is noted that maintenance personnel were at first reluctant to use the machine because it did not have a manual operation mode; the maintainers wanted to assert control. Its use became more widespread as the manual mode was introduced.

## 25. CATS-1

FUNCTION: A portable computerized troubleshooting system developed for large locomotive repair.

SPONSOR: Commercial.

DEVELOPER: General Electric Research and Development Center

LIFE: Current

DESCRIPTION: This electrical and mechanical diagnostic system uses expert systems technology combined with portable computers for use on the maintenance floor. The system initiates diagnostic technique by supplying a menu of possible symptoms and then prompts a series of detailed queries. At appropriate point in the interaction, the user may call up from the computer memory, displays and drawings, photos or movies of the locomotives various components, locations and functions. As malfunctions are determined, repair instructions are provided on the video screen.

This system uses a standard 16-bit microcomputer for information processing, additional memory for storing expert knowledge, a CRT, a printer, a video disc player and monitor for demonstration of repair procedures.

CAT-1 is currently in use at GE locomotive repair facilities nationwide.

## 26. CCP—CONTAMINATION CONTROL PROGRAM

FUNCTION: To reduce unnecessary maintenance and heavy-equipment downtime through progressive analysis of various non-engine lubrication and maintenance schedules.

SPONSOR: Mobil Oil

DESCRIPTION: Samples of engine lubrications are mailed to Mobil's Kansas City Laboratory and analyzed for levels of oxidation and sludge, viscosity, fuel dilution, dirt and glycol, water and wear metals. Lubricants are not changed until contaminated which also indicate the presence of or incipient maintenance actions.

## 27. CCS—COMPONENT CONTROL SYSTEM

| | |
|---|---|
| FUNCTION | To improve communication between aviation maintenance, inventory and scheduling departments without increasing data entry time. |
| DEVELOPER | USAir |
| LIFE | 1986. |
| DESCRIPTION | The Component Control System, part of the USAir publicly marketed Merlin System, is used for time control processing, removal/installation and history processing for components, major assembly processing of subassemblies and forecasting removal requirements. |

## 28. CEMS IV—COMPREHENSIVE ENGINE MANAGEMENT SYSTEM increment IV

| | |
|---|---|
| FUNCTION | To support the on-condition maintenance philosophy, combined with portable decision support devices using diagnostics and trending analyses. |
| SPONSOR | Air Force |
| DEVELOPER | Systems Control Technology, Inc., Palo Alto CA |
| LIFE | 1988 |
| DESCRIPTION | A fielded expert system automates equipment for fault isolation, diagnosis, and trend analysis, and recommends corrective maintenance action. This program is the standard to the Air Force base level maintenance. CEMS IV will be enhanced and fielded under the umbrella of Core Automated Maintenance System. |

## 29. CEPS - CITS EXPERT PARAMETER SYSTEM

| | |
|---|---|
| FUNCTION | Maintenance diagnostic system |
| SPONSOR | Air Force |
| DEVELOPER | Boeing Military Airplane Development |
| LIFE | 1987 |
| DESCRIPTION | CEPS couples expert system technology and conventional programming with a large data base to provide a system which will assist maintenance diagnostics. This system incorporates avionics design knowledge, avionics maintenance expertise, and statistical analysis of past and present failure indicators to improve fault detection and isolation. A prototype is under development for the B-1B. |

## 30. CITEPS —CENTRAL INTEGTRATED TEST - EXPERT PARAMETER SYSTE

| | |
|---|---|
| FUNCTION | System to utilize monitoring systems and built-in test systems on the B1-B to perform fault solation. |
| SPONSOR | US Air Force |
| DEVELOPER | Wright Patterson Aeronautical Laboratory. |
| DESCRIPTION | This system is built upon previous technological systems developed for Air Force maintenance procedures, such as the Central Integrated Test and Comprehensive Engine Monitoring System. This system receives data from these other systems and combines it with expert technology derived directly from the experience of mechanics. It enables a less experienced mechanic to perform advanced diagnostic analysis and maintains a higher production standard. |

## 31. CITS - CENTRAL INTEGRATED TEST SYSTEM

FUNCTION On-board central diagnostic system developed for the B1-B aircraft.

SPONSOR USAF

DEVELOPER Rockwell International Corporation, Los Angeles, California.

LIFE 1981

DESCRIPTION The B1-B Central Integrated Test System (CITS) is the on-board test system for the B1-B aircraft and the avionics subsystems. The CITS operates continuously and automatically in flight and on the ground to display performance and faults to the aircrew. It records approximately 19,600 parameters. Failed modes of operation are detected/recorded on all subsystems and faults are isolated to the line-replaceable-unit (LRU) level. Three snapshots of all CITS data parameters is recorded on magnetic tape for maintenance troubleshooting. The CITS performs pre-flight and postflight tests automatically. Reverification of systems and ground readiness tests are conducted on individually selected subsystems at the operators' request. This system was first developed for the B1-A aircraft, and refined for the B1-B aircraft.

## 32. CMS—COMPUTERIZED MAINTENANCE SYSTEM

FUNCTION Serving 26 US Coast Guard airstations and repair and supply facilities in the United States and Puerto Rico.

SPONSOR US Coast Guard.

LIFE 1988

DESCRIPTION The Computerized Maintenance System uses a relational database running on a Digital Equipment Corporation VAX 8530. Real-time information is provided on the status of more than 200 aircraft, in addition to the identification of trends and problems. It is used for assistance in troubleshooting, system reliability analysis the recording and reporting of aircraft data and the maintenance of records on airframes and components. The system functions by users entering data into a commercial off the shelf terminal which is then transmitted via telenet to the VAX 8530 located at Tamsco. Data integrity is maintained by a data entry system that automatically provides validation and cross checking.

## 33. COMPASS — CONDITION MONITORING AND PERFORMANCE ANALYSIS HOST SOFTWARE SYSTEM

FUNCTION This is a ground-based engine monitoring program for general application to engines in service after 1989, which integrates other engine monitors. This product is available from third party vendors to respect the proprietary information required to implement the software.

DEVELOPER Rolls Royce

LIFE Developed for use on new engine types entering service in 1989.

DESCRIPTION Maintenance functions, including reduced cost of operation, increased utilization of resources, improved procedures and increased visibility of engine and fleet condition are all more efficient due to built-in instrumentation to monitor performance of the unit, and more sophisticated computer system capabilities on the ground. The system supplies trend and operational monitoring information from four main areas (on-wing, ground, test cell, and maintenance action data) to a ground base, thus enabling early warning and maintenance decision and scheduling functions to be determined ahead of condition failure. Information regarding the operational parameters of the host engines and users must be fed into the system.

## 34. DC-9 REFRIGERATION SYSTEM DIAGNOSIS

FUNCTION — Early method of computer diagnosis in aircraft maintenance

DEVELOPER — Eastern Airlines, Inc., Miami, Florida

LIFE — 1973 PA, 1973.

DESCRIPTION — A early method of instantaneous diagnostics DC-9-30 refrigeration systems using readily obtainable data, suitable algorithms of component performance comparing performance to performance standard. Variable conditions are factored in such as hot day conditions, and effects of preventative maintenance procedures.

## 35. DCS—DIGITAL CONTROL SYSTEM

FUNCTION — Telecommunications-based diagnostic and support system

DEVELOPER — Kearney & Trecker, Milwaukee, WI

DESCRIPTION — The DCS Analyst is a telecommunications-based diagnostic and support tool available to users of Gemini controls. This includes equipment manufactured by Kearney & Trecker, Cross, Swasey, Warner for milling, boring, and machining equipment and lathes.

Used in conjunction with a modem, communication may be established to DCS analysts at the firms' headquarters in Milwaukee, and any Gemini-controlled machine, and thus control or monitor any machine function. The control system can set, alter, program software uploaded/downloaded, condition of the machine checked, and maintenance levels established.

Support is established by using the particular units' own service history as well as the history of other machines stored in the DCS database. The users computer may be interrogated and control may be bypassed to test sections of the control individually. In addition, a specific machine will be analyzed for its' own fingerprint, which will enable the customer to develop an appropriate preventative maintenance program.

## 36. DECISION SUPPORT SYSTEM FOR DIAGNOSIS OF A/C EMERGENCIES

FUNCTION — System designed to show the feasibility of expert systems technology utilizing existing on-board sensors to aid diagnosis of single and compound emergencies.

SPONSOR — US Navy

DEVELOPER — Naval Postgraduate School, Monterey, California

LIFE — 1986

DESCRIPTION — This system was developed to demonstrate the feasibility of using on-board sensors, specific knowledge bases with personal computer implementation, to assist the aircraft crew to respond to single and compound emergencies. The platform for the demonstration was the AH-1T attack helicopter. This system quantifies the information and respondent knowledge required to define emergencies.

## 37. DIAGNOSTIC DATA RECORDER

FUNCTION — On-Line computerized diagnostic tool used in the automotive industry.

SPONSOR — General Motors —Buick

DESCRIPTION — An on-line diagnostic tool installed on certain cars. This system records various indicators of 26 engine functions. When the auto is referred for service of an intermittent or other problem, the data recorder may be hooked up by modem to enable the data log to be examined, compared to heuristic data and fault diagnosed. Such items as engine temperature, O2 sensor, timing, and air-fuel mix control, are checked.

## 38. DIAGNOSTIC EXPERT SYSTEM FOR AIRCRAFT GENERATOR CONTROL UNIT

| | |
|---|---|
| FUNCTION | A generic, diagnostic expert system for generator control units. |
| DEVELOPER | Westinghouse Electric Corporation, Lima, OH |
| LIFE | 1988 |
| DESCRIPTION | This system may be applied to different devices. Modular variable-speed/constant frequency generators families are organized by standard modules to enable expert system technology to be applied. A general diagnostic expert shell is developed that will guide troubleshooting procedures of modules and line-replaceable units. System is applied to the generator control unit and may be applied to other types of units by incorporating device-specific rules from expert personnel. |

## 39. DMMIS—DEPOT MAINTENANCE MANAGEMENT INFORMATION SYSTEMS

| | |
|---|---|
| FUNCTION | To improve Air Force maintenance depot planning and control functions. |
| SPONSOR | US Air Force, Wright Patterson AFB, OH |
| DEVELOPER | Grumman Data Systems, Grumman Aerospace Corporation |
| LIFE | 1988, still in development |
| DESCRIPTION | This Grumman product will support Air Force maintenance depots engines, all types of aircraft, cargo, instruments, avionics, landing gear and accessories, and communication systems. It endeavors to improve planning and control functions of scheduling, workload planning, inventory control, productivity and planning and operational readiness. In addition, it will provide on-line data access and user interaction.<br><br>The DMMIS system is software intensive using commercial off-the-shelf software management systems to replace an existing 1500 computer programs. It will cluster all systems of management (material requirements, work order generation, logistics, budgeting, time and attendance, job cost, quality management, etc.) to reduce repetitive data entry and systems, increase amounts and variety of available information. |

## 40. DODT—DESIGN OPTION DECISION TREE

| | |
|---|---|
| FUNCTION | A method for systematic analysis of design problems and integration of human factors data. |
| SPONSOR | US Air Force AFHRL, Brooks Air Force BAse, TA. |
| DEVELOPER | Systems Research Laboratories, Dayton, OH. |
| LIFE | 1974. |
| DESCRIPTION | This method is represented by a schematic format termed the Design Option Decision Tree. It displays the various design options available at each decision point in the design process. Note that this system is not only applicable to aircraft systems, although the system is modelled on aircraft design problems. The user specifies design goals, and among the various design parameters are human factors considerations. |

## 41. EASTERN AIRLINES COMPUTER SYSTEM

FUNCTION Maintenance planning and scheduling

DEVELOPER Eastern Airlines

DESCRIPTION Use of a combination of mini and mainframe computers have improved

Eastern's productivity and costs, allowing a reduction of three aircraft assigned to periodic service. This system was particularly useful when the company had a known parts shortage—so that unnecessarily assigning the wrong aircraft this part would cause cancelled flights.

Computer information is transferred directly to the shop floor, and in bases where the maintenance operations do not have a designated computer, information may be sent via the computers used at ramp and customer service departments.

Capacity planning chores are also performed. Management can calculate the effects of line slippage, schedule constraints and workload/manpower planning, as well as modification impact assessment.

This computer system follows the recommendations of the ATA which specified that maintenance and engineering must have dedicated computers and staff using fully integrated systems available at the work areas using on-line data systems.

## 42. ED/CEMS ENGINE DIAGNOSTICS/COMPREHENSIVE ENGINE MGMT SYSTEM IV

FUNCTION Platform used for applications such as XMAN, used in jet engine diagnostics to support on-condition maintenance philosophy.

DEVELOPER Systems Control Technology, Palo Alto, California

LIFE 1986.

DESCRIPTION An expert system that automates equipment used for diagnosis of anomalies in engine operations based upon prescriptive parameters. Fault diagnosis, trend analysis and recommended corrective actions are features of this system. This system is a knowledge-based system composed of three modular software element: a knowledge base, a data base, and a control system.

## 43. EDS (ENGINE DIAGNOSTIC STS) FLT EVALUATION AIR FORCE

FUNCTION Engine diagnostics and trend monitoring

SPONSOR Air Force Aero-Propulsion Laboratory, Wright-Patterson AFB, OH.

DEVELOPER McDonnell Aircraft Co.

DESCRIPTION In the F15/F100 Engine Diagnostic System Flight Evaluation, data was collected to verify gas turbine engine fault detection/isolation and health trending algorithm employing gas path analysis.

## 44. ELATS—EXPANDED LITTON AUTOMATED TEST SET

FUNCTION Automated test systems for various flight functions.

DEVELOPER Litton Systems Canada

DESCRIPTION The Expanded Litton Automated Test Set is a comprehensive automated test system for radar, communications, microwave, electronic warfare systems and advanced depot-level support maintenance. It is designed as an inexpensive means for intermediate and depot-level support maintenance, combining existing instrumentation with a general design approach. The RF-ELATS can automatically simulate a variety of scenarios, modulation and noise and diagnose faults on the weapons replaceable assemblies. It also has built-in test routines and transfer standards and test subroutines.

## 45. EM/PA—MOBIL OIL ENGINE MAINTENANCE THROUGH PROGRESSIVE ANALYSIS

| | |
|---|---|
| FUNCTION | To reduce unnecessary maintenance and heavy-equipment downtime through progressive analysis of engine oils and maintenance schedules. |
| DEVELOPER | Mobil Oil |
| DESCRIPTION | Samples of engine lubrications are mailed to Mobil's Kansas City Laboratory and analyzed for levels of oxidation and sludge, viscosity, fuel dilution, dirt and glycol, water and wear metals. Lubricants are not changed until contaminated which also indicate the presence of or incipient maintenance actions. |

## 46. ETTR — ENGINE TIME TRACKING RECORDER

| | |
|---|---|
| FUNCTION | Part of larger system that monitors time and temperature of engine operation. |
| SPONSOR | Air Force |
| DEVELOPER | General Electric Co., Aircraft Engine Business Group, Lynn, MA. |
| LIFE | 1979. |
| DESCRIPTION | This system is one component of the Parts Life Tracking System is an engine time-temperature recorder system. Based on the on-condition maintenance, the recorder monitors operations and compares it to a set of designated parameters of satisfactory operation. The Parts Life Tracking System manages the TF34-100 engine in USAF/A10 aircraft. |

## 47. EXPERT SYSTEM FOR MAINTENANCE DIAGNOSIS

| | |
|---|---|
| FUNCTION | Self repair of digital control systems. |
| SPONSOR | US Air Force, Air Force Flight Dynamics Laboratory, Wright Patterson AFB, Ohio |
| LIFE | 1983. |
| DESCRIPTION | Using statistics collected from battle damaged repair history, i.e., from Southeast Asia, Falkland Islands, and Israeli data, the self-repairing concept was explored toward development of the diagnostic data /expert knowledge systems for maintenance diagnosis. |

## 48. FAMIS - FIELD ASSET MANAGEMENT & INFORMATION SYSTEM

| | |
|---|---|
| FUNCTION | CD-ROM based information retrieval system |
| DEVELOPER | Image Storage/Retrieval Systems IS/RS |
| LIFE | 1989 |
| DESCRIPTION | FAMIS is a field support tool for the gas, electric telecommunications and nuclear utility industry. Data is stored on CDs and enables field support personnel to access information such as maps, manuals, work orders and bulletins. It also collects data from the field for transfer to the home office via floppy disk or through the built-in modem. |

## 49. FAULT ISOLATION-BITE

| | |
|---|---|
| FUNCTION | Next generation of built-in test equipment. |
| SPONSOR | US Air Force |
| DEVELOPER | Boeing Commercial Airplane Company, Seattle |
| LIFE | 1982 |
| DESCRIPTION | Built-in test equipment developed for the Boeing 757 and 767 aircraft allows faults to be detected to the line replaceable unit level of maintenance. This extension to beginning fault isolation test equipment is designed for the mechanic's needs, as opposed to the engineer's. Intermittent faults will be detected. This is expected to lead to greater maintenance bay productivity, improved schedule reliability and decreased maintenance cost. |

## 50. FCMDS—FLIGHT CONTROL MAINTENANCE DIAGNOSTIC SYSTEM

| | |
|---|---|
| FUNCTION | Diagnostic system for maintenance of flight control systems. |
| SPONSOR | US Air Force, Wright Patterson Aeronautical Laboratories, Wright-Patterson AFB, Ohio |
| DEVELOPER | Honeywell Systems and Research Center, Minneapolis, MN |
| LIFE | 1988 |
| DESCRIPTION | Determination of maintenance diagnostic approaches has led to the development of flight control system diagnostics which will enhance the organizational-level technicians. Maintenance productivity improves as shop reliability and work load scheduling are able to improve. The system is composed of two parts: imbedded diagnostic sensors on the aircraft, and a computerized ground base system to extrapolate and test on-board generated data. |

## 51. FLIGHT DATA RECORDING SYSTEM TECHNOLOGY—FAULT TOLERANT MULTIPROCESSOR FOR AIRCRAFT SYSTEMS

| | |
|---|---|
| FUNCTION | Computer architecture |
| LIFE | 1988 |
| DESCRIPTION | FTMP, Fault Tolerant Multiprocessor is a digital computer architecture evolved over a ten year period. Its application to several life-critical aerospace systems, notably, as the fault tolerant central computer for civil air transport applications. The design is based upon independent processor-cache memory modules and common memory modules which communicate via redundant serial buses. All information processing and transmission is conducted in triplicate so that local voters in each module can correct errors. Modules can be retired and/or reassigned in any configurations. Reconfiguration is carried out routinely from second to second to search for latent faults in the voting and reconfiguration elements. Job assignments are all made on a floating basis, so that any processor triad is eligible to execute any job step. The core software in the FTMP will handle all fault detection, diagnosis, and recovery in such a way that applications programs do not need to be involved. |

## 52. FUZZY DIAGNOSTICS

| | |
|---|---|
| FUNCTION | System to assist diagnosis of faults difficult to describe in aircraft hydraulic systems. |
| SPONSOR | Peoples Republic of China |
| LIFE | 1986 |
| DESCRIPTION | Aircraft hydraulics systems, the drive systems which control attitude, extension and retraction of landing gear, and wing flaps, are composed of many parts. These are complex systems and often give rise to puzzling faults that are difficult to reenact and difficult to describe. The applications of computers in fault diagnosis can increase precision and speed so as to conveniently array the prerequisites which create the fault. The causes of system faults and the appearance of symptoms have a random or fuzzy nature. This system takes natural language and transforms it into machine language and crystallize human experience to simulate a fuzzy inference system. The characteristic nature of the system is first to select from events a set of symptoms and causes of model fault events and store them in a computer. Then during diagnosis a symptom is matched to a known fault to determine cause. |

## 53. GATEKEEPER (PROGRAM), TEXAS AIR

| | |
|---|---|
| FUNCTION | Helps airline managers coordinate and maintain gate schedules in response to changing flight schedules, aircraft routings, weather and airport conditions. |
| SPONSOR | Texas Air |
| DEVELOPER | Texas Air System One, Houston, TX |
| LIFE | 1989 |
| DESCRIPTION | This is a VAX-based expert system designed to alleviate effects of, and causes of, airport congestion. This is an intelligent, LISP-based distributed system that is operated on a UNIX-based workstation in the X-windows environment. It is connected via Ethernet to a relational database management system from Oracle on a VAX or 30386 database server.<br><br>GateKeeper coordinates flight operations and gate assignments in such locations as Continental (Houston, Newark and Denver), and Eastern (Miami). It is currently being marketed world-wide. The objective of the program is to improve efficiency and reduce operating costs. It uses artificial intelligence and incorporates four types of information: monthly and up-to-the-minute flight schedules, routing of aircraft for maintenance, flight information from each airline, and passenger information. The system is fault tolerant with triple redundancy and designed to reduce an airline's dependence on mainframe networks.<br><br>The system has predictive capability and may therefore avert potential crises by showing a manager the consequences of certain assignments. |

## 54. IEIS — INTEGRATED ENGINE INSTRUMENT SYSTEM

| | |
|---|---|
| FUNCTION | Computer driven display and processing instrumentation system used to monitor aircraft engine conditions. |
| SPONSOR | Naval Air Development Center, Warminster, PA |
| DEVELOPER | GE, Wilmington Mass Aerospace Instruments |
| LIFE | 1973 |
| DESCRIPTION | The Integrated Engine Instrument System (IEIS) is primarily concerned with the monitoring of aircraft engine conditions in response to the needs of flightcrews and maintenance personnel. |

## 55. IFL—INTELLIGENT FAULT LOCATOR

| | |
|---|---|
| FUNCTION | Designed to diagnose problems with the AH-64A Attack Helicopters. |
| SPONSOR | US Army |
| DEVELOPER | McDonnell Douglas Helicopter Co. |
| LIFE | 1988 |
| DESCRIPTION | US Army's expert system used on the AH-64A helicopter diagnosed faults on four of the eighteen systems with 96.3% accuracy, and reduced by half the time required to locate faults. The system was developed on a Texas Instruments Explorer symbolic processing workstation. |

## 56. IMIS - INTEGRATED MAINTENANCE INFORMATION SYSTEM

| | |
|---|---|
| FUNCTION | Integrates technical data collected from several sources and delivers that information in a practical form to the flight-line maintenance technician performing fault isolation procedures in a convenient and portable mode. |
| SPONSOR | US Air Force Human Resources Laboratory |
| LIFE | 1982, ongoing |
| DESCRIPTION | It uses a hand-held rugged computer for use during diagnostic maintenance, an aircraft maintenance panel connected to on-board computers and sensors, a maintenance workstation connected to various ground based computers systems, and sophisticated integration software which combines information from these various sources and presents data and conclusions to the maintenance technician in a consistent and practical manner. Functionally, this system includes technical data, training, diagnostics, management, scheduling and historical data bases, and transmits such data to the flight-line.<br><br>This system is consistent with technologies developed as Core Automated Maintenance System (CAMS), Automated Technical Order System (ATMOS) Phase IV, Integrated Turbine Engine System (ITEMS) and a variety of Automatic Test Equipment. |

## 57. INS-FAAMS—INERTIAL NAVIGATION SYSTEM

| | |
|---|---|
| FUNCTION | Inertial system fault analysis and management system to enhance US Army avionics. |
| SPONSOR | US Army |
| DEVELOPER | McDonnell Aircraft Company, St. Louis, Mo. |
| LIFE | 1984 |
| DESCRIPTION | The purpose of the Inertial Navigation System-Fault Analysis and Management System is to implement artificial intelligence in fighter aircraft avionics. This has the effect of enhancing the availability to mission and accuracy of the inertial navigation system. Inertial Navigation System failures are often difficult to isolate because the are related to incorrect procedures or non-repeatable conditions. The expert system identifies failures through the analysis of key failure paths, field maintenance data, and simulation testing of various mission profiles. The system is based upon blackboard architecture and has three divisions: current hypothesis and permanent knowledge, knowledge source demons searching for an antecedent to be true, and a priority based scheduler. |

## 58. IN-ATE - INTELLIGENT AUTOMATIC TEST EQUIPMENT

| | |
|---|---|
| FUNCTION | A fault diagnosis expert system environment. |
| DEVELOPER | Automated Reasoning Corp. New York |
| LIFE | 1987 |
| DESCRIPTION | IN-ATE is a fault diagnosis expert system software environment that is designed to reduce test-program development-time and test program run-time. |

## 59. INTEGRATED TURBINE ENGINE MONITORING SYSTEM

| | |
|---|---|
| FUNCTION | Complex engine diagnostic system. |
| SPONSOR | US Air Force Wright Patterson Aeronautical Systems Division |
| LIFE | 1986 |
| DESCRIPTION | Successor to the Turbine Engine Monitoring System, used on the TF34 and the F-15 Engine Diagnostics System, and the T-38 trainer Engine Health Monitoring System. |

## 60. INTERFACE II - ADVANCED DIAGNOSTIC SOFTWARE

| | |
|---|---|
| FUNCTION | Software appends software capabilities of various systems. |
| SPONSOR | US Air Force. |
| DEVELOPER | General Electric Co., Cincinnati, Oh. |
| LIFE | 1988 |
| DESCRIPTION | Interface II is a system of software designed to enable other systems to extend capability into new domains. An example of this system is JET-X, a system developed to coordinate Turbine Engine Monitoring Systems and Comprehensive Engine Monitoring Systems (TEMS and CEMS, respectively) to extend its diagnostic and troubleshooting capabilities and to allow use of the machine for training purposes. |

## 61. IRAN—INSPECT AND REPAIR AS NECESSARY

| | |
|---|---|
| FUNCTION | Maintenance philosophy and management framework. |
| SPONSOR | US Army |
| DEVELOPER | Rand Corporation |
| DESCRIPTION | The Inspect and Repair as Necessary concept demonstrated in the early phases of computerized maintenance planning and aircraft inspection capabilities. The system was demonstrated on the F-106 aircraft, and performance effects of the program were measured on the ADCM 66-28 parameters. The system was shown to have ambivalent effect; aircraft was neither received in a state of necessity, and procedures did not augment its reliability or in-service time. |

## 62. INTEGRATED TESTING AND MAINTENANCE TECHNOLOGIES

| | |
|---|---|
| FUNCTION | To receive and extract from data information required to troubleshoot interactive aircraft systems. |
| SPONSOR | Air Force, Wright Patterson Air Force Base, Ohio |
| DEVELOPER | Boeing Aerospace, Seattle, Washington |
| LIFE | 1988 |
| DESCRIPTION | Technology which will enable coordination of various on-board and ground support systems. The multitude of systems covered partially or entirely by particular avionics leads to a vast amount of replication of processing and software unless integrated. Maintenance ground support diagnosis also entails replication. |

## 63. IUSM - INTEGRATED UTILITIES SYSTEM MANAGEMENT SYSTEM

| | |
|---|---|
| FUNCTION | Integrates aircraft utility systems onto a common data bus. |
| SPONSOR | US military |
| DEVELOPER | Smiths Industries |
| LIFE | 1986 |
| DESCRIPTION | The ISUM was developed on the Experimental Aircraft Program(EAP). The system combines the fuel management, hydraulics, engine control, and environmental control systems onto a common military standard data link. This system reduces system complexity and also provides a method by which a CRT display could be integrated, thus giving the pilot quick access to data via soft keys or menus. The system can be configured so that any parameter which is out of tolerance is displayed as it arises. One of the main advantages of this system is a weight savings of 50% and volume savings of 25% when compared to other systems. This in turn eases maintenance. |

## 64. JET-X

| | |
|---|---|
| FUNCTION | Expert system works interactively with other systems. |
| SPONSOR | US Air Force |
| DEVELOPER | General Electric Co., Cincinnati, OH |
| LIFE | 1988 |
| DESCRIPTION | Jet-X is a knowledge based expert system used to diagnose and aid maintenance of the TF-34 jet engines installed on the USAF A-10A aircraft/ This system uses input from the Turbine Engine Monitoring System (TEMS) installed on the airplane, and combines it with information retrieved from the CEMS (Comprehensive Engine Management System) database that is part of the computer ground support system. This combination generates alarms which activates the JET-X analyses. Troubleshooting procedures are imbedded in the system for each type of alarm. In addition, "help" will assist the inexperienced technician so that it may be used both as a flight line tool and a training tool. |

## 65. LAMP—LOGISTICS ASSESSMENT METHODOLOGY PROTOTYPE

| | |
|---|---|
| FUNCTION | Computer model developed to assess technology effects of advanced USAF aircraft supportability and logistics requirements. |
| SPONSOR | US Air Force Integrated Logistics Technology Office |
| DEVELOPER | Dynamics Research Corporation |
| LIFE | First analysis performed in June 1986 investigated an advanced self-repairing flight control system. In August, 1986, the system demonstrated the effects of the incorporation of a particular radar system in an advanced aircraft. |
| DESCRIPTION | This computer model is designed on the premise that supportability of an item (such as advanced fighters) is as important as such factors as cost, performance and schedule. Embedded in the LAMP software are models for cost, manpower, sortie generation and airlift support models. The USAF F-16 data is used as the reference system. The LAMP system runs on the logistics assessment workstation (LAWS). |

**66. LEADER**

| | |
|---|---|
| FUNCTION | Automatic, real-time diagnostic system |
| DEVELOPER | Textron Lycoming |
| LIFE | 1988 |
| DESCRIPTION | LEADER is an expert system that supports acceptance testing functions of gas turbine engines. The system aids in problem diagnosis by automatically analyzing engine parameters for fault identification. It models the reasoning of an experienced engineer for a specific steady-state testing procedure with several hundred rules. |

**67. LEADS 200**

| | |
|---|---|
| FUNCTION | Flight data recording system |
| DEVELOPER | Technische Hochschule, Aachen Instrumentation for Jet Propulsion and Turbomachinery. |
| LIFE | 1983 |
| DESCRIPTION | The LEADS 200 flight data recording system was introduced into a F104G wing of the German Air Force in order to monitor aircraft and engine maintenance. The main software routines in the system for engine data performance monitoring and fault diagnosis. |

**68. LIPS - LIST PROCESSING LANGUAGE**

| | |
|---|---|
| FUNCTION | Prototype Maintenance Expert System for the CH-47 Flight Control Hydralic System. |
| SPONSOR | U.S. Army Research Office Dept. of Mechanical and Aerospace Engineering |
| LIFE | 1986 |
| DESCRIPTION | List Processing Language, or, LIPS, is a computer language used to facilitate data processing during the hydraulic flight control system inspection of Boeing CH-47 helicopters. |

**69. MACPLAN—MILITARY AIRLIFT COMMAND PLAN**

| | |
|---|---|
| FUNCTION | Logistics support |
| SPONSOR | US Air Force Military Airlift Command, Wright Air Force Base |
| LIFE | 1989 |
| DESCRIPTION | This plan was developed with cost-containment specifically in mind. It is designed to help the Military Airlift Command move large cargo quantities between the US and overseas bases. Factors include types of available aircraft, numbers of flights, routes, refueling and other adverse contingencies. Possible extrapolation to the commercial aviation field as logistics support for parts and replacement kit movement for all types service business. |

**70. MACSPEC PGW - PORTABLE GRAPHICS WORKSTATION**

| | |
|---|---|
| FUNCTION | CD-ROM based catalog. |
| DEVELOPER | Image Storage/Retrieval Systems IS/RS |
| LIFE | 1989 |
| DESCRIPTION | PGW is a CD-ROM based system that is used by Mack Trucks and their dealers to store their parts catalogs on CD-ROM. The system was to help the dealer find an specific part in less time. It was designed with a touch-sensitive screen, packaged for a hostile environment, portability for use on the road, and expandability for enhancements such as inventory control. The system contained images and text. |

## 71. MADARS—MALFUNCTION DETECTION ANALYSIS AND RECORDING SYSTEM

| | |
|---|---|
| FUNCTION | To provide engine analysis. |
| SPONSOR | US Air Force, Wright Patterson AFB, Ohio |
| DEVELOPER | Lockheed-Georgia, Marietta, Georgia |
| DESCRIPTION | C5A malfunction detection analysis and recording system for on-board flight isolation of several functions including engines. |

## 72. MACH—MAINTENANCE ACTIVITY COMMUNICATIONS HISTORY

| | |
|---|---|
| FUNCTION | To minimize aircraft maintenance downtime and improve communications between maintenance, scheduling, and inventory without increasing data entry time. |
| SPONSOR | USAir, Pittsburgh, PA. |
| DEVELOPER | The Maintenance Activity Communications History system is used for aircraft history reporting and data collection, aircraft reliability reporting and control, and an interface for line planning functions. It also functions as a communcations network for maintenance and engineering. The system is an adjunct to the existing Merlin system. |

## 73. MAINTENANCE ANALYST

| | |
|---|---|
| FUNCTION | System which uses Artificial Intelligence to troubleshoot an avionics subsystem on Sikorsky Blackhawk helicopters. |
| SPONSOR | US ARMY |
| LIFE | 1986 |
| DESCRIPTION | The Maintenance Analyst is a portable real-time consultant for field-level troubleshooting the SAS-1 avionics subsystem aboard the Sikorsky Blackhawk helicopter. This system runs on IBM compatible computers in LISP (an artificial intelligent programming language) and is designed to reduce the time required to troubleshoot the system under test. |

## 74. MAINTENANCE DATA BUS MONITOR AND RECORDER (MIL-STD-1553b)

| | |
|---|---|
| FUNCTION | Technology of data transmission which enables continuous data flow from a monitor system to the receiving recorder system. |
| SPONSOR | National Aeronautics and Space Administration, Washington |
| DEVELOPER | Normalair-Garrett Ltd., Yeovil, England |
| DESCRIPTION | The use of data buses for communication creates the need for the monitoring and collection of data for a variety of purposes including trend data for analysis of databus or subsystem performance, as well as diagnostic data relating to continuous or intermittent failures. The technology also created the need for data monitoring and recording systems with redundant data buses. |

## 75. MCS—MODIFICATION CONTROL SYSTEM

| | |
|---|---|
| FUNCTION | Used for aircraft modification and development, status update and reporting, workload planning and scheduling. |
| DEVELOPER | USAir, Pittsburgh, PA. |
| LIFE | 1986 |
| DESCRIPTION | This system part of the larger Merlin System developed by USAir to improve efficiency and communications between all phases of maintenance. |

## 76. MDC—USAF MDC—US AIR FORCE MAINTENANCE DATA COLLECTION SYSTEM

| | |
|---|---|
| FUNCTION | Provision of a limited number of measures to access fleet condition and identify likely candidates for reliability and maintainability improvement. |
| SPONSOR | US Air Force |
| DEVELOPER | RAND Corporation, Santa Monica, California |
| DESCRIPTION | The Air Force has determined that the maintainability of products and systems is as important as other utility and cost factors; hence, the development of a set of parameters, organized into the MDC system, to enable the user to determine which areas of the purview are likely candidates for improvement in reliability and maintainability. Since the program looks at subsystems, a better-than-average understanding of maintenance data collection and base-level maintenance systems is required to manage this complex system. The system provides the user with condensed organized data so that decisions and actions may be further determined. |

## 77. MDIS—MAINTENANCE AND DIAGNOSTIC INFORMATION SYSTEM

| | |
|---|---|
| FUNCTION | Generic model-based expert system for use in maintenance. |
| SPONSOR | US Air Force |
| DEVELOPER | Boeing Aerospace Co., Boeing Military Aircraft Div. |
| LIFE | 1986 |
| DESCRIPTION | Software system with capability of building a description of any type of equipment, currently used in the Portable Computer-Based Maintenance Aid System (PCMAS) being built by Boeing for the US Army. |

## 78. MERLIN SOFTWARE

| | |
|---|---|
| FUNCTION | Software package marketed by USAir to improve the efficient performance and communication among operating departments of aviation maintenance organizations. These departments include maintenance, overhaul, scheduling, shops, and inventory. |
| DEVELOPER | USAir, Pittsburgh, PA. |
| LIFE | Since 1986. |
| DESCRIPTION | The Merlin software package developed by USAir is composed of five management information systems which integrate various aspects of aviation maintenance. These include MACH (Maintenance Activity Communications History), CSS (Component Control System), MCS (Modification Control System), MSCS (Material Services Control System). Several carriers have acquired this software. Among them are Federal Express, Aeromexico, Kuwait Airways, Cameroon Airlines, BWIA International Airline, Ansett Airlines, Turkish Airlines, UTA and Flying Tigers. |

## 79. MICROFICHE MAINTENANCE MANUAL STORAGE AND RETRIEVAL

| | |
|---|---|
| FUNCTION | To store maintenance manuals in microfiche form for delivery to maintenance areas and airline shops throughout the US. |
| SPONSOR | Delta Airlines |
| DEVELOPER | Minolta Corp. |
| LIFE | 1985 |
| DESCRIPTION | Job performance aid which supplies bulky compendia such as airplane maintenance manuals in microfiche form. Readers used by Delta are the RP407 and RP407E reader-printers located in maintenance areas or airline shops and repair stations, allow standard, complete, and easy distribution of information which may need to be needed by various departments. |

## 80. MIMS—MAINTENANCE INFORMATION MANAGEMENT SYSTEMS

| | |
|---|---|
| FUNCTION | To bridge the information assimilation gap between data acquisition and maintenance operations. |
| SPONSOR | US Air Force |
| DEVELOPER | Systems Control Technology, Inc., PaloAlto, California |
| LIFE | 1981 |
| DESCRIPTION | The Turbine Engine Fault Detection and Isolation Program Model Development resulted in the Maintenance Information Management System in 1981. Although the acquisition of engine monitoring systems has been effective in prototype and operational modes, it was determined that the acquisition of data, although reliable, was not formulated in a manner in which it could be utilized by the maintenance management. There were no procedures for integrating the data into the maintenance process. This systems attempts to resolve the complexity of integrating data received. The system establishes standards for managing information flow effectively in the standard Air Force maintenance units. |

## 81. MSCS—MATERIAL SERVICES CONTROL SYSTEM

| | |
|---|---|
| FUNCTION | Computer software system to facilitate communication between material control, purchasing, planning, receiving and issuing functions in an aviation maintenance organization. |
| DEVELOPER | USAir, Pittsburgh, PA |
| LIFE | Since 1986. |
| DESCRIPTION | This software system is a component of the Merlin package, which include MACH, CCS, and MCS. This phase of the system is used in material control, planning, purchasing, receiving and issuing functions in aviation organizations. |

## 82. MAINTENANCE TRAINING SIMULATOR—US ARMY

| | |
|---|---|
| FUNCTION | Efficient, complete training for specified aircraft or maintenance systems. |
| SPONSOR | US Army |
| DEVELOPER | BBN Laboratories |
| LIFE | 1988 |
| DESCRIPTION | Maintenance training simulators are designed to reduce training costs, reliance upon certain types of equipment availability, and condense training time with increased training effectiveness. As an example, the simulator developed for the F-16 fighter aircraft environmental system has reduced eleven days overall training with one day hands-on, to seven days hands-on. This simulator, developed by BBN Laboratories for the US Army is for the Sikorsky Black Hawk air defense system radar. Using artificial intelligence, the trainer embodies the knowledge of an expert. It can be used to train or function as a diagnostic tool. |

## 83. MULTIPLE FAULT DIAGNOSTIC GAS PATH ANALYSIS SYSTEM

| | |
|---|---|
| FUNCTION | Demonstration of Hamilton Standard's Gas Path Analysis Technique. |
| SPONSOR | Naval Air Propulsion Test Center, Trenton, Nj |
| DEVELOPER | United Technologies, Windsor Locks, CT |
| LIFE | 1975 |
| DESCRIPTION | System demonstrates the results of Hamilton standard's gas path diagnostic system for a complex twin-spool mixed flow, variable geometry turbofan engine. Possible diagnostic routines are specified with sensor and control uncertainties. |

## 84. NASA/US AIR FORCE SELF-REPAIRING FLIGHT CONTROL PROGRAM

| | |
|---|---|
| FUNCTION | Aircraft self-diagnostics system. |
| SPONSOR | NASA/US Air Force |
| DEVELOPER | General Electric |
| LIFE | 1989 |
| DESCRIPTION | The Self-Repairing Flight Control Program was developed to assist fault failure detection and maintenance. The program detects and identifies failures as they occur in-flight, thus eliminating the difficulty of replicating failures in ground tests after the aircraft lands. General Electric has developed an aircraft maintenance self-diagnostic system that will perform these in-flight tests on an F15 research aircraft. |

## 85. ORION 4400 AUTO TEST SYSTEM

| | |
|---|---|
| FUNCTION | To maintain inertial navigation and aircraft management system. |
| SPONSOR | Japan Air Lines |
| DEVELOPER | GEC Avionics |
| LIFE | 198 |
| DESCRIPTION | The Orion 4400 is a system used to help maintain inertial navigation systems and aircraft management systems. The equipment is of modular design and has self-diagnosing and self-repair capabilities. These systems are used in production control and maintenance applications. |

## 86. PCMAS —PORTABLE COMPUTER BASED MAINTENANCE AID SYSTEM

| | |
|---|---|
| FUNCTION | Portable maintenance expert system |
| SPONSOR | US Air Force |
| DEVELOPER | Boeing Military Aircraft Company |
| LIFE | 1986 |
| DESCRIPTION | Portable Computer-Based Maintenance Aid System, PCMAS, is maintenance system which utilizes expert systems called MDIS. |

## 87. PLTS—PARTS LIFE TRACKING SYSTEM

| | |
|---|---|
| FUNCTION | System designed to manage on-condition maintenance. |
| SPONSOR | US Air Force |
| DEVELOPER | General Electric Corp., Aircraft Engine Business Group, Lynn, MA. |
| LIFE | 1979. |
| DESCRIPTION | The system is designed to support the philosophy of on-condition maintenance. |

The system manages maintenance of USAF/A10 aircraft. Included in the overall system are Parts Tracking Systems, and Engine Time-Temperature Recorder systems. The central data base includes a parts master file encompassing all designated parts entered into the system either as spares or as a part of the engine data. The PLTS requires data from the mechanic responsible for changing parts (engine serial number, part serial number, location of part and date, for example) and periodic reading and recording of information taken from the units at other times.

**88. PRISM - PRODUCTIVITY IMPROVEMENTS IN SIMULATION MODELING PROJECT**

| | |
|---|---|
| FUNCTION | To provide a proof of concept for an integrated model development environment. |
| SPONSOR | USAF Air Force Human Resources Laboratory |
| LIFE | 1988 |
| DESCRIPTION | Event simulation models have been, and continue to be, major decision support aids in logistics capability assessment. Results of a survey conducted by the Air Force Human Resource Lab indicate a large amount of user dissatisfaction with various aspects of many of these decision support aids. The Prism project was created to address these problems by providing a proof of concept via a software environment. |

**89. Q-GERT SIMULATION LANGUAGE**

| | |
|---|---|
| FUNCTION | Simulation language |
| SPONSOR | USAF |
| LIFE | 1983 |
| DESCRIPTION | Q-GERT is a simulation language that was used to develop a model that would determine B-1B automatic test equipment station quantities required to support the B-1B avionics components at base level. Two techniques were developed to determine test station quantities based on the model output. The first technique was to buy sufficient test stations to achieve a four day maximum base repair cycle time for the avionics components. The second technique was to conduct a cost-benefit analysis by comparing the costs of additional test stations (benefits of a shorter repair cycle times)to the benefits of fewer test stations (the costs of longer repair cycle times). The research effort provides a range of management options for consideration by the B-1B System Program Office. |

**90. RADstation**

| | |
|---|---|
| FUNCTION | Speech recognition-based radiology reporting system. |
| DEVELOPER | Lanier Voice Products |
| LIFE | 1990 |
| DESCRIPTION | The RADstation is a radiology reporting system that is based on an IBM-compatible PC and Dragon Systems' speech recognition technology. The software package is menu driven and contains an on-line vocabulary of 30,000 words. This system enables the radiologist to read the X-ray and call out a particular finding. This will trigger the system to produce a complete and formatted report on that finding. The report can be written into one of the three available levels of detail. This report can be sent to physicians quickly via computer network interface or by fax using a fax/modem. |

**91. RF-ELATS —RADIO FREQUENCY EXPANDED LITTON AUTOMATED TEST SETS**

| | |
|---|---|
| FUNCTION | Test various systems/equipment of F/A-18 aircraft |
| SPONSOR | Royal Australian Air Force |
| DEVELOPER | Litton Systems Canada |
| LIFE | 1987 |
| DESCRIPTION | Radio Frequency Expanded Litton Automated Test Sets (RF-ELATS) performs comprehensive tests and fault diagnosis on radar, communications, microwave and Electronic Warfare (EW) equipment. The system utilizes a touch-sensitive screen, a keyboard a printer and a plotter. |

## 92. RMMS - REMOTE MAINTENANCE MONITORING SYSTEMS

| | |
|---|---|
| FUNCTION | Monitor, control and verify remote equipment. |
| SPONSOR | FAA |
| LIFE | 1989 |
| DESCRIPTION | The RMMS monitors, controls, and verifies the performance of National Airspace System equipment and sites. The program to modernize this isdesigned to centralize and automate thesystems' activity. Presently, thesystem is setup up in a master/slave relationship. By 1995, the setup should be changed so that the controller transparently accesses the remote facilities through the main Advanced Automation System (the host system for air traffic). |

## 93. SAIFE—STRUCTURAL AREA INSPECTION FREQUENCY EVALUATION

| | |
|---|---|
| FUNCTION | To assist in the evaluation of proposed structural inspection programs for commercial jet transport aircraft. |
| DEVELOPER | Technology, Incorporated, Dayton, Ohio |
| LIFE | 1978 |
| DESCRIPTION | SAIFE is a computer program developed to assist management in the evaluation of alternative structural inspection and modification programs. Its logic simulates various structural defects, failures and inspections and their ramifications in five areas of control: (1) aircraft design analysis; (2) fatigue testing; (3) production, service, and corrosion defects; (4) probability of crack or corrosion detection; (5) aircraft modification economics. The goal of this program is to quantify the evaluation process currently used to establish and modify inspection intervals for commercial jet transport. |

## 94. SAMT - SIMULATED A/C MAINTENANCE TRAINING

| | |
|---|---|
| FUNCTION | To increase effectiveness of maintenance procedure instruction. |
| SPONSOR | USAF |
| DEVELOPER | Honeywell Training and Controls Systems Operations |
| LIFE | 1982 |
| DESCRIPTION | The F-16 engine diagnostic SAMT is comprised of simulated aircraft cockpit and test equipment control panels, an instructor station, and a computer simulation of the Pratt & Whitney F-100 engine. Computer simulation seeks to provide realistic engine performance for maintenance training. Use of this vehicle allows students to practice engine trimming procedures, and diagnosis of a variety of engine component failures. |

## 95. SELF-REPAIRING FLIGHT CONTROL SYSTEMS

| | |
|---|---|
| FUNCTION | Flight control system |
| SPONSOR | USAF - Aeronautical Systems Division |
| DEVELOPER | Honywell & McDonnel Douglas |
| LIFE | 1985 |
| DESCRIPTION | This is a reconfigurable or 'self-repairing' flight control system that continually evaluates the aerodynamic conditions of aircraft, and reconfigures itself in the event that certain control surfaces are unavailable due to damage or malfunction. A reconfiguration module contained in the system is capable of choosing the correct combination of control surface deflections to execute certain maneuvers. The system will also provide instructions to the pilot to compensate for the alteration in control surface. This reconfiguration computer technology might be adapted to future civilian aircraft. |

## 96. SEMSA WEAPON SYSTEM AND MAINTENANCE SIMULATOR

| | |
|---|---|
| FUNCTION | Weapon system and maintenance simulator |
| DEVELOPER | Sogitec |
| LIFE | 1988 |
| DESCRIPTION | The SEMSA weapon system and maintenance simulator is designed to train technicians in Mirage 2000 maintenance methods. The simulator is used to familiarize technicians with weapon system operation, fault-finding and diagnosis of malfunctions. SEMSA contains four elements: a cockpit cabinet with a display of the pilot's station; and aircraft cabinet with another display of the stores system and test equipment; an instructor's station; and a data processing suite. |

## 97. SERVICE BAY DIAGNOSTIC SYSTEM I

| | |
|---|---|
| FUNCTION | Computer to guide automobile maintenance technicians through repair of Ford's electronic engine control unit (EEC-IV) and the many components with which that unit interacts. |
| SPONSOR | Ford Motor Company, Ford Parts and Service Division |
| DEVELOPER | Hewlett-Packard Co. |
| DESCRIPTION | This diagnostic system incorporates a touch screen computer and printer, and a portable engine analyzer that may be operated during a road test. Functionally, it taps into the EEC-IV system through the data link, and talks to other modules in the system. It can activate other sensors and actuators. It can also communicate with Ford's OASIS (On-Line Automotive Service Information System) to receive technical information, updates and manual information and service bulletins. The computer will also display diagrams and drawings of parts and sensors, which may be otherwise difficult to locate or discern. |

## 98. SERVICE BAY DIAGNOSTIC SYSTEM (SBDS) II

| | |
|---|---|
| FUNCTION | Auto diagnostics expert system using hypertext capability. |
| DEVELOPER | Ford Motor Company |
| LIFE | Operation by December 1989 in 2000 dealerships |
| DESCRIPTION | Hypertext is a method of organizing related information via computer systems. Hypertext-based automobile diagnostics and repair workstation helps mechanics repair cars. The Service Bay Diagnostic System has an expert system in the diagnostic mode to analyze the meter readouts, symptoms data entered into the computer by the technician. |

## 99. SPS—SHOP PLANNING SYSTEM

| | |
|---|---|
| FUNCTION | To reduce the amount of duplicated effort and improve accountability and control of shops parts tracking and shop planning systems. |
| DEVELOPER | USAir |
| LIFE | Since 1986. |
| DESCRIPTION | This is a software tool, part of the larger Merlin package, to improve aviation maintenance management and staff function efficiency. This portion of the Merlin package governs shop planning, scheduling, and parts inventory control. A combined system such as this reduces paperwork without reducing efficiency. |

**100. STAR-PLAN**

| | |
|---|---|
| FUNCTION | To help satellite control operators identify and resolve system faults in orbiting spacecraft. |
| DEVELOPER | Ford Aerospace & Communications Corporation, Sunnyvale |
| LIFE | 1986 |
| DESCRIPTION | Increasing complexity of spacecraft systems and the unavailability of technical advisors in some remote ground stations and mobile control facilities, has emphasized the need for automation of these satellites diagnostic and advisory functions. Satellite expert control systems must accommodate multiple disciplines and complex relationships between sub-systems. The prototype system will be a ground based decision aid to replace or augment the work of the technical analyst who monitors incoming telemetry data stream from a satellite and compares that data with expected conditions (heuristic reasoning). Models for incorporating procedures for automating the knowledge acquisition process are also included. |

**101. STEMS —STRUCTURAL TRACKING AND ENGINE MONITORING SYSTEM**

| | |
|---|---|
| FUNCTION | Monitoring system for aircraft structures. |
| SPONSOR | USAF |
| DEVELOPER | Northrop |
| LIFE | 1983 |
| DESCRIPTION | STEMS is a system that determines inspection and repair schedules forindividual aircraft, determines aircraft surface life expectancy, provides data for future specifications, and establishes operational limitations. It consists of an on-board processor, diagnostic display unit and a data collection unit. |

**102. THREE-DIMENSIONAL TRAINING SIMULATOR**

| | |
|---|---|
| FUNCTION | Training Simulator |
| SPONSOR | Commercial. Used by NASA and General Motors and others. |
| DEVELOPER | Autodesk, Salsaulito, California VPL Research, Redwood City, California |
| LIFE | 1989 |
| DESCRIPTION | The simulation is accomplished through tiny computer monitor goggles which users wear over each eye. The goggles deliver coordinated messages to the user's brain. The computer linked to the user through a sensor glove. Use of the glove creates and guides perceived movement, thus creating an artificial reality. This is called Cyberspace. It puts the user in a simulated, realistic 3-D world.<br><br>This is being used and developed for use in training helicopeter pilots and other types of applications by GE, NASA and the Army. |

**103. TEDS—TURBO ENGINE DIAGNOSTIC SYSTEMS**

| | |
|---|---|
| FUNCTION | To electronically monitor various engine conditions and functions. |
| SPONSOR | US Air Force, and others. |
| DESCRIPTION | A generic term for systems using electronic means to determine engine conditions and satisfactory functions. The first system was called, Events History Recorder, developed for the Air Force F100 engine. Other systems using same and developing technology include that for the T-38 trainer J85 engine, the A-10 ground support aircraft's TF34 turbofan engine, and those installed in the KC-135, B1-B, and F-16 aircraft. Representative systems are known as Integrated Turbine Engine Monitoring System and Joint Advanced Fighter Engine diagnostic system. |

## 104. TEMS—TURBINE ENGINE MONITORING SYSTEMS

FUNCTION Generic term for a variety of engine monitoring systems.

SPONSOR USAF

DESCRIPTION TEMS is representative of one of the earliest applications of technology to the maintenance process. This system focuses on engine monitor parameters seeking to predict when and what maintenance is required on the engine to achieve on-condition maintenance. TEMS is a generic name for a variety of early systems which use different means of collecting data. Some data is collected manually, others automatically. Recent systems collect data and in real-time transmit it to the ground station. All systems collect this data to spot anomalies, leading to increased aircraft availability, reduced overall engine maintenance costs.

## 105. TEXMAS —TURBINE ENGINE EXPERT MAINTENANCE ADVISOR SYSTEM

FUNCTION Used in conjunction with a system such as TEMS, TEXMAS uses human-like reasoning to achieve reduced maintenance costs and increase aircraft availability.

DEVELOPER Textron, Inc., Avco Lycoming Textron, Stratford, CT

LIFE 1988.

DESCRIPTION TEXMAS takes raw data and carries out functions such as engine performance measurement, event monitoring, and life monitoring, and fault isolation and diagnosis. It can also be used to walk an inexperienced mechanic through the diagnosis process. TEXMAS is based on expert system technology, implemented on a laptop computer.

Developed for the T53 engine. This is an engine with few sensed parameters (two rotor speeds, torque, exhaust gas temperature, oil pressure and oil temperature. With no other measurements available, the diagnosis process requires the knowledge of an expert.

## 106. TROUBLESHOOTER

FUNCTION Training tool to aid aviation mechanics in learning troubleshooting and diagnostic skills utilizing simulation oriented computer-based instruction methods.

DEVELOPER Flight Safety International

LIFE First introduced in 1986, successive developments in 1988 with anticipated additional developments.

DESCRIPTION Flight Safety International has developed a series of simulation oriented computer-based instruction aids for virtually all major subsystems of Cessna Citation 500, Dassault Falcon 50 and the Sikorsky S-76. First introduced in 1986, the diagnostic courses are being expanded to a wide range of business aircraft. This system uses actual pilot write-ups of service difficulty reports, manufacturers service write-ups, with cockpit indicators programmed into the software. Students review subsystems individually or in teams in order to develop and critique solutions. Review of the steps taken to diagnose the problem and the components replaced determine the effectiveness of the recommended procedures. Use of the system does not require previous computer experience.



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## 107. VSLED— VIBRATION, STRUCTURAL LIFE AND ENGINE DIAGNOSTIC

| | |
|---|---|
| FUNCTION | Monitoring system for V-22 tiltrotor aircraft, this system is representative of the latest generation of performance aids, distinct by its integration into the aircraft itself. It extends the monitoring process to the aircraft structure. |
| DEVELOPER | Bell Aerospace |
| LIFE | 1989 |
| DESCRIPTION | Vibration, Structural Life and Engine Diagnostics (VSLED) is a monitoring system developed for the V-22 tiltrotor aricraft. This system seeks reduce maintenance costs by 50% By monitoring the structure of the aircraft and analyzing trends and parameters as do engine monitoring systems, VSLED integrates several systems, and uses automatic detection of exceeded limits. This data is analyzed and fault isolation analysis is performed. It monitors the aircraft's vibration, temperatures, structural life, and engine events, and can generate reports that specify needed maintenance actions. |

## 108. XMAN—EXPERT MAINTENANCE TOOL

| | |
|---|---|
| FUNCTION | An expert maintenance system designed to be a user interface to the maintenance data base created by systems such as TEMS. |
| SPONSOR | US Air Force |
| DEVELOPER | System Control Technology Corporation |
| DESCRIPTION | XMAN was developed for use on the USAF A-10A. It uses expert systems technology and builds upon other related technologies (such as TEMS) to automate diagnostic and troubleshooting procedures. Since this tool can communicate to the user the sequence of conclusions in the diagnostic procedure, it may be used for training. |