CHAPTER 6
PEN COMPUTER BASED NON-ROUTINE REPAIR WRITE-UP SYSTEM

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6.1 INTRODUCTION

In the past, the research program has investigated the use of pen computer technology for inspection and auditing tasks in cooperation with FAA Flight Standards Service (Layton, in press). This line of applied research has been well received by industry representatives as a valuable aspect of the research program. This year the research program once again teamed up with industry representatives to study other applications of pen computing technology. One of the applications was developed for the Coordinating Agency for Supplier Evaluation (CASE) and is reported in Chapter 5 of this phase report.

This chapter describes another application developed in conjunction with personnel from United Airlines (UAL) Oakland Modification Center to use pen computer technology for the collection of non-routine repair write-up information during heavy maintenance inspections. The system design and software development were completed solely under UAL funding. However, UAL allowed the research team to conduct a pilot study using the pen computer based non-routine repair system in the Oakland facility. This report describes the UAL Pen Computer Non-Routine Write-up System, its development, the pilot study and its conclusions so that other industry personnel can benefit from this endeavor.

6.2 NON-ROUTINE REPAIR WRITE-UPS: CURRENT SYSTEM

Heavy maintenance checks of aircraft are scheduled to occur at regular intervals. Standard inspections are performed for each type of maintenance. For safety reasons, the FAA requires an airline to document every maintenance action that is taken on an aircraft. Standard inspections are typically documented using a routine inspection job card. However, a substantial number of maintenance actions are not covered by a routine job card. A non-routine repair write-up form is used to document such maintenance actions.

When an aircraft arrives at the maintenance facility for a heavy maintenance check, the airplane is opened up in preparation for the preliminary inspection. During preliminary inspection, the inspectors use standard job cards to assess what maintenance work is needed on this particular aircraft. During the preliminary inspection process, a number of non-routine repair write-ups are generated by the inspectors. These write-ups represent additional work that must be completed in the scheduled time-frame of the visit.

After the inspector generates a number of write-ups, the forms are wanded into a bar coding station for transmission to a central data base. The paper forms are left in the planning center for additional processing. First, a lead mechanic processes the paper write-up, indicating what repair is to be performed. The lead also provides an estimate of the number of hours that will be needed to complete the repair. The planner/analyst uses this information to plan man-power needs. One or more mechanics will complete the non-routine repairs and sign-off the non-routine form, on the portion of the repair they have performed. When the repair is completed, the non-routine repair form is returned to the planning center. An inspector must then verify that the repair has been completed properly and sign-off on the repair. This last step is known as buy-back. Finally, there is an audit process that verifies all the paper work is accounted for and that all standard and non-routine maintenance have been completed prior to releasing the aircraft for service.

6.2.1 Problems Associated with the Current System

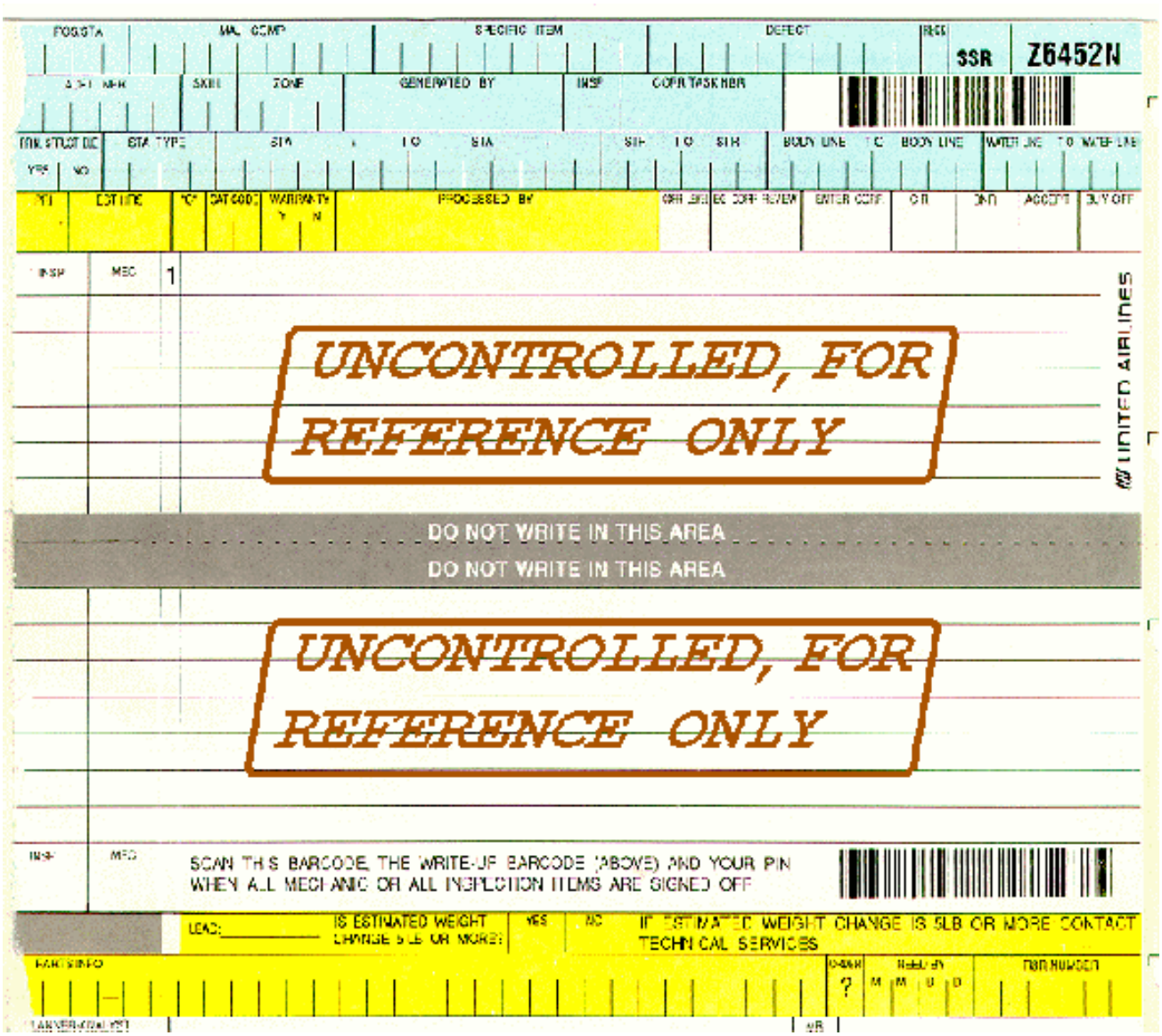
The current paper process has been used successfully to generate and track non-routine repairs. However, the airline can save money by improving the efficiency of the process. For example, time is lost when write-ups are not easy to read or are incomplete. In such cases, work cannot proceed until the inspector is tracked down and clarifies what has been written on the write-up form.

Tracking and planning is also hindered by the current system. There is little ability to analyze the non-routine repairs reported over time. Common repairs can become part of the routine maintenance planned on a particular aircraft. This is partly due to the lack of a database of defects and locations. Another major hindrance to such analysis is the lack of standardized terminology for identifying defects.

Inspectors have indicated that they frequently rely on reference material that is not available to them at the inspection site. It is not practical for the inspector to carry around the complete set of reference material in paper form. Therefore, in order to access the reference material needed to correctly complete an inspection, the inspectors must often leave an inspection area.

The inefficiencies described above generally translate to lost time, which in turn translates to lost money. One element of the current process can be quantified directly in terms of costs. This is the cost of the paper write-up forms themselves. These forms are specially printed in quadruplicate to support tracking of the paper work. (See Figure 6.1). Consequently the cost of these specialized forms is relatively high. The number of forms used per aircraft maintenance visit varies depending on the type of aircraft, age of the aircraft, and type of maintenance visit. UAL found that it uses anywhere from approximately one thousand to five thousand write-ups per visit. When multiplied by the number of maintenance visits that are that are completed each year, the figure that results is significant in terms of maintenance costs.

Figure 6.1 Current UAL Non-Routine Write-Up Form



6.3 NON-ROUTINE REPAIR WRITE-UPS: THE AUTOMATION APPROACH

The United Airlines personnel were well aware of the problems associated with the current non-routine repair write-up system. The question of how to improve the process had been discussed both formally and informally for years. An automated approach to the process was desired, but the proper technology was needed before it could be implemented. United personnel learned of the results of the first fielding of pen computers for the Flight Standards Service that was performed as part of the FAA/AAM Human Factors research program (Layton, in press). Given that pen computers are similar in size to the clip boards that inspectors carry during preliminary inspections, there was interest in this relatively new technology. In June 1995, UAL funded a project to determine if pen computer technology was a viable alternative to the current paper-based method for generating and tracking non-routine repair write-ups.

6.3.1 The Goals

The immediate goals of the initial project were two-fold. First, UAL wanted to determine if pen computer technology was a feasible solution for this aircraft maintenance application. If the technology proved feasible, many of the problems identified above could be addressed. Second, the project would allow inspectors and other personnel to evaluate various brands of pen computers to help select appropriate hardware. The long-term vision of the project was to provide better tools to the inspectors, lead mechanics, and planner/analysts in order to improve the creation and processing of non-routine repairs. The expected result was a reduction in the time it takes to complete a maintenance visit.

6.3.2 Expected Benefits of Pen Computer Based System

The pen computer approach provides solutions to many of the problems listed with the current system: cheaper paper forms, language standardization, improved database to support planning and analysis. In order for the automated system to be successful, however, it must provide sufficient tools and support for the inspectors so that they are willing to use the system. The expected benefits of the system for inspectors include:

- Less handwriting (e.g., pick-lists, duplicate write-ups)
- Standardization of language (e.g., constrained fields)
- Information is complete (system checks write-up before saving)
- Improved readability of printouts
- All Inspectors will be "Rovers" (no longer constrained to one area of the aircraft)
- Transfers occur automatically during breaks
- Easier to review write-ups after transfer
- Easier to get reprints if needed.

Note that inspectors were not expected to generate write-ups more quickly using the pen computer write-up system compared to the paper forms. It was also noted that the initial system had limited benefits compared to the operational system that is planned. If the technology proves feasible, the additional benefits include:

- Expanded database to handle entire UAL fleet
- Wireless radio frequency (RF) transfers data transparently and "instantaneously"
- Access to on-line reference material
- Automated routing of information
- Improved planning/scheduling.

In essence, the bottom line benefit of the full system would be to improve the collection and flow of non-routine repair information to reduce the time it takes to complete a maintenance visit.

6.3.3 Pen Computer Models Evaluated

Pen computers are a general class of computer that employ a specialized operating system which allows a pen stylus to be used as an input device. This stylus can be used to print characters that are then "recognized" and converted to digital representations of the character. Pen computers have evolved over the past five years. A wide range of pen computer technology has become available, from low-end personal digital assistants to slate computers to "convertibles" with both a pen stylus and a standard keyboard.

Table 6.1 lists the minimum specifications desired for the pen computer hardware and software to be used for the Phase 1 inspector system platform. Several models of pen computers were considered for inclusion in the field study. However, for a variety of reasons, some models were not actually fielded.

Table 6.1 Specifications for Inspector Pen Computer Platform

Hardware

- 486/25 MHz
- 8 MB RAM
- 100 MB Hard Drive
- Type II PCMCIA Slots
- 5 MB PCMCIA Memory Card
- One of the following
- Ethernet PCMCIA Card
- Cradle with network and power connections
- Docking station with an Ethernet card.

Software

- MS-DOS 6.2
- Microsoft Windows for Pen Computing
- Novell Netware

Table 6.2 summarizes units that were considered for the evaluation and includes, where applicable, a note explaining the primary reason(s) why a unit was not fielded.

Table 6.2 Pen Computers Considered for Fielding

Make/Model	Fielded?	Why Not?
Fujitsu Stylistic 500	Yes	
Hammerhead 486	Yes	
Inforite Phoenix	No	Too slow (386SXLV/25MHz); Screen too small
Kalidor K2100	Yes	
MicroSlate Datellite 400L	No	Too heavy/bulky, poor screen clarity
NCR Safari	No	No longer available

Telepad SL	No	Too slow, poor usability
Telepad 3.0	No	No units provided by Vendor
Telxon 1134	No	Screen too small, problems with network communications
Telxon 1184	Yes	
Toshiba Dynapad T200	No	No longer available
Zenith CruisePAD	No	Requires RF capability

6.3.4 Scope of Pen Computer System

Given that the initial system development was targeted at determining feasibility of the technological approach rather than operational use, the initial scope was limited. The proof-of-concept system supports:

- Initial data entry of write-up data by inspectors on a pen-based computer
- One model of aircraft (i.e., classic 747)
- Batch transfer of data via Ethernet network
- Automatic data transfer between the pen units and the local data base
- Automatic data transfer between the local data base and UAL's master data base
- Administration of users and privileges
- Administration of aircraft visit information
- Administration of printing and data transfer functions
- Modification of write-ups after initial transfer.

This partial implementation allowed for a smaller up-front investment. Feasibility, therefore, could be assessed without risking the larger quantity of dollars needed for full, operational implementation.

6.4 PEN COMPUTER SYSTEM: DESIGN AND DEVELOPMENT

The Pen Computer Non-Routine Repair (NRR) Write-up System was designed, developed, and tested over a nine month period, from June 1995 to February 1996. Ten personnel from UAL and four developers from Galaxy Scientific Corp. formed the project team. The first two months involved development of detailed design specifications. Software development and testing took place over a four-month period. The final three months encompassed system integration, installation and testing.

6.4.1 Interface Design Methodology

From past research we have learned that persons who do not routinely use computer technology to perform their jobs generally have a modest understanding (though possibly greater aptitude) concerning such tools, and an even lower appreciation for them. Such persons are often suspicious of new technologies and may reject new solutions if they perceive any difficulties with it. To address such users, we integrated the following concepts in the design of this project:

•***Human-Centered design:*** Galaxy Scientific prides itself on its application of Human Factors principles to production software. Every attempt was made to ensure that the system was easy to learn and to use. At many points throughout the project, Galaxy Scientific used an iterative approach that included soliciting feedback and suggestions from those who would ultimately use the system.

•***Limit the amount of work:*** Redundant information was eliminated. Once data is entered, it would remain and propagate for as long as it was still valid.

•***Restrict the possibility of error:*** Handwriting recognition technology is not perfect. Through the use of selection lists and other standard controls provided in the MS Windows interface, the ability to enter invalid data was greatly reduced.

•***Check for errors***: Not all input can be constrained to eliminate errors on input. Therefore, to the extent that was practical, the data was checked prior to saving to verify that the information was complete and accurate.

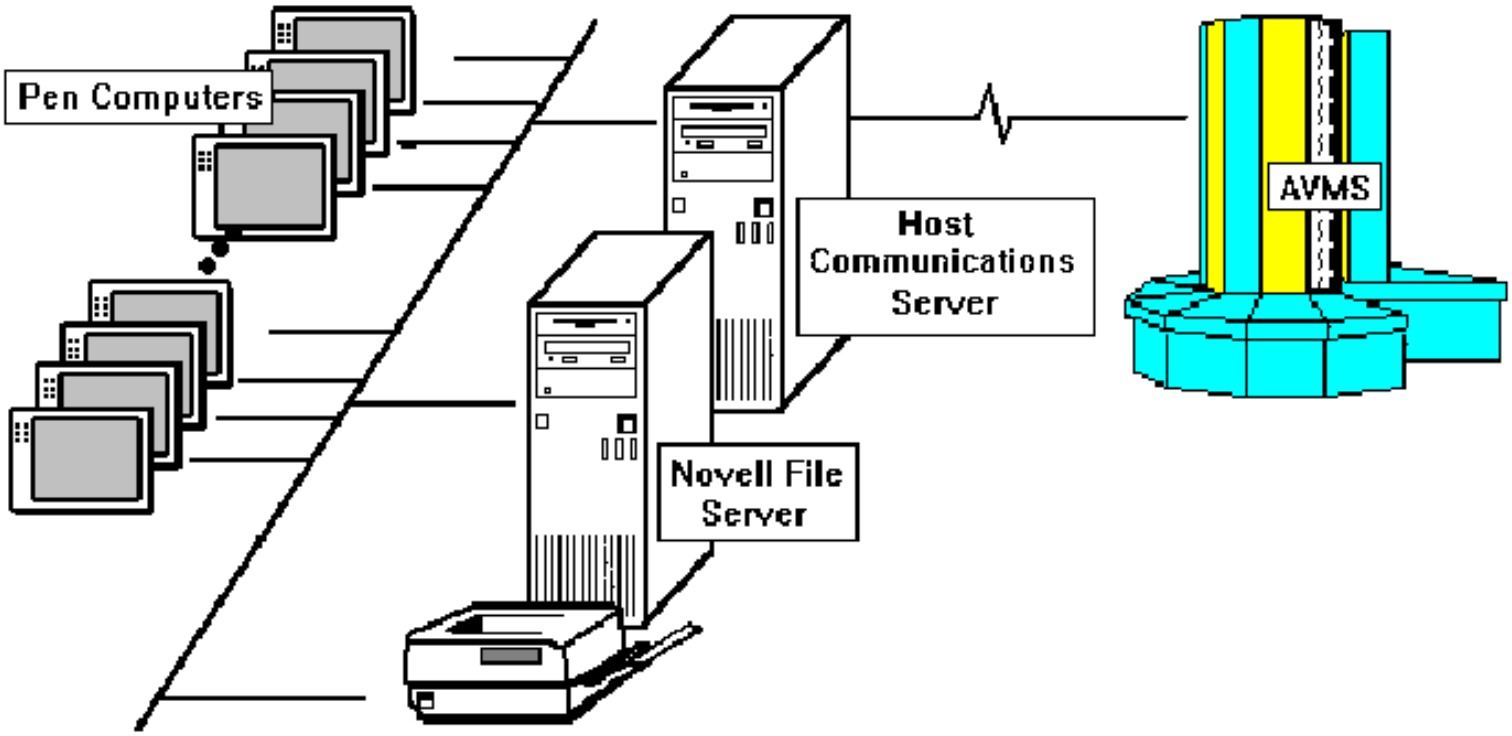
•***Standardized data entry:*** One of the goals of this project was to provide statistical analysis data from inspection results. In order to properly perform such analysis, a standard format and language were established in the collection of defect information and comments.

•***Multiple input methods:*** Different users feel comfortable using the computer in different ways. In order to accommodate as many preferences as possible, multiple methods of data entry, including keyboard, pen, and mouse, were supported.

6.4.2 System Configuration

Figure 6.2 illustrates the architecture of the automated UAL Non-Routine Repair Write-up System. The network system is a Novell-based, Ethernet network system. This data network is comprised of multiple pen computers, one host communication server, one host file server, and one double-sided laser printer. The file server stores the central (local) database for the pen computers and handles the printing of write-up forms. The communication server is used to transfer data to UAL's Aircraft Visit Maintenance System (AVMS). The laser printer prints the non-routine repair write-up forms, filled out with the inspection write-up information.

Figure 6.2 The Architecture of the Automated UAL Non-Routine Repair Write-Up System



6.4.3 Work Flow: Using the Pen Computer

The software that runs on the pen-based computer is called the Pen Computer Application. An inspector uses the Pen Computer Application to enter and transmit non-routine write-up information. This application actually consists of two separate programs -- one for entering the non-routine write-up data and a second which transmits the data to the Host System.

An inspector beginning his shift will select a pen-based computer from the bank of computers designated for this purpose. The computer will be running the Non-routine Repair Write-up software already, unless it is powered off, in which case powering on will initiate the software automatically.

At this point, the application is in **"docking mode"**, a restricted state in which two functions are available: Data Transfer and Inspector Log-in. Data transfer should have been completed when the computer was last docked. When an inspector is ready to begin work, at the beginning of the shift or after a break, the inspector will log-in to a pen unit. The log-in requires him to enter his personal identification number (PIN) via bar code, password, and the bay in which he will be operating. Once the identification is accepted, the computer will restart in **"data entry mode"**. (The computer must be rebooted so that the network software may be unloaded.)

The data entry screen consists of two parts. The first screen contains all the standard information collected from the inspection. The second screen displays a summary of the defect location information, and will allow entry of additional details (up to 255 characters).

After completing a single write-up, the inspector may then initiate a new write-up record. Selecting "New" from the pull-down menu will display a dialog box allowing the choice of creating a completely blank form or carrying over information from the previous write-up.

At the completion of the shift (or at the next break), the inspector will return the unit to the docking station. Since battery life for the Pen-based computers is not expected to last the entire shift, it will be necessary for the inspector to change out batteries during breaks. When the inspector returns the computer to the docking station, he should replace both batteries (one at a time) with spare batteries that are fully charged. The "used" batteries should be placed in the external charging unit. Next the inspector will initiate the data transfer sequence that will restart the machine in the docking mode. All data collected since the last upload session will be sent to the Host File Server and deleted from the pen-based computer. Also, at this point, any reference tables updated at the Host system will be downloaded to the pen unit. This transfer is normally an automatic process, so the inspector does not need to monitor the process. However, in the event that a transfer is aborted for any reason, it will also be possible to start the process manually.

6.4.4 Description of the Pen Computer Application Software

The software residing on the pen computers is known as the Pen Computer Application. The Pen Computer Application is divided into two programs: the Write-up program and the Transfer program. The Transfer program handles transfer of non-routine write-ups to the file server (see Figure 6.3) and permits log-in to the Write-up program (see Figure 6.4).

Figure 6.3 Example of the Transfer System

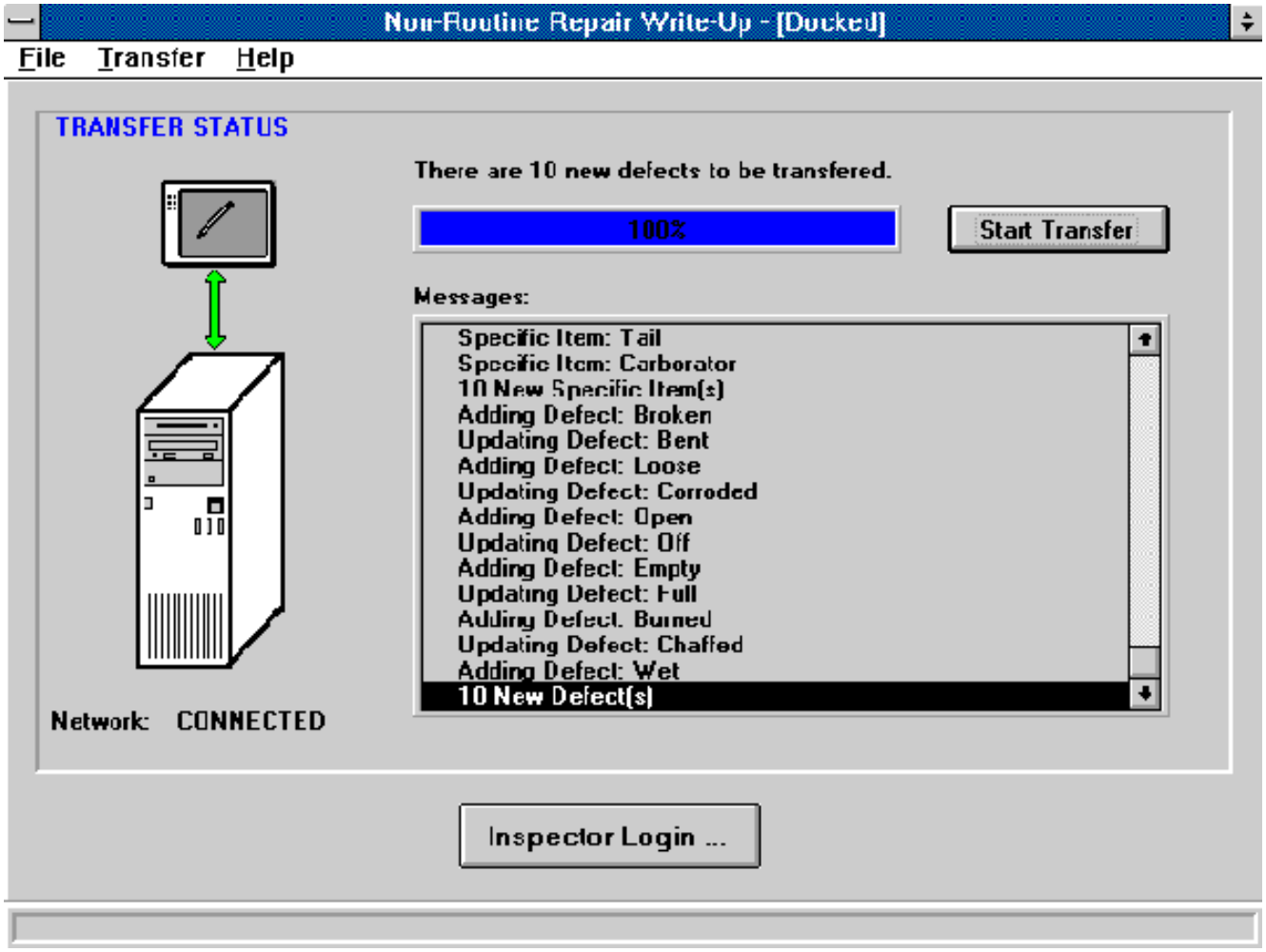
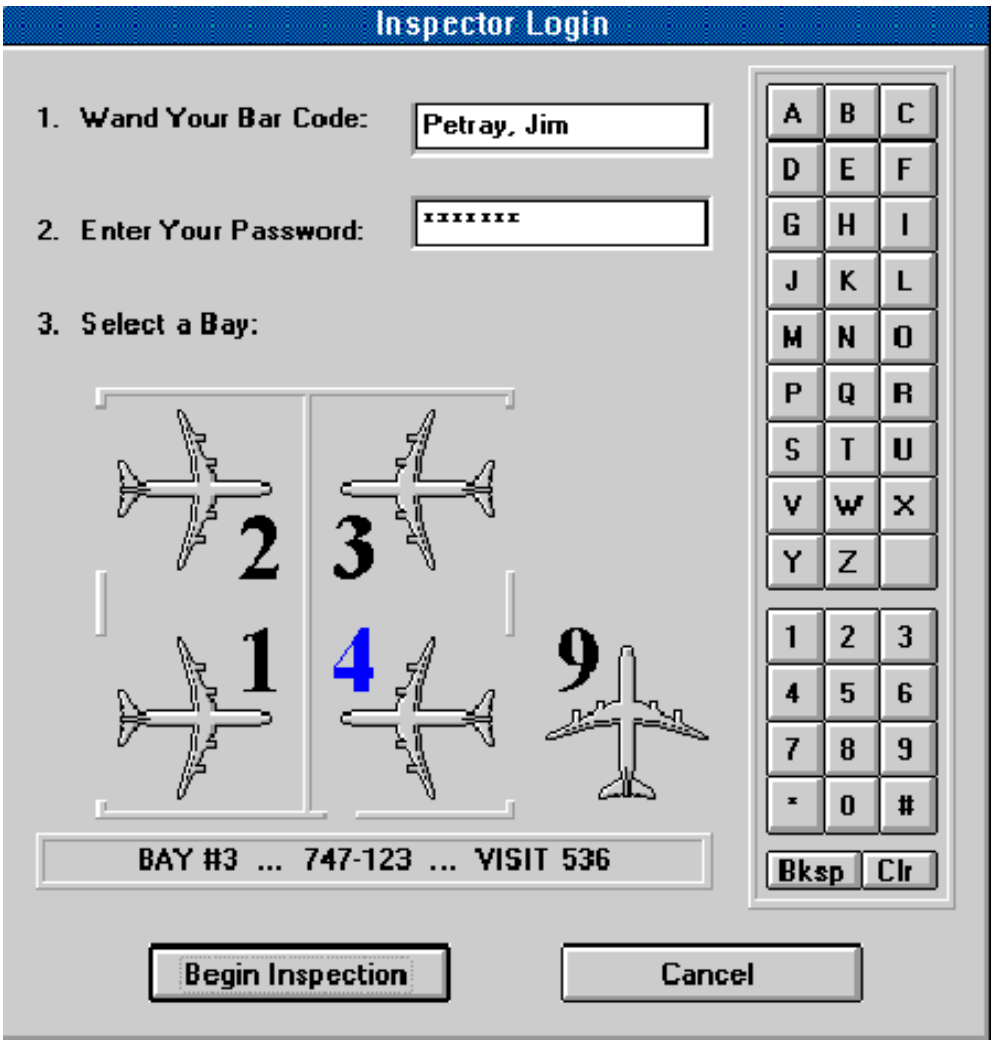
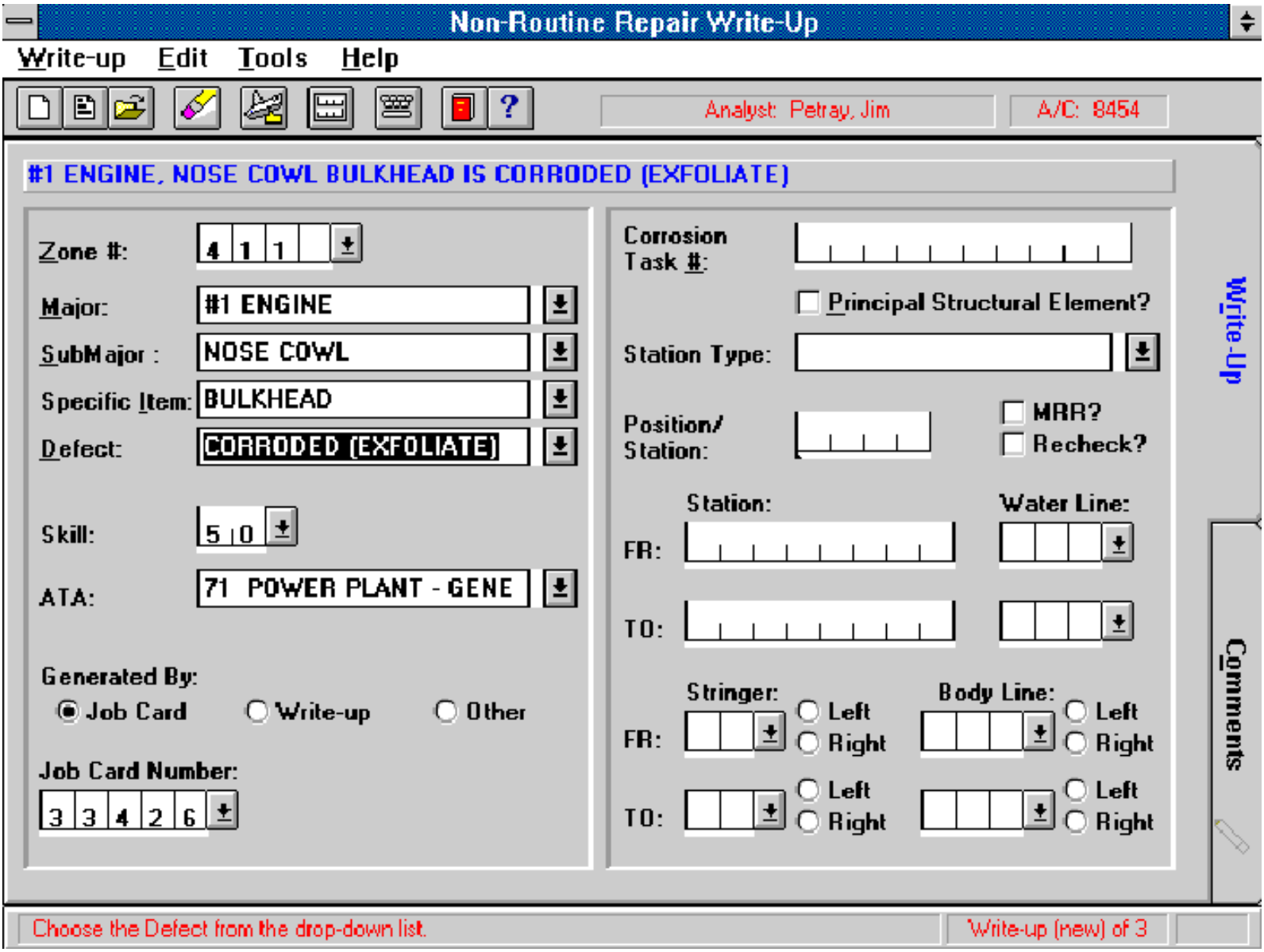


Figure 6.4 Example of Log-in Screen



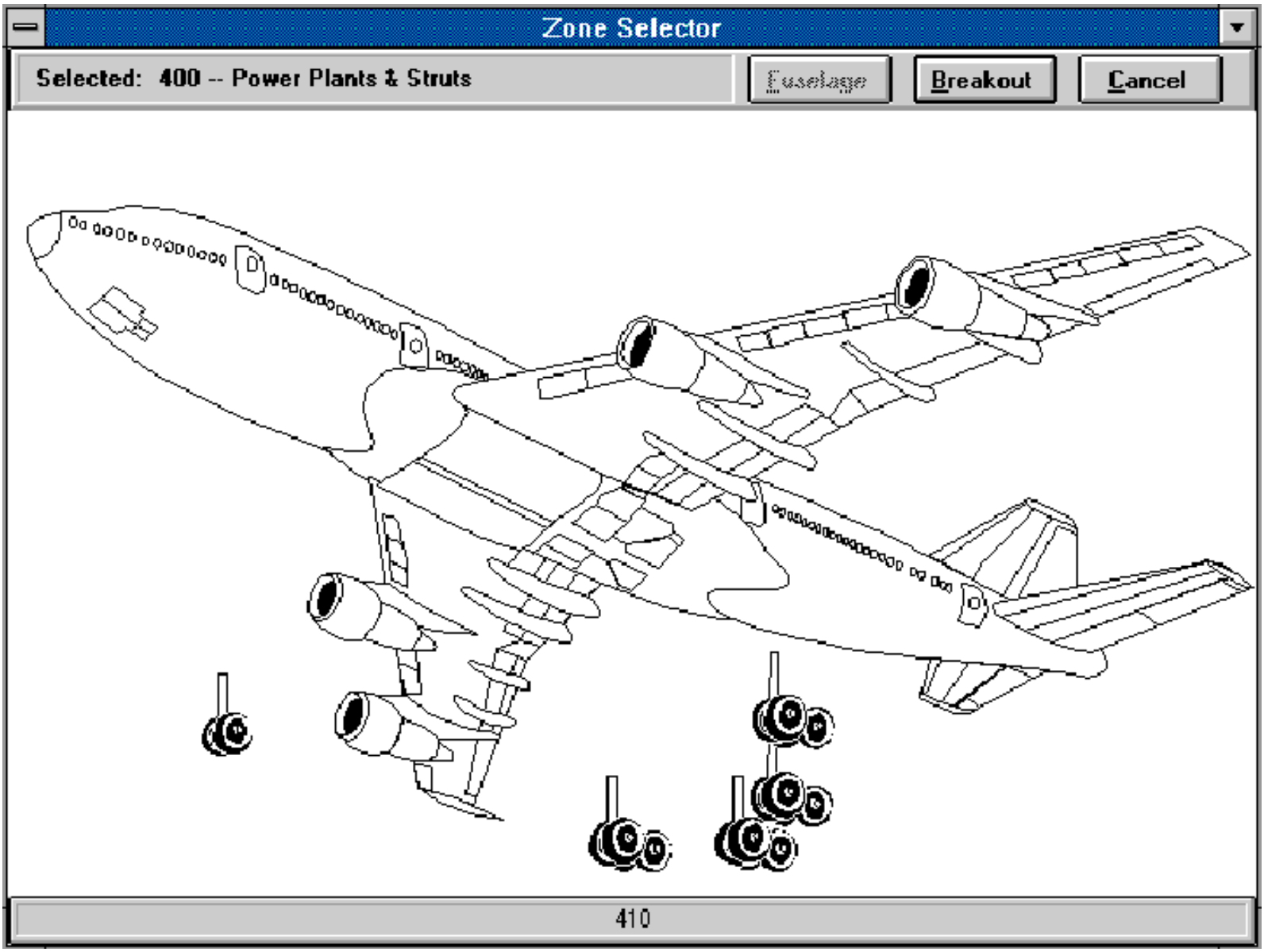
The Write-up program is used to enter initial write-up information. The main form is used to enter standard write-up information (see Figure 6.5) using the pen stylus. Rather than handwriting the information, much of the form can be completed by selecting items from drop-down lists. Related fields are linked such that entering information in one field will determine the content of the related fields. For example, if the Zone Number is entered, then the Major and Submajor fields are automatically filled in for the inspector. A change to any of these three fields will affect the other two.

Figure 6.5 Main Write-Up Form



In addition, Zone Charts are available for identifying the location of the defect (see Figure 6.6). The inspector can use the pen stylus to select the location of the defect and have the corresponding zone number and major and submajor fields automatically completed.

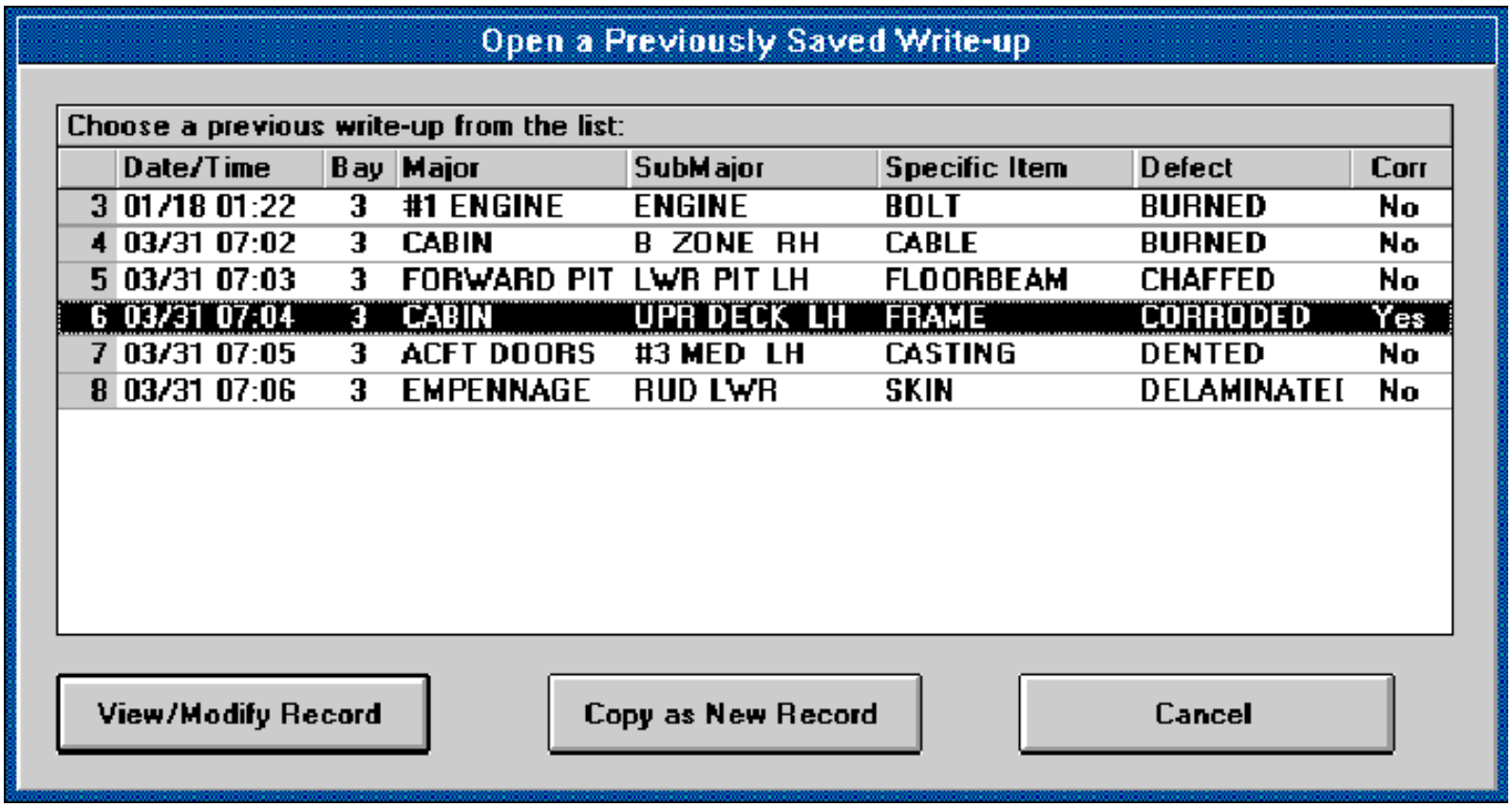
Figure 6.6 Example of an On-Line Chart



The drop down lists for Specific Items and Defects are not intended to hold all possible options. Rather, the lists contain the most frequently occurring items and defects. If an inspector wants to record a defect that is not currently in the list, the inspector can use the Expanded Input Field to write the defect. The new defect will not be added immediately to the drop down list, but it will be added to a separate database. The system administrator can then determine whether or not this item should be added to the default list based on the frequency of its occurrence.

If a similar defect is found in multiple locations, the write-up can be duplicated and modified to indicate the different location, thus reducing repetitious inputs by the inspector. Figure 6.7 illustrates how the user can open previous write-ups for copying or for modification.

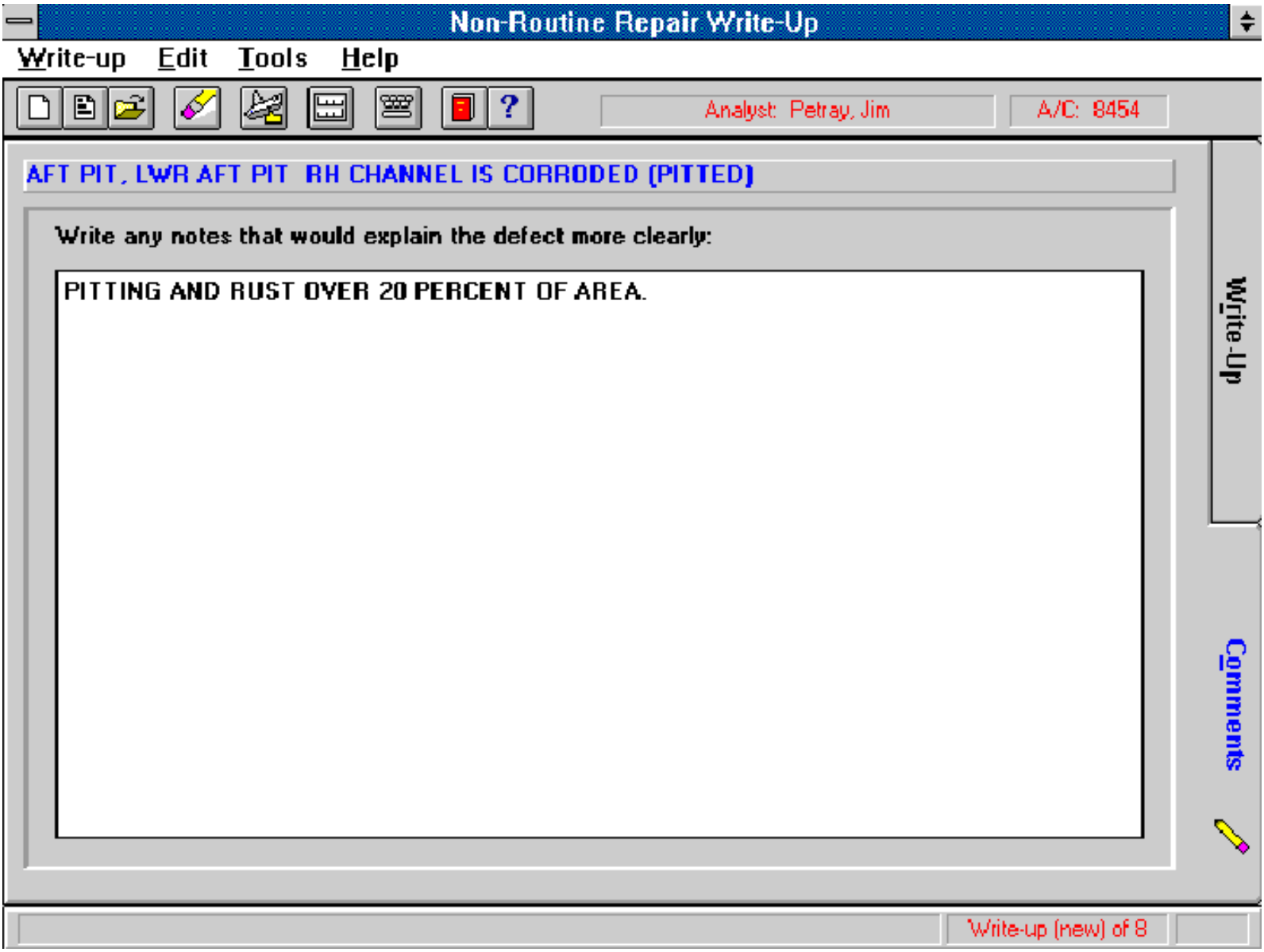
Figure 6.7 Example of Opening a Previous Write-Up



	Date/Time	Bay	Major	SubMajor	Specific Item	Defect	Corr
3	01/18 01:22	3	#1 ENGINE	ENGINE	BOLT	BURNED	No
4	03/31 07:02	3	CABIN	B ZONE RH	CABLE	BURNED	No
5	03/31 07:03	3	FORWARD PIT	LWR PIT LH	FLOORBEAM	CHAFFED	No
6	03/31 07:04	3	CABIN	UPR DECK LH	FRAME	CORRODED	Yes
7	03/31 07:05	3	ACFT DOORS	#3 MED LH	CASTING	DENTED	No
8	03/31 07:06	3	EMPENNAGE	RUD LWR	SKIN	DELAMINATE[	No

The Comments form in the Write-up program contains a free-form field for expanding on the location or description of the defect (see Figure 6.8). As with any field that accepts handwriting, the user may use the on-screen keyboard or expanded input field for entering or editing information.

Figure 6.8 Example of Adding Comments to a Write-Up



6.4.5 The Host System Application And Transfer Program

The software responsible for maintaining the data on the Host File Server is known as the Host System application. The software that transfers data from the file server to the Aircraft Visit Maintenance System (AVMS) is known as the Host-AVMS Transfer application.

The Host System application performs functions necessary to maintain the host database, print write-up data, and initiate the upload of database information to AVMS. Some functions are carried out at regular intervals by the program and others are initiated by the user. Of the user initiated functions, some are concerned with the write-ups and others with administration. Functions performed by the Host System application are:

- Automatic Functions
    - Write-up Printing
    - Initiate AVMS-Host Transfer Application
- User Initiated Functions (Write-ups)
    - Reprint Write-ups
    - View Write-ups
    - Modify Write-ups
    - View Write-ups History

    - Print Summary Report
    - View Print Queue
- User Initiated Functions (Administrative)
    - Visit ID Management
    - User ID Management
    - Database Maintenance
    - Initiate AVMS Transfer Application

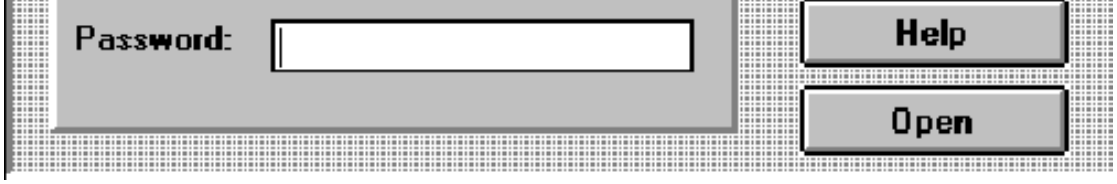
Automatic Functions

The Host System application performs two functions automatically. These are printing non-routine write-ups and calling the Host-AVMS Transfer application. Between shifts or during breaks the pen computer transfers data to the Host Database. The Host application periodically prints all new write-up data on 8.5 x 11 inch paper using a two-sided laser printer. Similarly, the Host System application periodically activates the Host-AVMS Transfer application to transfer write-up data from the Host File Server to AVMS.

User Initiated Functions

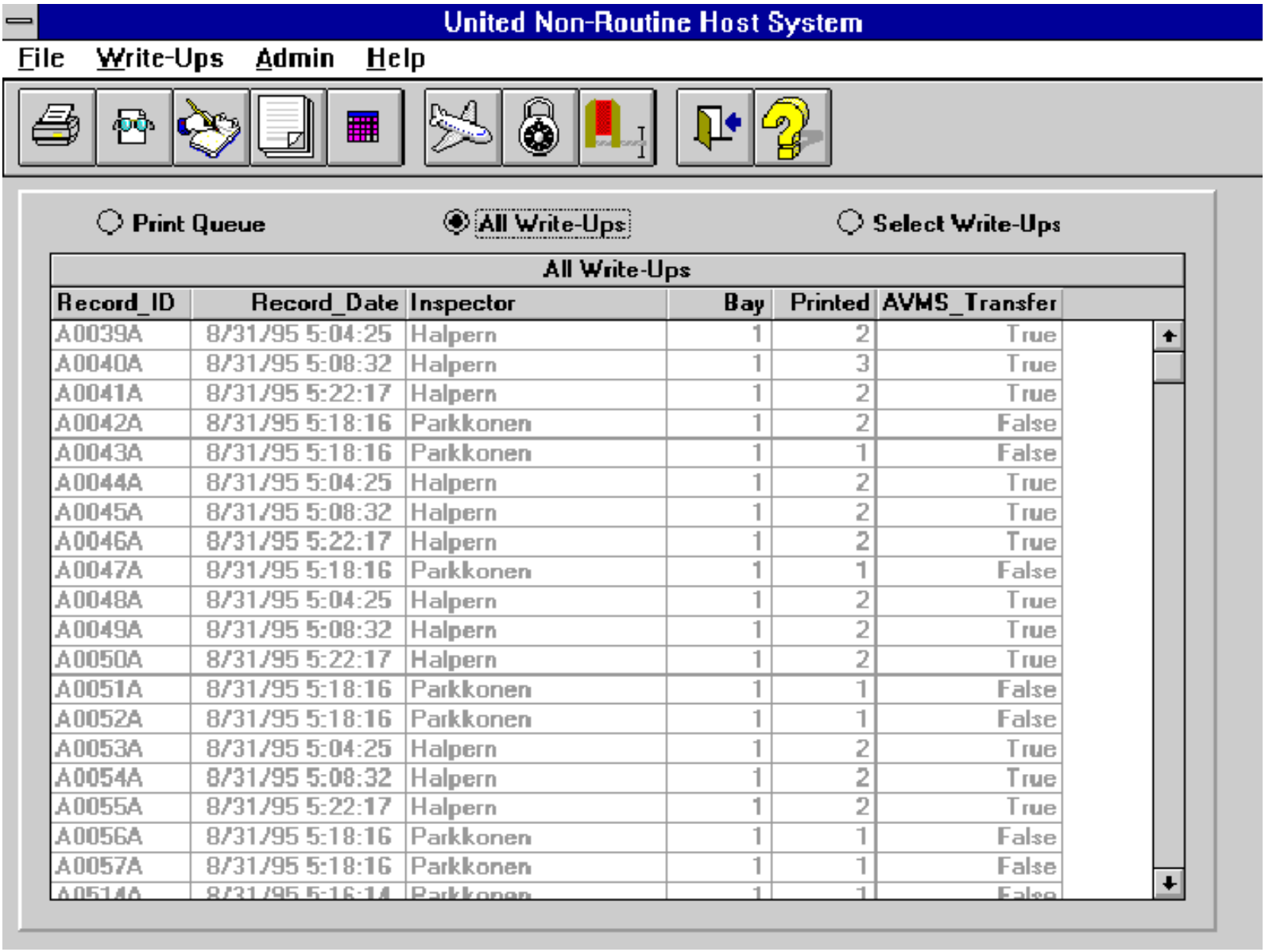
In order to access user-initiated functions of the Host application, users must log-in. To log-in, the user must swipe his identification card through the bar-code reader and enter a log-in password. (see Figure 6.9) Only persons with a valid password and matching bar-code scan, will be able to access the user-initiated functions of the Host System application.

Figure 6.9 Host Application Log-in Screen



User Initiated Functions are accessed via the toolbar or the menubar of the Main Window (see Figure 6.10). The toolbar is divided into three groups. The group on the far left allows the user to perform functions on write-ups. The group to the right of that allows the user to perform administrative functions. The last group allows the user to exit the program or get help. The menubar is grouped similarly to the toolbar.

Figure 6.10 Host System Application Main Window



Record_ID	Record_Date	Inspector	Bay	Printed	AVMS_Transfer
A0039A	8/31/95 5:04:25	Halpern	1	2	True
A0040A	8/31/95 5:08:32	Halpern	1	3	True
A0041A	8/31/95 5:22:17	Halpern	1	2	True
A0042A	8/31/95 5:18:16	Parkkonen	1	2	False
A0043A	8/31/95 5:18:16	Parkkonen	1	1	False
A0044A	8/31/95 5:04:25	Halpern	1	2	True
A0045A	8/31/95 5:08:32	Halpern	1	2	True
A0046A	8/31/95 5:22:17	Halpern	1	2	True
A0047A	8/31/95 5:18:16	Parkkonen	1	1	False
A0048A	8/31/95 5:04:25	Halpern	1	2	True
A0049A	8/31/95 5:08:32	Halpern	1	2	True
A0050A	8/31/95 5:22:17	Halpern	1	2	True
A0051A	8/31/95 5:18:16	Parkkonen	1	1	False
A0052A	8/31/95 5:18:16	Parkkonen	1	1	False
A0053A	8/31/95 5:04:25	Halpern	1	2	True
A0054A	8/31/95 5:08:32	Halpern	1	2	True
A0055A	8/31/95 5:22:17	Halpern	1	2	True
A0056A	8/31/95 5:18:16	Parkkonen	1	1	False
A0057A	8/31/95 5:18:16	Parkkonen	1	1	False
A0514A	8/31/95 5:16:14	Parkkonen	1	1	False

User Initiated Functions, Write-ups

The left most group of buttons on the toolbar perform functions on the write-up data (see Figure 6.11). The user can select a specific write-up or group of write-ups and then use a tool to perform any of the following operations: reprint, view, modify, or view the history of the write-ups. Additionally a user may print a summary report of write-ups recorded on a certain date. Of course, whether or not a specific user can perform these operations will depend on privileges given to the user.

Figure 6.11 Host Application Write-up Tools: Reprint, View, Modify, View History, Print Summary

User Initiated Functions, Administration

The group of buttons right of the Write-up buttons is the Administration buttons. The Administration buttons are shown in Figure 6.12. Using these buttons, an administrator can assign write-up numbers to a visit, assign user ID's, and perform database maintenance functions (e.g., compact and repair). Only users with administrative privileges will be allowed to do so.

Figure 6.12 Host System Application Administration Tools

6.5 THE PILOT STUDY

The Pilot Study was conducted using inspectors at United Airlines Oakland Modification Center. The study was conducted in two stages. The primary goals of the first stage of the study were to (a) train inspectors on how to use the system and (b) to refine the study procedures and feedback forms. The primary goals of the second stage of the study were (a) to have inspectors evaluate various aspects of pen computer hardware, (b) to obtain feedback from inspectors on the features of the software system, and (c) to obtain input from inspectors on what items should have priority for future development.

6.5.1 Stage One

In the first stage, inspectors were trained to use the pen computer write-up system and gained experience using the application on two different pen computer models: the Fujitsu Stylistic 500 and the Kalidor K2100. Eleven inspectors representing all three shifts participated over several days in early December 1995. Despite the logistical and technical problems encountered, this first fielding made four major accomplishments:

- trained inspectors on all three shifts in how to use the system
- provided inspector feedback on pen computers and the Non-Routine Repair Write-up application
- identified procedural and system problems
- identified problems with the feedback forms.

Table 6.3 contains the outline of the training that was provided. Hands-on training was considered an essential element for the training to be effective. Participants completed a post-training evaluation form immediately after the training session. The evaluation form accessed their comfort level with performing each of the key tasks associated with system usage. All participants indicated a medium to high comfort level for each task. Participants also were instructed to complete a follow-up form at the end of the pilot study. This form was intended to provide a better gauge of the training effectiveness by having participants rate the training after they had completed the pilot study. However, very few of the participants completed the post-study training evaluation form. Hence no conclusions could be drawn about how the training could be improved.

Table 6.3 Training Outline

1. Project Overview
- Problem Statement
- Goals
- Present status
- Benefits
- Future plans

2. Write-up Process Overview
- Write-ups created on-line using pen-computer
- Data transferred automatically to local master database via network connection during breaks
- Printouts are automatically printed on duplex laser printer
- Data automatically transferred to AVMS database via Host Computer

3. Demonstration and Practice
- Logging in
- Making Write-ups
- Docking and Logging out

5. MS Windows Basics

6. Understanding Different Fields
- Types of Handwriting Fields
- Drop down Pick Lists
- Option Buttons
- Check Boxes

7. Handwriting Tips

8. Data-entry Aids

9. Introduction to Help Features
- Contents
- Search for Help on
- Using Help
- Using a Pen
- On-line Manuals

10. Hardware Tips
- Pen
- Screen Lighting Controls
- Batteries
- Power Modes

Most of the inspectors did provide feedback on the pen computer hardware and the automated Non-routine Repair Write-up system. Two main findings came from this portion of the evaluation. First, two-thirds of the inspectors who responded indicated that they preferred the pen computer system over the current paper system for creating non-routine repairs. Given that change of any kind is often rejected or met with much skepticism, it was encouraging to find that inspectors saw the potential benefit of computer technology and were ready to use it on the job.

The second main result was that the inspectors found the handwriting recognition technology was not very accurate. This finding was not surprising. Handwriting recognition software has not improved noticeably in the past few years. Also, people understandably are annoyed by even a small percentage of recognition errors. Recognizing this fact, the Non-Routine Repair application was developed with as few handwriting-only fields as possible. The inspectors expressed appreciation for the drop down lists and other aids that limited the need for handwriting. The only free-form field is the comments field. It was questionable whether inspectors would provide comments given the current inaccuracy of handwriting recognition and the difficulty of using an on-screen keyboard. However, the inspectors indicated that they did enter comments and that they used the on-screen keyboard to enter this information. Thus, when a small number of free-form fields are necessary, the on-screen keyboard appears to provide sufficient support. If an application had a large requirement for free-form data entry, a hardware keyboard probably would be recommended.

Several valuable lessons were learned in this first fielding. Many of these lessons were helpful in designing a more realistic study for the second stage. For example, the initial study plan called for:

- equal numbers of inspectors on all three shifts
- 6-8 hours of hands-on training for all participants
- equal amounts of time on each pen computer model
- working in parallel with the current system (i.e., participant shadows actual inspector)
- operate system during entire D-Check preliminary on a 747 (12 shifts = 4 days for 24 hours).

While these were valid design goals, the scheduling and logistical problems of the aircraft maintenance environment made most of these goals unattainable. The first change was that the 747 D-Check was changed to a Mid-Point Visit (MPV). This adjustment was due to the schedule of aircraft coming in for inspection. Other scheduling problems were also encountered with assigning inspectors for the test. For example, the inspectors that would be present for training on the day prior to the start of the preliminary inspection would not all be present for the remaining days of the test. This logistical problem is due to the complex regular day off (RDO) schedule that is a fact of life in aircraft maintenance. Similarly, personnel who might be present for several days of the test, may not be present the day of training. Consequently, some training had to be provided later for these individuals. Obviously, this type of scheduling constraint prevented researchers from using the inspectors for four consecutive days.

In addition, it was not practical for participants to work in parallel with another inspector. The plan was for the study participant to be paired with an inspector assigned to work the 747 preliminary. The participant would create write-ups using the pen computer to match the ones being generated by the "actual" inspector on the traditional paper forms. This arrangement had strong appeal since it would provide a strong test of the actual working conditions in which the system would be expected to function. Although inspection had agreed to provide redundant personnel ahead of time, the conditions at the time of the study would not allow it. That is, four preliminaries were being conducted simultaneously; naturally, business priorities dictated that redundant personnel could not be justified, since the inspectors were needed to complete "real" inspections.

6.5.2 Stage Two

A second pilot study was conducted in early February 1996. Nine inspectors participated: four on day shift, four on swing shift and one on midnight shift. Table 6.4 summarizes the background of the inspectors.

Table 6.4 Stage 2: Summary of User Background

Inspector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Avg.**
Yrs at airline	10+	11	10	12	9	12	27	9	9	12.1 yrs
Yrs as inspector	7	7	6	7	6	8.5	8	6	7	6.9 yrs
Shift	2	2(5)	2(5)	2(5)	3	1	1	1	1	Day: 44.5% Swing:44.5% Mid: 11.0%
Age	45-55	35-45	35-45	45-55	35-45	35-45	45-55	25-35	35-45	25-35: 11.0% 35-45: 44.5% 45-55: 44.5%
Ever used PC?	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes: 78%
How long?	0	1 mos	8 yrs 386	6 yrs	10 mos	3 mos	2 yrs		Own	~3 yrs
Ever used MS Windows?	No	Yes		Yes	Yes	Yes	Yes	No	Yes	Yes: 67% No: 22% ?: 11%
Participated in the 1st study?	Yes	No	Yes	Yes	No	Yes barely	Yes	No	Just	Yes: 67% No: 33%

Methodology

Stage 2 of the study was conducted over one 24-hour period. Each inspector used the five pen computers and completed the revised feedback forms during one shift, as detailed in the schedule shown in Table 6.5. A separate day of training was not included in this stage of the study because six of these nine inspectors participated in the first pilot study. Rather, each shift began with a briefing to explain the purpose of the second study and to clarify what software and procedural changes had been made since the first study.

Table 6.5 Schedule for Stage 2 Pilot Study

	Swing (2/8/96)	**Midnight** (2/8-9/96)	**Day** (2/9/96)
Briefing	3:30 pm - 4:30 pm	11:30 pm -12:30 am	7:30 am - 8:30 am
Computer 1	4:30 pm - 5:30 pm	12:30 am - 1:30 am	8:30 am - 9:30 am
Computer 2	5:30 pm - 6:30 pm	1:30 am - 2:30 am	9:30 am - 10:30 am
Computer 3	6:30 pm - 8:00 pm	2:30 am - 4:00 am	10:30 am - 12:00 pm
Computer 4	8:00 pm - 9:00 pm	4:00 am - 5:00 am	12:00 pm - 1:00 pm
Computer 5	9:00 pm - 10:00 pm	5:00 am - 6:00 am	1:00 pm - 2:00 pm
Complete Forms	10:00 pm - 11:00 pm	6:00 am - 7:00 am	2:00 pm - 3:00 pm

One goal of the stage 2 study was to gain feedback on additional pen computer hardware. Three additional brands of pen computer hardware were available for evaluation in this stage: Hammerhead 486, Norand Pen*Key 6600, and Telxon PTC-1184.

Feedback obtained from the initial pilot study was used to identify both software and procedural changes that were made prior to the second stage of the study. The primary software changes centered around eliminating rebooting problems associated with the network transfer/log-in portion of the write-up program. In addition, a procedural change was needed to prevent the problem from occurring. In the initial training, inspectors were told that they could disconnect from the network as soon as they had completed the log-in. However, in stage 2, the inspectors were retrained to wait for the rebooting process to begin, prior to disconnecting the computer from the network. Both of these changes succeeded in correcting the rebooting problems encountered in the first fielding.

The inspectors simulated a C-Check preliminary inspection on a 747. In this stage, there was no attempt to pair up the study inspectors with "real" inspectors since this approach proved impractical in stage one. Rather, inspectors were given C-check inspection job cards to work various areas of the aircraft.

During the last hour of each shift, the inspectors were given dedicated time to complete the feedback forms. The feedback forms used in Stage 2 are included in Appendix A.

Evaluation Results

The nine inspectors were asked to evaluate each of the pen computers on nine different hardware factors:

- screen size
- durability/weight
- overall speed
- screen lighting
- screen clarity
- battery life
- battery replacement
- ease of carrying
- stylus feel

This section describes each of these criteria and summarizes the feedback received.

Before describing the specific characteristics, some overall comments should be made about the feedback received. First, some inspectors did not provide complete feedback on all criteria for all models. For example, Inspector #1 did not evaluate the Hammerhead unit, Inspector #8 did not evaluate the Telxon unit and Inspector #6 only evaluated the Fujitsu and the Norand units. Also some inspectors did not evaluate certain criteria. For example, Inspector #1 did not evaluate battery life or battery replacement, Inspector #8 did not evaluation battery life and Inspector #5 did not evaluate stylus feel. Such omissions are recorded as No opinion in the following analysis. A detailed compilation of the inspector responses on all criteria is included as Appendix B.

Screen Size, Lighting and Clarity

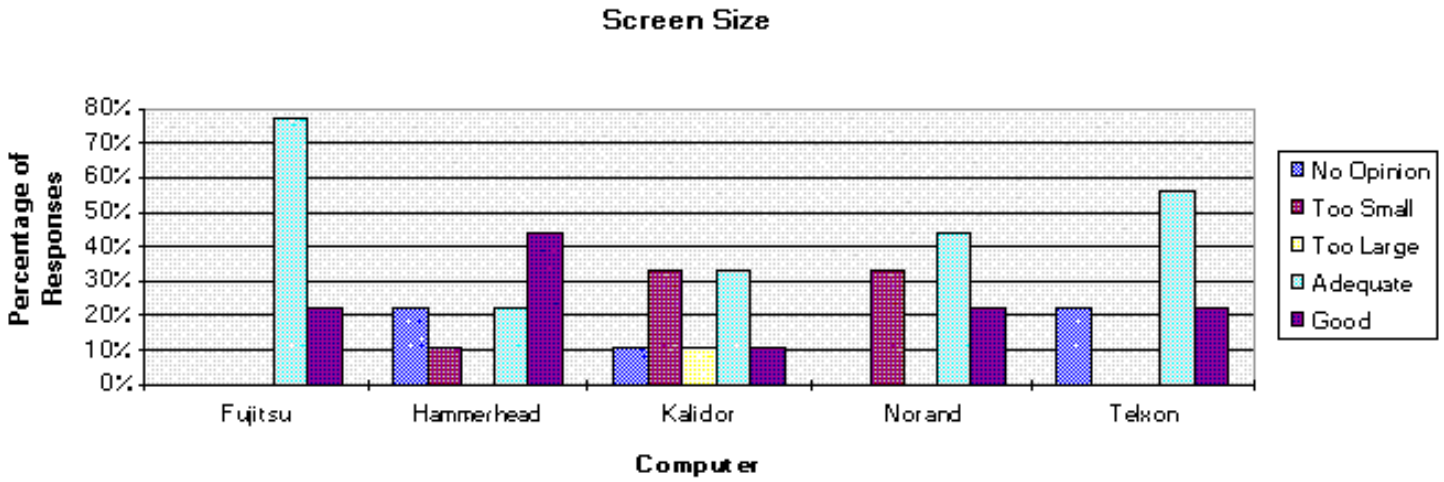
Screen size, lighting and clarity are important factors to be considered in evaluating a pen computer. Table 6.6 summarizes the screen characteristics for each of the models evaluated.

Table 6.6 Screen Characteristics of Five Pen Computers

	Fujitsu Stylistic 500	Hammerhead 486	Kalidor K2100	Norand Pen*Key 6600	Telxon PTC-1184
Size	8" diag.	9.4" diag.	7.5" diag.	7.25" diag.	9.5" diag.
Lighting	Backlit	Backlit	Sidelit	Backlit	Backlit
Type	Transmissive	Transflective	Transflective	Transflective	Transflective
Resol.	max 640x480	max 1024 x 768	max 640x480	max 640x480	max 640x480

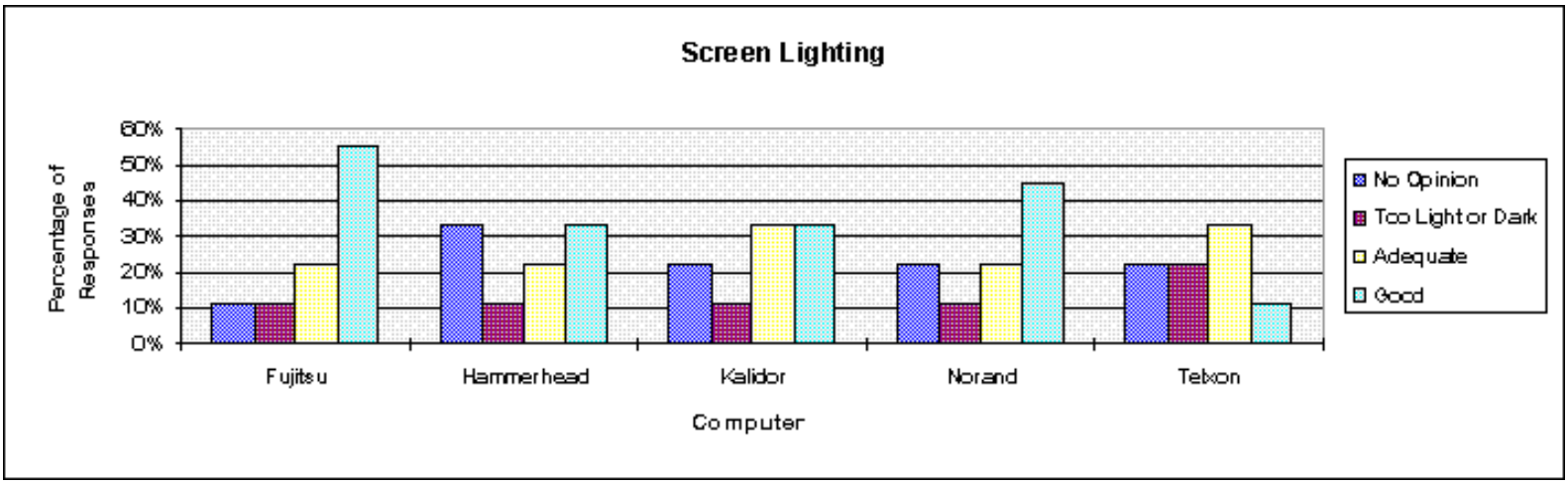
The Telxon and Hammerhead screens are the largest, followed by the Fujitsu, Kalidor, and Norand respectively. In general, the three larger screens were rated more favorably than the two smallest screens (see Figure 6.13). All screens were evaluated at 640 x 480 pixel resolution (The Hammerhead 486 is the only one of the models evaluated that can be used in a higher resolution). Thus, the same display elements appear larger on a larger screen and smaller on a smaller screen. For example, the field for inputting characters is larger on a larger screen, making it easier to print characters for handwriting recognition. Also, a larger screen allows more detailed graphics to be displayed more clearly.

Figure 6.13 Inspector Evaluation of Screen Size by Computer



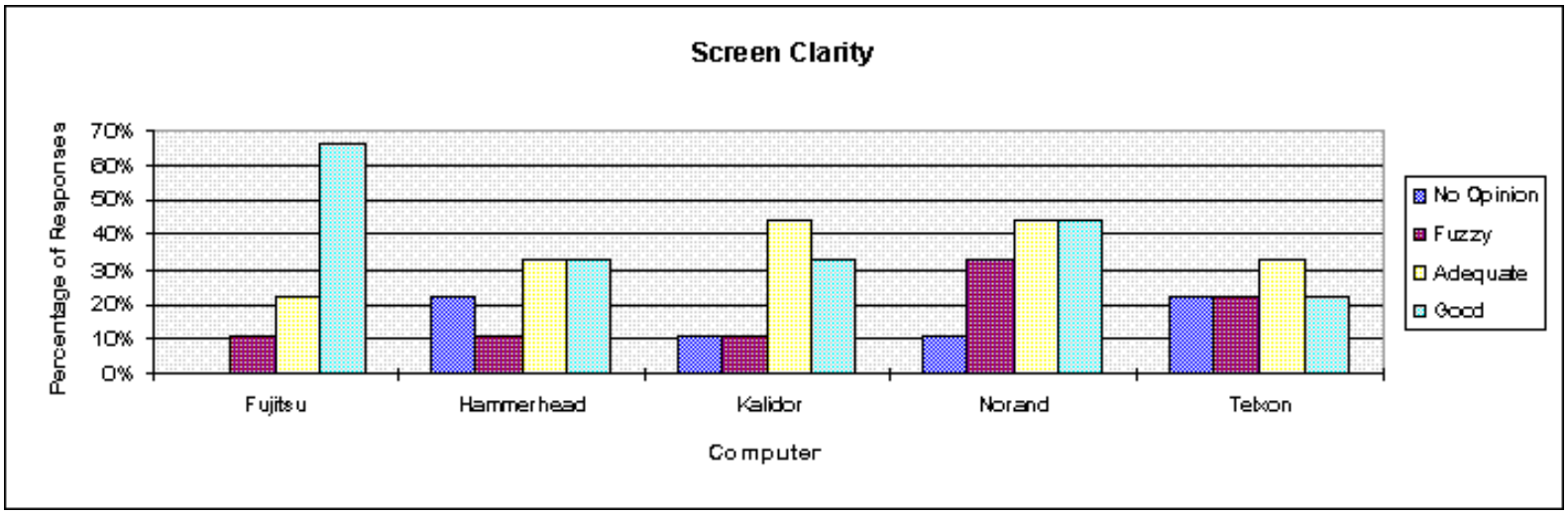
While screen lighting is an important consideration, nearly all pen computers incorporate similar types of technology that accommodate various lighting conditions. A back or side light can be used to brighten the display when working in a darkened area. This additional lighting can be turned off when in a brightly lit area. While bright sunlight can washout the display due to glare, inspectors did not seem to have a problem with this. In general the inspectors were generally satisfied with the screen lighting on all the computers, except the Telxon. As shown in Figure 6.14, the Fujitsu was rated most favorably on this feature.

Figure 6.14 Inspector Evaluation of Screen Lighting by Computer



The clarity, or sharpness, of the screen display was also evaluated by the inspectors for each of the five brands of pen computers. Figure 6.15 charts the percentage of responses for each brand. The inspectors were generally satisfied with the clarity of the screens on all machines. Once again, the Fujitsu was rated the best on this dimension.

Figure 6.15 Inspector Evaluation of Screen Clarity by Computer



Durability and Weight

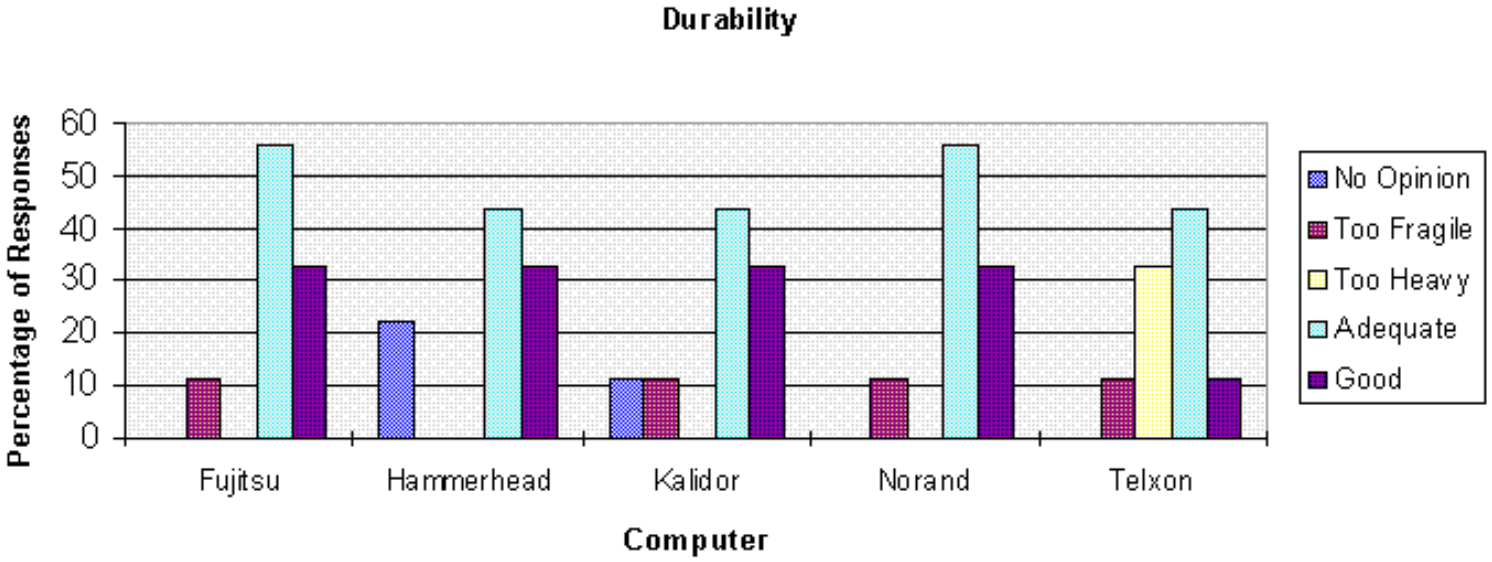
Weight and durability of a computer tend to be inversely related. The more rugged computers are generally heavier. Although all computers incorporated some design aspects with increased ruggedness, inspectors were not fully briefed on the internal ruggedness features of units. Therefore the inspector's ratings indicate perceived durability. Table 6.7 summarizes the overall unit dimensions, weight of the unit (including battery), and more rugged features of each of the five units. The type of case provided for each unit is also included in the table, since case type may affect the perception of unit durability.

Table 6.7 Summary of Features for the five pen computers evaluated.

	Fujitsu Stylistic 500	Hammerhead 486	Kalidor K2100	Norand Pen*Key 6600	Telxon PTC-1184
Dimension	7.2"x10.7"x1.5"	11"x7.75"x1.5"	9.7"x6.4"x1.8"	10.1"x8.5"x2.1"	12.25"x9.5"x1.5"
Weight	2.6 lbs	4.0 lbs	3.35 lbs	4.0 lbs	4.0 lbs
Case	Plastic	Aircraft grade Aluminum	Rubber	Plastic	Plastic

A majority of the inspectors found these five machines were adequate in weight and durability (see Figure 6.16). However, the number of adequate responses was greater than the number of good responses for all types. Combining this result with the fact that the Telxon PTC-1184 was the only model that was rated as being too heavy (33%) suggests that inspectors would like the machines to be a little more durable. One inspector also rated this same unit as being too fragile. The Hammerhead was the only computer that did not receive any negative ratings (Too Heavy or Too Fragile).

Figure 6.16 Inspector Evaluation of Durability/Weight by Computer



Overall Computer Speed

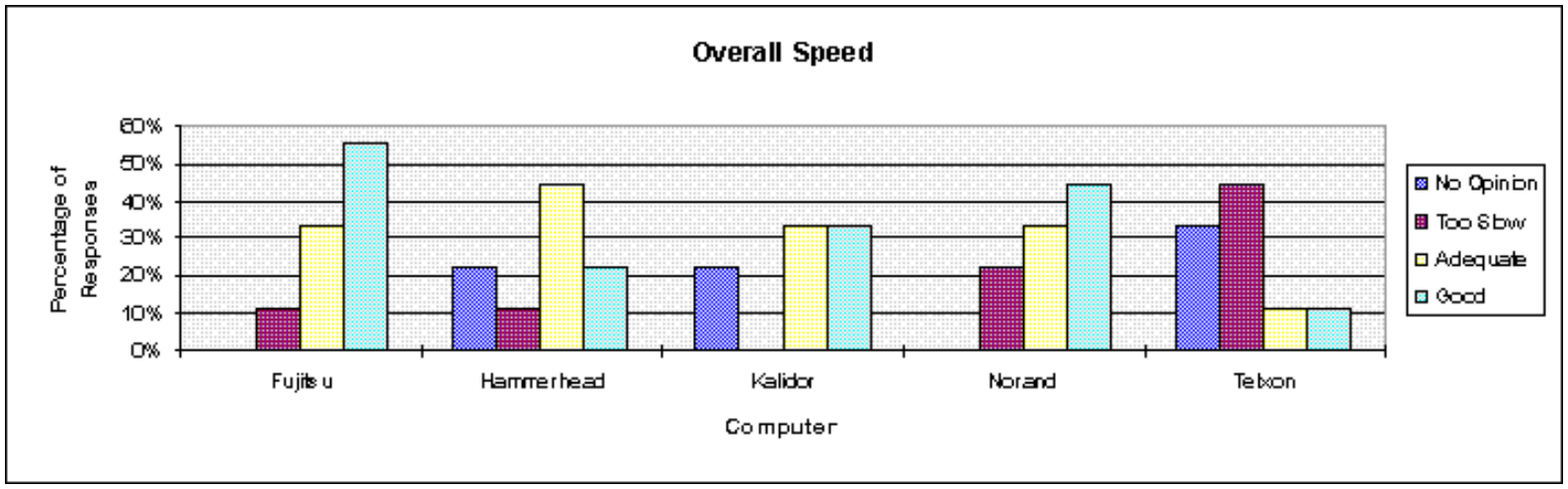
Perceived speed of a computer is important for end user acceptance. Processor type and speed, system configuration, amount of RAM, battery power management features, and stylus response all have an impact on system response time to user input. No attempt was made to optimize or change the default power management features for any of the units. Table 6.8 summarizes the basic configuration for each of the five computers. Software demands also effect response time, but all units were configured with the same operating systems, handwriting recognition software (except the Norand) and application software.

Table 6.8 Basic configuration for the five pen computers.

	Fujitsu Stylistic 500	Hammerhead 486	Kalidor K2100	Norand Pen*Key 6600	Telxon PTC-1184
Processor	486 DX2 SL	486 DX	486 SLC	486/DX2	486 SLC
Speed	50 MHz	33MHz	50 MHz	50 MHz	25 MHz
RAM	8 MB	8 MB	8 MB	16 MB	3 MB
Hard drive	170 MB PCMCIA Type III	170 MB Shock Tolerant Hard Drive	170 MB PCMCIA Type III	170MB	60 MB
Stylus Type	Active (touch screen optional)	Active	Passive	Active	Active

As shown in Figure 6.17, the Fujitsu, Norand, and Kalidor (all 486/50mhz units) were rated the most favorably on overall speed. The Hammerhead (at 33mhz) was not far behind with two-thirds of the inspectors rating it adequate or good. The Telxon, with the slowest processor and least memory, was rated as being unacceptably slow by nearly half of the inspectors.

Figure 6.17 Inspector Evaluation of Speed by Computer



Battery Replacement and Battery Life

For a high-end application being used nearly continuously, battery technology has not advanced to a level where an entire shift can be covered on a single battery. In a 24-hour maintenance environment, battery issues are important. While an eight hour battery would be desirable, the initial pilot study showed that the inspectors work in two-hour blocks. During breaks and meals, the units were returned to the planning area for security reasons. Thus inspectors were asked to initiate uploading the data and to recharge/replace batteries prior to going on breaks. Consequently, for this application, two hour battery life would be sufficient.

Table 6.9 summarizes the battery related information for each of the models evaluated. Battery life and time to recharge are based on vendor provided specifications. Battery life in actual usage will depend on many factors, including amount of application usage, backlight usage, and power management features.

Table 6.9 Battery Related Characteristics

	Fujitsu Stylistic 500	Hammerhead 486	Kalidor K2100	Norand Pen*Key 6600	Telxon PTC-1184
Battery Type	Lithium Ion Hydride	Nickel-Metal Hydride	Nickel-Metal Cadmium	Lithium Ion	Nickel
No. in Unit	2	1	1	1	1
Battery Life	2 hours continuos operation; power management	2.5-4 hours continuous runtime w/out 6-8 hrs. with power savings	2 hours continuous operation;	5 hours	2-4 hours
Time to Recharge	1.5 hrs - 90% 3 hrs - 100%	1 hour	2 hours	1.5 hrs	
External charger?	Yes	No*	Yes	Yes	Yes
Hot change?	Yes	No	Yes	Yes	

Since all units are rated for at least two hours of continuous usage, the most important consideration is the ability to charge batteries with an external charger. An external charger permits extra batteries to be charged and carried around as spares. The Hammerhead is the only unit that does not currently permit external charging. It was designed with the battery sealed in the unit and has been tailored to the "traveling salesman" model: work for a while, then dock the machine in a vehicle dock for recharging before the next use. The next issue of importance is the ability to change the battery without applying AC power to the unit. This feature, referred to as "hot changing" of batteries, allows the inspector to swap batteries on the job site. One issue that has been resolved by improvements in battery technology related to fully discharging batteries before recharging. In the past, batteries had to be fully discharged before re-charging

The results for battery life and battery replacement are shown in Figure 6.18 and Figure 6.19. Unfortunately the results are not very informative because the structure of this second pilot study was not particularly conducive to evaluating these parameters. With inspectors swapping machines every hour during a single shift, inspectors did not get the opportunity to change batteries on every unit. In fact, some inspectors may have been biased against a machine which just happened to need the battery changed during their turn to use it. Nor did the study allow the inspectors to get a true sense of how often the battery would need to be changed during continuous usage. Since there were more units than inspectors, when a computer was not in use, external AC power was supplied to charge the unit.

Figure 6.18 Inspector Evaluation of Battery Life by Computer

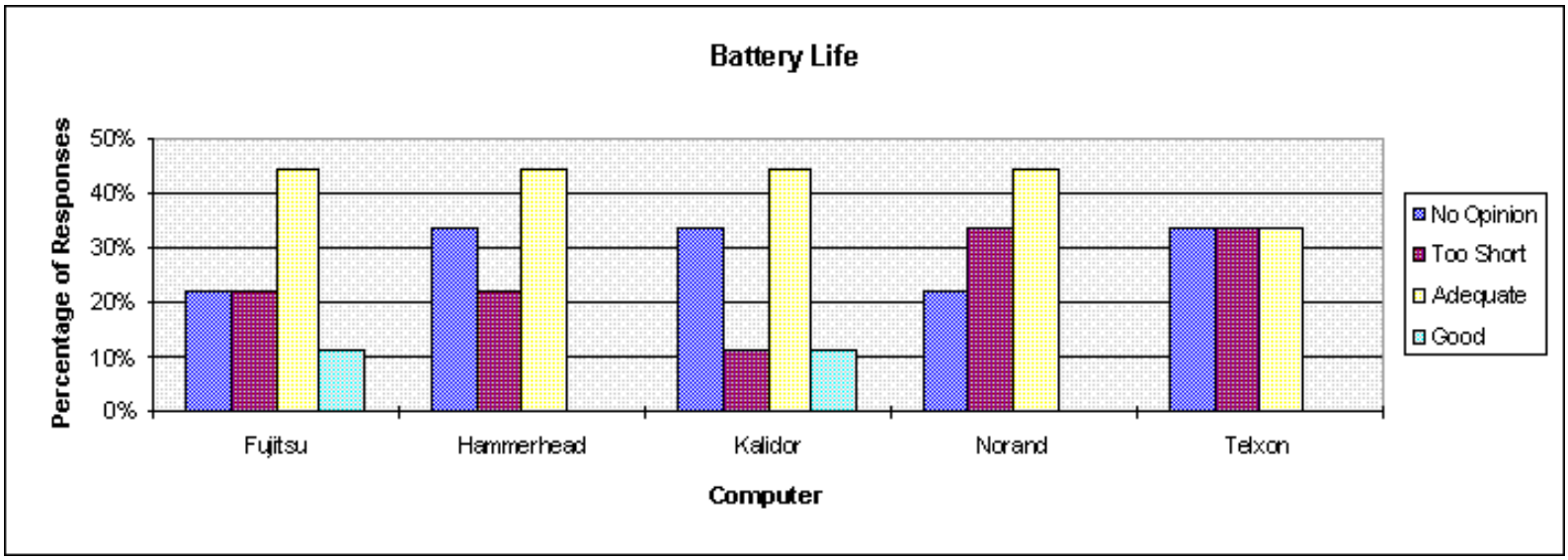
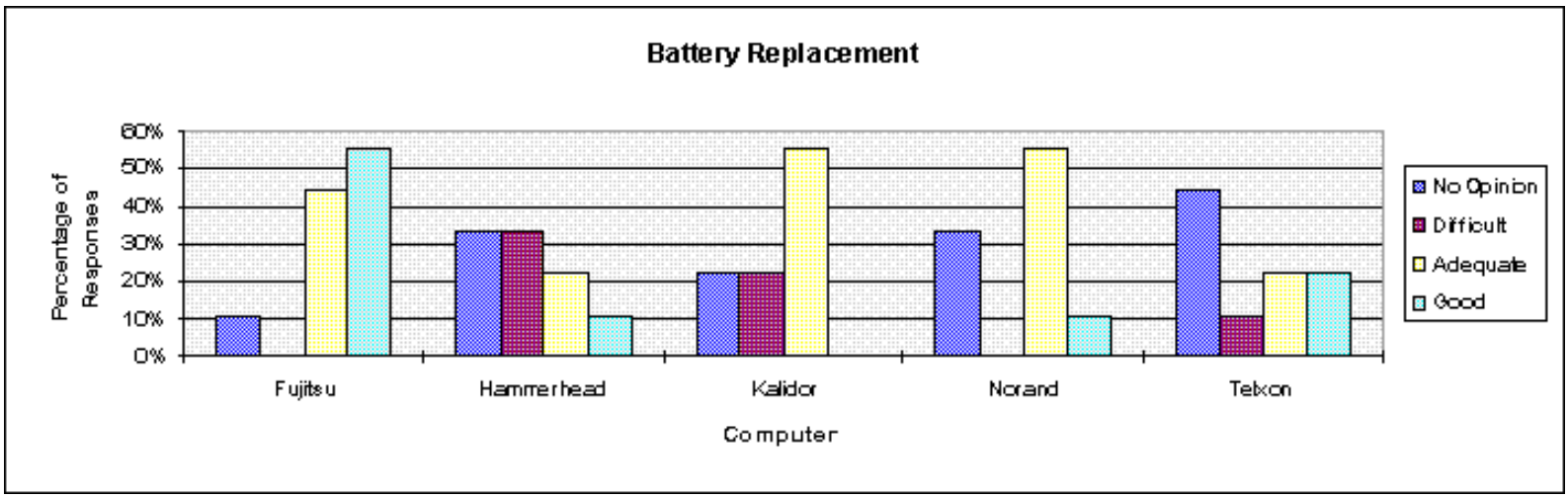


Figure 6.19 Inspector Evaluation of Battery Replacement by Computer



Ease of Carrying

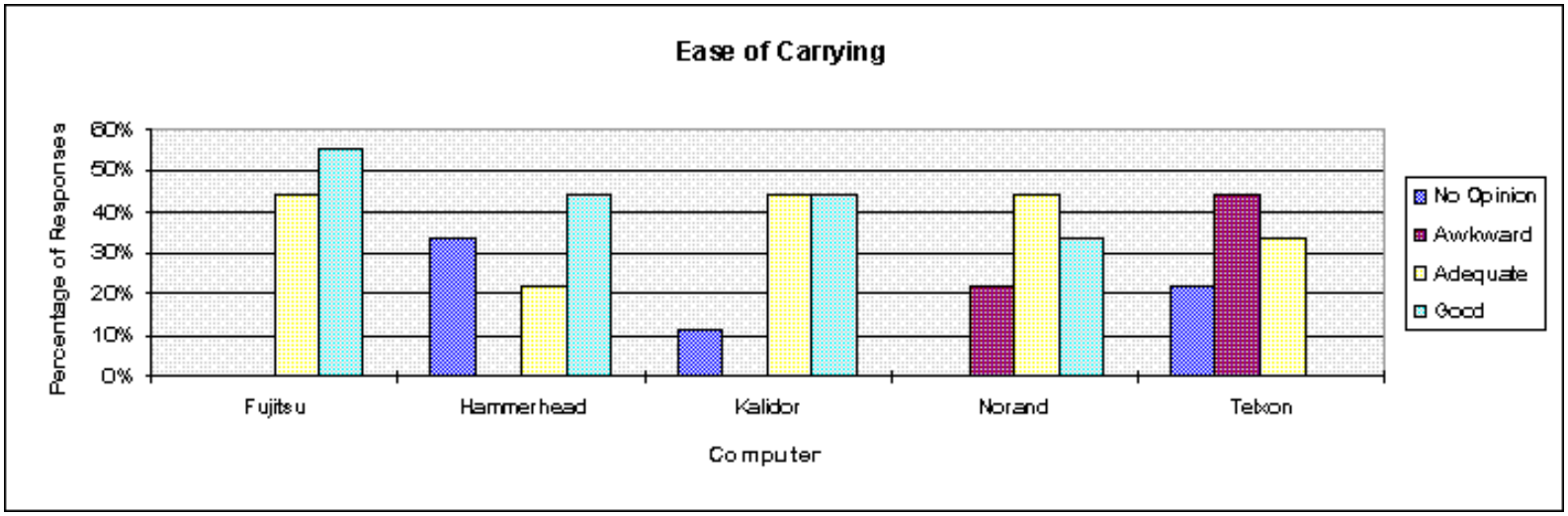
In general, the pen computers are similar in size to the clipboards currently used by the inspectors, although the computers are more fragile and somewhat heavier. Therefore, the inspectors were asked to rate each unit on how easy/comfortable it is to carry around on the job. Most of the units include handles and/or shoulder straps to aid in carrying the unit, either as part of the computer case itself or as a separate carrying case. Some units also include hand straps to aid in holding the unit during usage. Table 6.10 summarizes these features for each of the five pen computers. It should be noted that the external cases were made available, but the inspectors were not required to use them. Most inspectors opted to use the carrying cases.

Table 6.10 Summary of Carrying Case Features

	Fujitsu Stylistic 500	Hammerhead 486	Kalidor K2100	Norand Pen*Key 6600	Telxon PTC-1184
Unit	Stylus Holder	Stylus Holder	Stylus	Handle	Shoulder
	Holder	Shoulder	Strap		
	Strap	Hand			
	Stylus Holder	Strap			
	Stylus Holder				
Case	Handle	Handle	Shoulder	None	None
	Shoulder	Shoulder	Strap		
	Strap	Strap			
	Hand	Stylus Holder			
	Strap				
	Stylus Holder				

The inspector evaluation results for ease of carrying the various pen computers are summarized in Figure 6.20. In general, the Fujitsu and Kalidor were rated most favorably on this feature, while the Telxon was rated poorly. The poor rating for the Telxon may have been influenced by the overall size and weight of the unit rather than the carrying features themselves. It is not apparent why the inspectors preferred the Fujitsu and Kalidor units. However, it may have something to do with familiarity with the units. In fact, the inspectors were much more favorable on this dimension in the second pilot study compared to the first (in which only the Fujitsu and Kalidor were evaluated). This change of opinion suggests that inspectors needed some time adjusting to the new tool before they became comfortable carrying it around instead of a clipboard.

Figure 6.20 Inspector Evaluation of Ease of Carrying by Computer



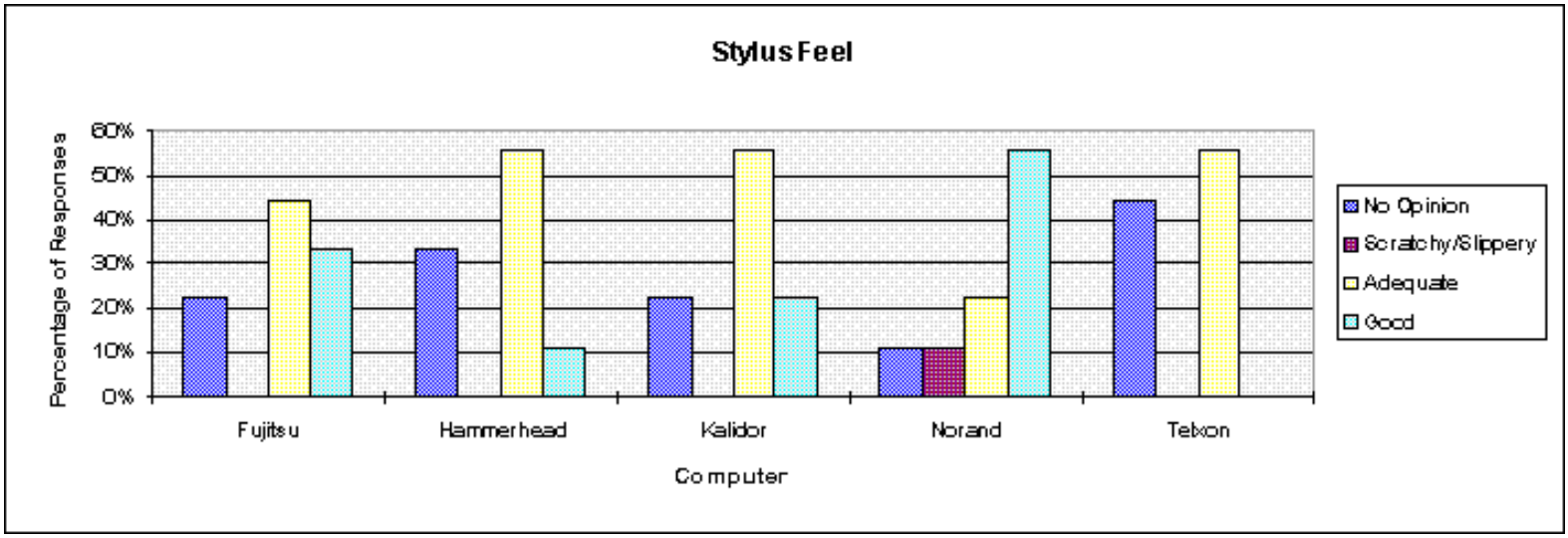
Stylus Feel

One of the appeals of a pen computer is that they use a pen stylus, instead of a keyboard or mouse device, which is more similar to the way people currently record information on paper. However, not all styluses have the same "feel" when used on a computer screen. Table 6.11 summarizes the objective features of a pen stylus. An active stylus contains one or more batteries and are considerably more expensive than a passive stylus. Some of the vendors provide a tether that attaches the stylus to the pen computer by a lanyard or cord. The Norand was the only unit that was with the tethered configuration. The Figure 6.21 summarizes the inspectors' subjective rating of stylus feel. The Norand stylus was preferred over all others.

Table 6.11 Summary of Stylus Features

	Fujitsu Stylistic 500	Hammerhead 486 6600	Kalidor K2100	Norand Pen*Key	Telxon PTC-1184
Type	Active	Active (touch screen optional)	Passive	Active	Active
Tethered	No	No (Optional)	No	Yes	No (Optional)

Figure 6.21 Inspector Evaluation of Stylus Feel by Computer



Trade-off Results

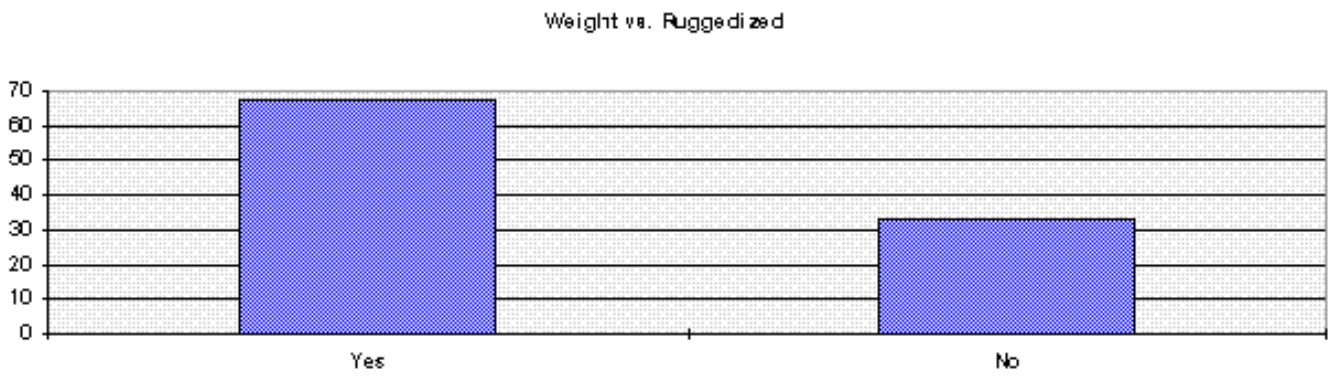
In addition to ranking the performance of specific computer brands, inspectors were asked to identify trade-offs they would make in the characteristics of the pen computers. Because each desirable feature often has negative side-effects, trade-offs are important in evaluating pen computers. Inspectors were asked for their preferences in eight categories:

- weight vs. ruggedness
- weight vs. screen size
- keyboard vs. imperfect handwriting recognition
- tethered pen vs. untethered
- case vs. no case
- printed stickers vs. handwritten stickers
- barcode reader vs. no barcode reader

Weight vs. ruggedness

As noted earlier, inspectors generally gave the computers an adequate or good rating for durability/weight (see Figure 6.16). However the lower number of "Good" (compared to adequate) responses and the lower number of "Too Heavy" (compared to fragile) responses suggest that inspectors would like machines to feel a little more durable. This was shown to be the case when inspectors were asked if they would trade of added weight (1-2 lbs) for more ruggedization. As shown in Figure 6.22, 67% of the inspectors said they would accept added weight for a more rugged computer. A common reason for this response was a concern for the cost of repairing/replacing the pen computers.

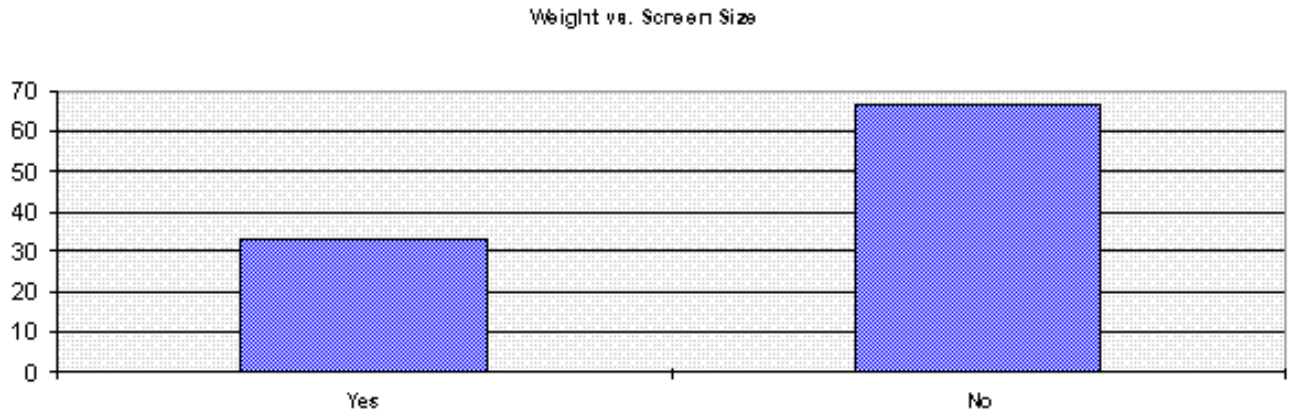
Figure 6.22 Would you be willing to use a machine that is heavier (1-2 lbs) in order to get a more rugged unit?



Weight vs. screen size

Weight vs. screen size did not have the same results as weight vs. ruggedness. When asked if they would trade added weight for larger screen size, 67% of the inspectors said "No" (see Figure 6.23). This seems surprising since the initial screen size results are similar to ruggedness (more adequate than good). However, of the three computers with the larger screen size (Hammerhead, Fujitsu, and Telxon) there was only one "Too Small" response. In addition, the Hammerhead received more "Good" than "Adequate" votes. This suggest that screen size within the larger range (8" - 9.5") is acceptable, but the pen-computer should not have significant added weight for this size.

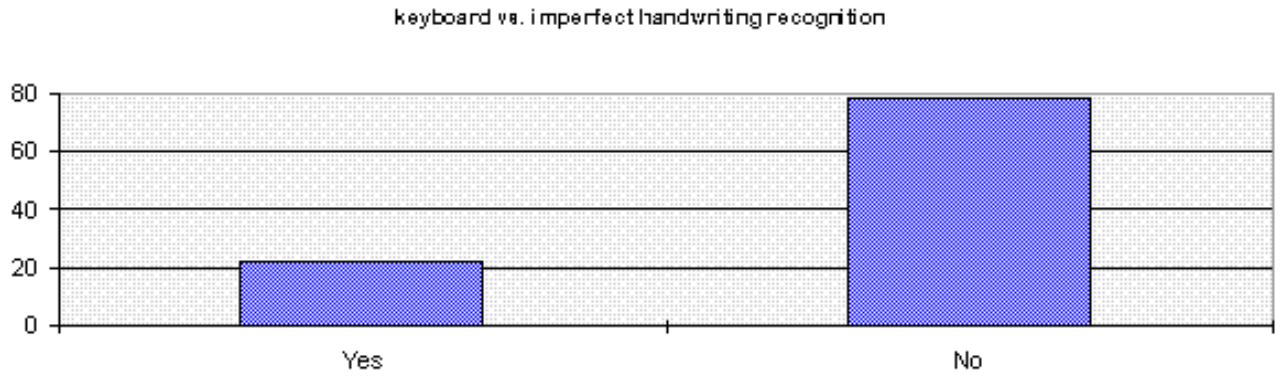
Figure 6.23 Would you be willing to carry around a heavier machine (1-2 lbs) in order to have a larger screen?



Keyboard vs. imperfect handwriting recognition

Although many inspectors expressed dissatisfaction with the performance of the handwriting recognition software, only two (22%) stated they would prefer to carry a keyboard. One of them is a trained typist and feels that typing would improve speed. Generally, inspectors do not want to carry a keyboard while performing their inspections. Most felt it would be cumbersome and get in the way. A few felt the on-screen keyboard was sufficient.

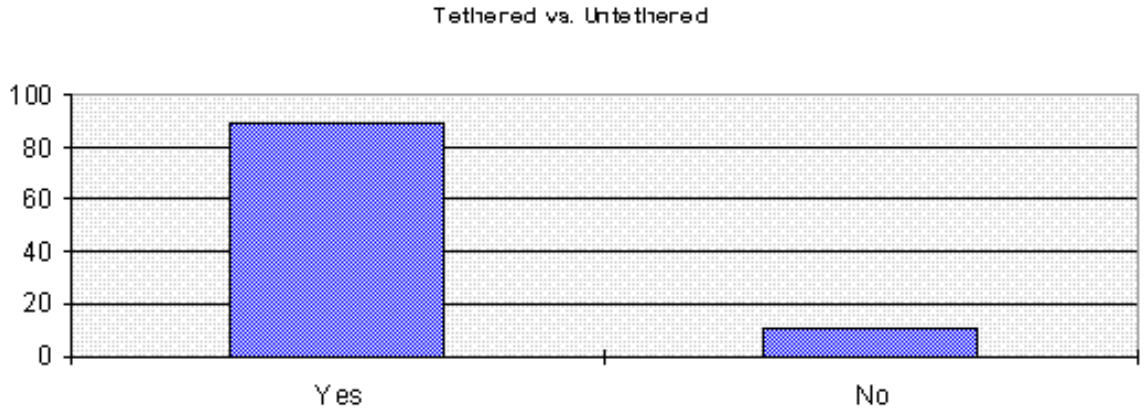
Figure 6.24 Assuming that handwriting recognition cannot be improved substantially, would you prefer to use/carry around a portable computer with a keyboard rather than just use the pen stylus and on-screen keyboard?



Tethered pen vs. untethered

Inspectors overwhelmingly preferred a tethered pen (89%) to an untethered pen (11%). Nearly all inspectors were concerned with dropping or loosing the pen. The only non-tethered voter felt that the tether got in the way.

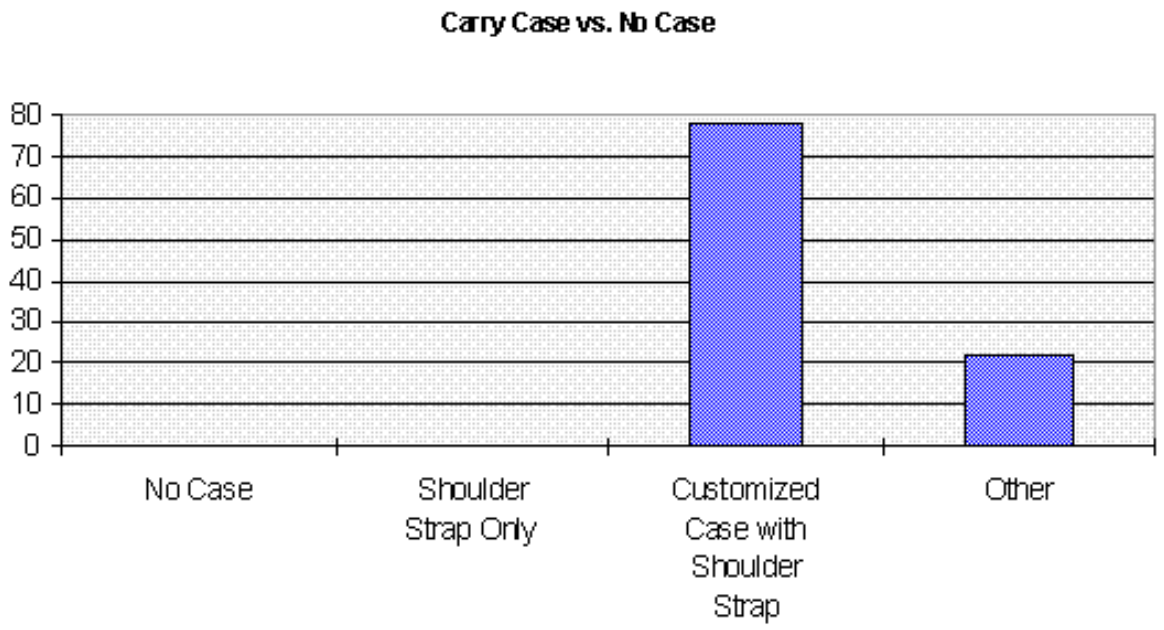
Figure 6.25 Would you prefer to have the pen stylus tethered to the machine rather than loose?



Case vs. no case

All inspectors preferred a case to carry the pen computer. Seventy-eight percent stated that they would prefer a case with a shoulder strap. The 22% that choose "Other" preferred a case with a handle. Inspectors feel that a case will help protect the computer against damage. One inspector also liked to carry additional objects in the case (pens, job cards, etc.).

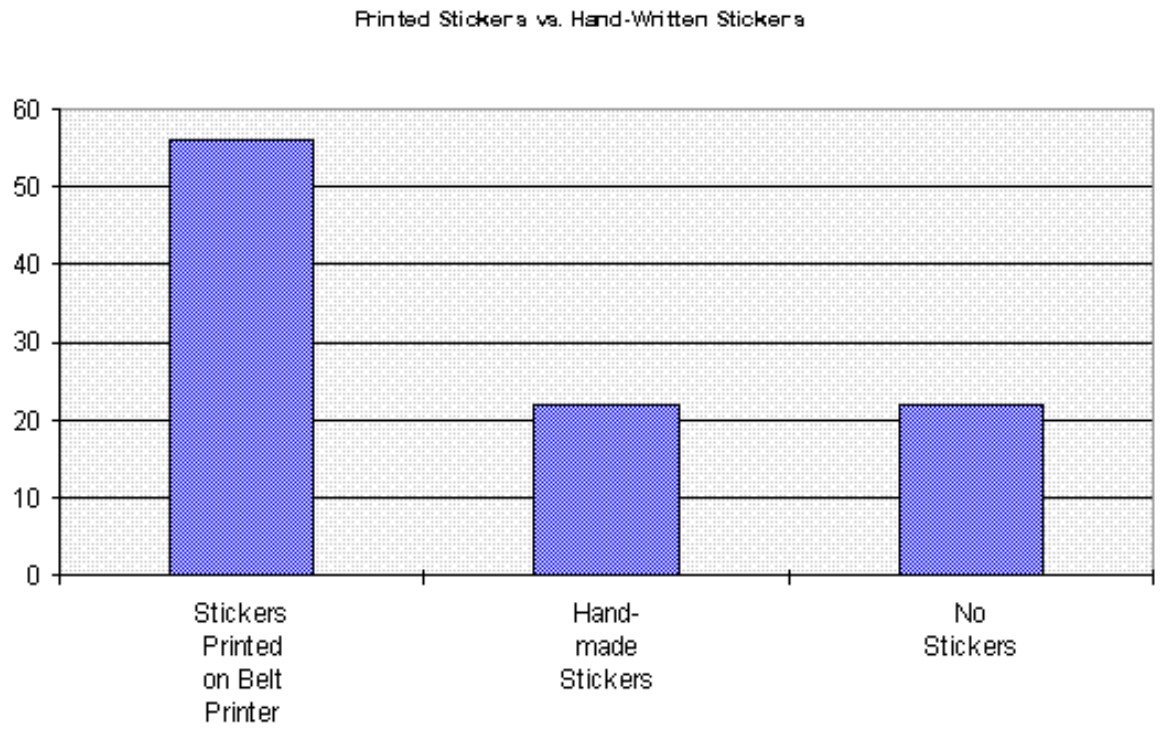
Figure 6.26 Which would would you prefer?



Printed stickers vs. handwritten stickers

Presently, when inspectors record an non-routine write-up they mark the location of the item with a sticker that contains the write-up number. These sticker come printed on the current paper non-routine write-up forms. When the pen computer-based write-up is incorporated, an alternative method of locating the write-up item must be used. A majority of the inspectors (56%) preferred to use "stickers printed on a belt printer". Many of them, however were concerned that the computer should not become too heavy or cumbersome. Twenty-two percent of the inspectors preferred to use "hand made stickers" and the same amount (22%) preferred to use the location information used in the write-up.

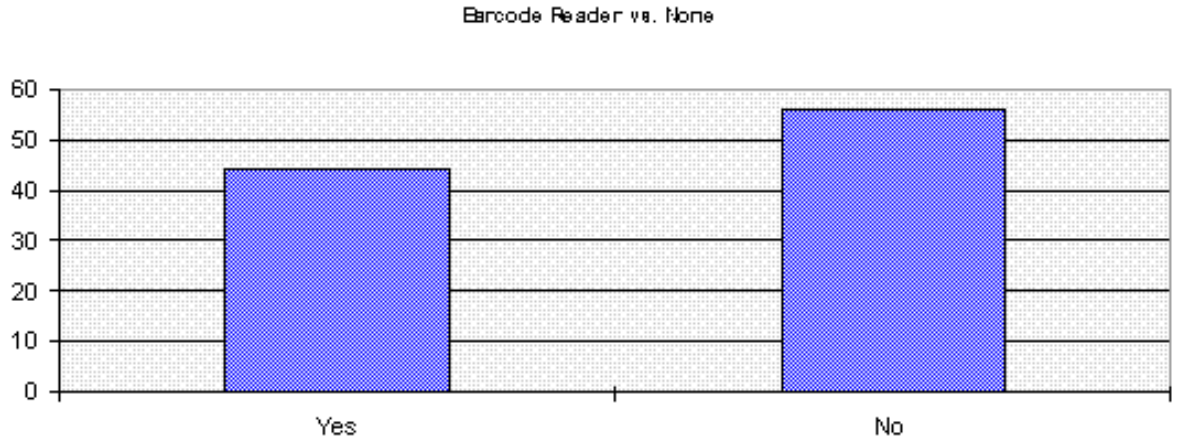
Figure 6.27 Which would would you prefer?



Barcode reader vs. none.

A barcode can often serve as a convenient input device. This may be especially true when you consider the imperfections in handwriting recognition. However, a barcode reader also adds extra weight and size to the pen computer system. When asked, inspectors were mixed on carrying a bar-code reader. Forty-four percent preferred not to carry a barcode reader while 55% preferred to carry one. As expected, nearly all inspectors were concerned with size and weight of the barcode reader. Inspectors voting "Yes" either believed it would not add much size/weight to the computer or made this a stipulation. Inspectors voting "No" generally believed that the computer would become too big or bulky.

Figure 6.28 Would you be willing to carry a small, portable barcode reader attached to the pen computer in order to enter barcode information (e.g. , job card #, write-up #, login) rather then write/type it in?



6.6 LESSONS LEARNED

6.6.1 Loaners vs. Buying

In the process of completing this project, a considerable amount of effort was required to obtain pen computers for use in the field evaluation. One of the major constraints in this effort, was the need to obtain "loaner" or "evaluation" units for testing. From the airline's perspective, it is unreasonable to purchase one or two units of several different brands in order to determine which one meets their needs. From the pen computer vendor's perspective, it is not practical to lend units to every potential customer for several weeks or months. As a result, some vendors were unable to provide units for the evaluation. In some cases, the vendors initially provided units that were unreliable engineering samples that did not give a good representation of their products capability. Also, when you opt for the loaner route, you can only *request* a particular configuration for a loaner. When you purchase, you have much more control over what configuration and peripherals you get. Finally, a unit that is "loaned" may not command the same resources in terms of vendor support on technical issues. Given these trade-offs, it may be cost-justifiable to purchase units for evaluation purposes rather than dealing with the limitations and the hassles of loaners.

6.6.2 Support for System Configuration and Administration

Vendors that supplied "loaner" computers, often did not provide the units until the last minute. In some cases, not all of the system administrative support and maintenance items that were required for the fielding, such as keyboards, floppy drives, and external battery chargers were readily available. While this may seem like a minor inconvenience, it was very apparent from this experience that system administrative support should be a major consideration in selecting an appropriate system. These units often employ non-standardized connections; hence, specialized adapters or peripherals must be obtained from the vendor to make system configuration and support feasible.

6.6.3 Nothing is Standard in Pen Computer Hardware (even Standards)

Every pen computer included in this study had some specialized feature about it. Everything from the type of keyboard port, to the power management features, to the rebooting procedure, to the battery is customized to the machine. Even the PCMCIA standard is not completely standard, that is, some units had lists of approved brands of PCMCIA network cards that could be used with their machine. While this problem is a slight annoyance when fielding a single brand of computer, the problem magnifies greatly with every additional unit. This is a fact of hardware evaluation that cannot be avoided; however, it should provide caution to those who consider fielding multiple brands for operational use.

6.6.4 Evolution of Technology is Inevitable

The brands and features of pen computers that were available for this study will most likely be replaced by a new generation of computers in a relatively short period of time, perhaps in as little as six months. This evolution of technology is typical for the computer hardware and software age. In addition, the pen computer industry has not yet stabilized in terms of vendors. Therefore, there are little assurances that any particular vendor will still be manufacturing and supporting pen computer technology a year or two from now. These facts make it difficult to know when to purchase such specialized hardware. The approach taken in this effort helped to minimize the effect of hardware evolution. That is, the system was developed for a standard operating system. As hardware capabilities increase, the software is easily moved to the new platform.

6.7 SUMMARY AND OPTIONS FOR NEXT STEP

The Pen Computer Non-Routine Repair (NRR) Write-up System was shown to be a feasible system in Phase I. However, the system was designed to be a proof-of-concept system rather than a system for immediate implementation. In order for the system to be minimally functional in operation, there are some additional issues that need to be addressed. The following describes various options that could be pursued at this point.

Option 1: Implement Laser printed forms ONLY

The initial proposal for the Pen Computer NRR Write-up System was justified on the cost savings of printing write-ups on normal laser paper as opposed to the current specialized 4-ply printed form. This cost savings could be realized with minimal additional investment by putting into use the laser printed forms as designed and printed by the NRR Write-up System.

- **Additional Hardware Required**: No additional hardware is required to implement this option. These forms can be printed using the double-sided laser printer that was purchased for the project. The software runs on any existing PC-compatible desktop computer.

- **Additional Software Required**: A minor adjustment would need to be made to the Host software to allow easy printing of a large number of blank forms with sequential write-up numbers. The beginning and ending number could be input by the user. If any changes are desired in the format or content of the blank form (prior to or after implementation) software changes would be needed to accomplish the changes.

- **Additional Training/Procedural Changes**: New procedures need to be constructed for handling the new paper documents. Appropriate parties must be re-trained per the new procedures

    - Who is going to be in charge of printing documents?
    - Who is going to communicate the write-up number sequence for a given aircraft?
    - Who is going to distribute documents?
    - Are write-ups going to be assigned to different write-up boards based on the sequence number or will all inspectors become "Rovers" as with the Pen Computer system?

- **System Support Personnel Required:** Personnel must be assigned responsibility to support the laser printer.

Option 2: Implement Pen Computer System in 747 Bay only

The scope of the current software was limited to a classic 747. Therefore, there is NO support for making write-ups on any other fleet type. Fielding the system in the 747 Bay would require the least amount of development and equipment investment.

- **Additional Hardware Required**: Pen computers and peripherals (batteries, battery chargers, etc.) for one Bay. Ethernet cables and power hook-ups. NOTE: Phase 2 implementation may select DIFFERENT hardware for RF capabilities than would be selected for immediate implementation in network configuration.

- **Additional Software Required:**

1. Add graphics - Inspectors have indicated that the current level of graphics in the software supports Zone selection for 747 classic, but does not cover all 747 models and series. In addition, the system does not provide all of the graphics that they currently reference during inspections. Panel and Station charts would need to be added to the software OR inspectors would need to carry the paper copies of these graphics. None of the pen computers or their cases provide a convenient place to store such paperwork. Custom cases may be an option if desired.

2. Database expansion: the UAL provided database of Major and Submajor zones is not complete. Inspectors would like additional choices for handling such locations as external fuselage, as in the case of lightening strikes. In addition, inspectors have asked for larger field lengths for specific items and defects. Also, any additional zone information needed to handle non-classic 747 a/c would also be needed.

3. Rule modification: the current software rules require the inspector to fill in data in the corrosion task # field whenever corrosion is indicated as the defect. Inspectors have pointed out that the corrosion task # is not needed if corrosion is noticed during an inspection controlled by a C-check inspection job card.

4. Additional functionality: There are several items that have been requested in order to make the system usable for full operation or more user-friendly. Listed below are some of these options:

    - Add functionality to handle write-up's for removal of parts/robbing or parts rather than defects
    - Add functionality to handle planner/analyst write-ups generated from analysis of log book items
    - Add functionality to handle additional security measures (i.e., limit user to one machine at a time).
    - Add customized on-screen keyboard.
    - Add functionality to retrieve handwriting recognition profile for current user.
    - Add screen customization option for left-handed users

- **Additional Training/Procedural Changes**

1. New procedures need to be constructed for handling the new paper documents (same as Option 1)

2. Appropriate parties must be re-trained per the new procedures.

3. All inspectors in targeted bay would require training on the pen computer system.

4. Must decide who is going to have access to the Host software and then provide training accordingly.

- **System Support Personnel Required:** Personnel must be assigned responsibility to support the laser printer, pen computer equipment, Host, and associated software.

Option 3: Implement Pen computer system for all fleet types

This option expands on Option 2 by expanding the system capability to include all fleet types handled by United Airlines. All issues raised above would have to be addressed for this option as well. In addition, this option would require additional resources in all categories to handle the added scope of implementing the system for all fleet types and all bays.

Option 4: Add Functionality, User Groups, Technology

This is the most ambitious option of all. It basically constitutes a complete new phase of effort that would require specification of the additional functionality desired. This specification should take into account the needs of additional user groups (e.g., lead mechanics, planners) and may include consideration of additional technology (e.g., wireless communications).

6.8 ACKNOWLEDGEMENTS

We wish to acknowledge and thank all of the members of the United development team as well as the inspectors who participated in this study.

6.9 REFERENCES

Layton, C., (1995 in press) Job Aiding: Performance Enhancement System. *Human Factors in Aviation Maintenance, Phase V: Progress Report*, (contract No. DTFA01-94C0103).

6.10 APPENDICES

6.10.1 Appendix A - Questionnaires Used in Study

User Background Form

INSPECTOR # _____

Thank you for agreeing to participate in the Pen Computer Non-Routine Repair Write-up System Pilot Study. Please complete the following information so that we can describe the general background of participants in this study. The information that you provide on this and other feedback forms will be used for two purposes: (a) to aid in planning improvements/ changes to this system in the future and (b) to complete reports for the FAA Office of Aviation Medicine Human Factors program on the performance of the hardware and software aspects of this system.

PART A

Number of years at United: _____ Number Years as an Inspector: _____

Have you ever used an IBM compatible PC before? Yes No

If yes, how long? _____ months/years (circle one)

Have you ever used Microsoft Windows software? Yes No

What shift are you working? 1 2 3

Age: < 25 26-35 35-45 35-45 45-55

Did you participate in the initial Pilot study? Yes No

PART B (To be completed during the pilot study)

Circle Inspection Job-cards worked. Indicate Unit used for each:

F= Fujitsu H=Hammerhead K=Kalidor N=Norand T=Telxon

_____GALLEY/LAV SUPT STRUCTURE-INSP

_____FWD BLKHD AND RADOME INSPECT

_____AIR COND COMPT - INSPECTION

_____KEEL BEAM AREA - INSPECTION

_____BULK CARGO COMPARTMENT INSPECT

_____FUSELAGE BILGE INTERNAL INSP

_____CHECK ATTND'S SEAT UPPER DECK

_____MAIN ENTRY DOOR RH INSPECT

_____M.E.D. CRACK CHECK - 2LH

_____MAIN ENTRY DOOR LH INSPECT

_____AFT CARGO DOOR AND FITTING INSP

_____LT WING FLAP TRACK FAIRING-INSP

_____LH WING EXTERIOR SURFACES-INSP

_____LH WING UPPER SURFACE-INSPECT

_____LH WING LEADING EDGE INSPECT

_____VERTICAL STABILIZER - INSPECT

_____APU COMPT ZONE 317/318 INSP

_____NOSE GEAR/WHEEL WELL INSPECT

_____TAIL COMPT ZONE 315/316 INSP

_____HORZ STAB CENTER SECTION INSP

_____TAIL COMPT ZONE 311/312 INSP

_____#2 L/H MED EMER ASSIST BTL DATE

_____COCKPIT WINDOWS INSPECT

_____CHECK MAIN DECK ATTNDT'S SEATS

_____LH WLG WHEEL WELL INSPECTION

_____LH WING LNDG GEAR INSPECTION

_____ATTENDANTS SEAT CHECK

_____FWD CARGO COMPARTMENT INSPECT

_____INSPECT NOSE WHEEL WELL

_____E&E COMPT LADDER-INSPECT

_____PITOT STATIC PROBE INSPECTION

_____RH LOWER FUSELAGE INSPECT

_____LH LOWER FUSELAGE INSPECT

_____EXT LWR FUSELAGE INSPECT

_____NLG W//W STRUCTURAL INSPEC.

_____NOSE GEAR AREA INSPECTION

Hardware Evaluation Form

INSPECTOR # _____

Compare the basic hardware features of the pen-computers used in this pilot study. For each model, place a check mark in the box of the choice that applies for each evaluation criteria. Rank the models from 1 (best) to 5 (worst) in overall performance on the last line of the table.

Evaluation Criteria	*Choices*	*Fujitsu Stylistic 500*	*Hammer-head 486*	*Kalidor K2100*	*Norand 6600*	*Telxon PTC-1184*
Screen Size	Too Small					
	Too Large					
	Adequate					
	Good					
Durability/ Weight	Too Fragile					
	Too Heavy					
	Adequate					
	Good					

Overall Speed	Too Slow Adequate Good
Screen Lighting	Too light or dark Adequate Good
Screen Clarity	Fuzzy Adequate Sharp
Battery Life	Too Short Adequate Good
Battery Replacement	Difficult Adequate Easy
Ease of Carrying	Awkward Adequate Comfortable
Stylus Feel	Scratchy/Slippery Adequate Good
Overall	Poor Adequate Good
RANKING	

Evaluation of Trade-offs Form

INSPECTOR # _____

PART 1

In selecting the best system for your environment and use, trade-offs may need to be made between two opposing traits. To help identify trait priorities, please answer the following questions by circling your answer and then explain the reason for your answer.

1. Would you be willing to use a machine that it heavier (1-2 lbs) in order to get a more ruggedized unit?

Yes No

Why/Why not?

2. Assuming that the handwriting recognition cannot be improved substantially, would you prefer to use / carry around a portable computer with a keyboard rather than just use the pen stylus and on-screen keyboard?

Yes No

Why/Why not?

3. Would you prefer to have the pen stylus tethered to the machine rather than loose?

Yes No

Why/Why not?

4. Which would you prefer:

Stickers printed on belt printer attached to pen computer

Hand-made stickers made using masking tape or "dots"

No stickers - rely on location information on write-up

Why?

5. Would you be willing to carry around a heavier machine (1-2 lbs) in order to have a larger screen?

Yes No

Why/Why not?

6. Which would you prefer:

No case

Shoulder strap only

Customized case with shoulder strap

Why?

7. Would you be willing to carry a small, portable barcode reader attached to the pen computer in order to enter barcode information (e.g., job card #, write-up #, login) rather than write/type it in?

Yes No

Why/Why not?

<u>PART 2</u>

1. Describe the special environmental conditions in which the pen computer hardware must operate (ex: temp, vibration, corrosion, lighting, etc.).

2. Describe areas of the A/C where you had problems using the pen computer and explain why.

3. What other areas of the A/C (areas you didn't work) do you foresee possible problems with operating the pen unit and explain why.

Hardware Evaluation

INSPECTOR # _____

1. Describe general features/functionality of pen computer hardware you liked.

2. Describe general features/functionality of pen computer hardware you would change (explain the desired change).

3. Describe model specific features/functionality you like.

Fujitsu

Hammerhead

Kalidor

Norand

Telxon

4. Describe model specific features/functionality you did not like.

Fujitsu

Hammerhead

Kalidor

Norand

Telxon

Application Evaluation Form

INSPECTOR # _____

This form requests your input on the Non-Routine Repair Write-up software application. Complete and return this form at the conclusion of the pilot study.

<u>QUESTIONS:</u> Complete the following questions by circling your response.

1. a. Which system do you prefer for making write-ups?

Current paper system Pen computer system

b. Why?

2. a. What is your opinion of the Transfer portion of the program?

Easy to Use Adequate Difficult to Use

b. Why?

c. Other comments

3. a. What is your opinion of the Write-up portion of the program?

Easy to Use Adequate Difficult to Use

b. Why?

c. Other comments

4. What are your comments on the laser printouts (ex: format, content, speed, etc.)?

Priorities for Future

INSPECTOR # _____

The current pen computer system is NOT a complete system. It supports initial NRR write-up creation for one aircraft type only. Prioritize the items below in terms of which would be make the Pen-Computer Non-Routine Repair System most useful to you.

H= High Priority M= Medium Priority L= Low Priority X= Undesirable

_____ On-line GN/MM

_____ **On-line IPC**

_____ **On-line SRM**

_____ **On-line Panel Charts**

_____ **On-line Detailed Zone Charts**

_____ **On-line Detailed Station Charts**

_____ **On-line Job card and W/U Numbers**

_____ **Support for Buy-back**

_____ **Bar code reader attachment**

_____ **Physical keyboard attachment**

_____ **Sticker Printer attachment**

_____ **OTHER_____**

_____

_____ **OTHER_____**

_____

_____ **OTHER_____**

_____

6.10.2 Appendix B Summary of User Responses

Summary of Hardware Evaluation

Evaluation Criteria	Fujitsu Choices	Hammer-Stylistic 500	Kalidor head 486	Norand K2100	Telxon 6600	PTC-1184

	Too Small	7	3,4,5	2,3,5	
Screen Size	**Too Large**	2			
	Adequate	1,3,4,5,7, 8,9	8,9	7,8,9	4,6,7,8	1,2,4,5,9
	Good	2,6	2,3,4,5	1	1,9	3,7

	Too Fragile	4	4	7	2
Durability/ Weight	**Too Heavy**	2,5,7			
	Adequate	1,3,7,8,9	5,7,8,9	5,7,8,9	2,4,5,8,9	1,3,4,9
	Good	2,5,6	2,3,4	1,2,3	1,3,6	3

	Too Slow	1	9	2,3	4,5,7,9
Overall Speed	**Adequate**	5,8,9	4,5,7,8	4,5,7,8	7,8,9	3
	Good	2,3,4,6,7	2,3	1,3,9	1,4,5,6	2

	Too light or dark	1	9	3	3	1,4,9
Screen Lighting	**Adequate**	5,9	5,7	4,5,7	5,9	3,5,7
	Good	2,3,4,6,7	2,3,4	1,2,9	1,2,4,6	2

	Fuzzy	1	9	7	7	1,4
Screen Clarity	**Adequate**	5,9	4,5,7	1,4,5,9	1,5,9	3,5,9
	Sharp	2,3,4,6,7,8	2,3,8	2,3,8	2,4,6,8	2,7

	Too Short	4,9	4,7	4	4,6,7	4,7,9
Battery Life	**Adequate**	2,3,5,7	2,3,5,9	2,3,5,7	2,3,5,9	2,3,5
	Good	6	9			

	Difficult	2,3,5	3,5	5
Battery Replacement	**Adequate**	5,8,9	8,9	2,4,7,8,9	2,5,7,8,9	2,9
	Easy	2,3,4,6,7	7	3	3,7

	Awkward	5,7	1,2,3,5
Ease of Carrying	**Adequate**	1,4,7,9	4,9	3,4,7,9	2,4,6,9	4,7,9
	Comfortable	2,3,5,6,8	2,3,5,8	1,2,5,8	1,3,8

	Scratchy/Slippery	3				
Stylus Feel	**Adequate**	2,4,6,9	2,3,4,7,9	2,3,4,7,9	2,9	2,3,4,7,9
	Good	3,7,8	8	1,8	1,4,6,7,8	

	Poor	8	4,5			
Overall	**Adequate**	9	4,5,9	3,4,5,7,8	5,9	7,9
	Good	3,4,5,6,7,8	3	1,9	1,3,4,6,8	

RANKING	1 - 3,7	1 - 2	1 - 1,9	1 - 4	1
	2 - 2,4,5	2 - 3,5	2 - 5,7	2 - 1,9	2
	3 - 1,9	3 - 4,7	3 - 4	3 - 3	3
	4	4	4 - 3	4 - 2,5	4 - 1,7,9
	5	5 - 9	5	5 - 7	5 - 2,3,4,5

Inspector 6 rated only Fujitsu and Norand; did not rank
Inspector 8 did not rate Telxon; Did not rank but could derive ranking from overall rating

Evaluation of Trade-offs Form

INSPECTOR # _____

PART 1

In selecting the best system for your environment and use, trade-offs may need to be made between two opposing traits. To help identify trait priorities, please answer the following questions by circling your answer and then explain the reason for your answer.

1. Would you be willing to use a machine that it heavier (1-2 lbs) in order to get a more ruggedized unit?

Yes 3, 4, 5, 6, 7, 9

Why?

3 Could save a lot of money on repairing units

4 - It doesn't matter as long as it's durable

5 To get the most updated features

6 Given the cost of replacement and or repair, I don't feet that a heavier unit is a large price to pay.

7 Less damage [means] less down time

9 - A few more lbs would not affect the machines mobility

No 1, 2,8

Why not?

1 - Carry around the whole aircraft, and won't fit some small corners.

2 - I feel the units are rugged enough. If an inspector can hang onto the machine, we need to change the carry handle/strap or council the Inspector.

8 - The machines at their current weight get noticeably heavy after 20 mins.

2. Assuming that the handwriting recognition cannot be improved substantially, would you prefer to use / carry around a portable computer with a keyboard rather than just use the pen stylus and on-screen keyboard?

Yes 6,9

Why?

6 - I would prefer the keyboard because I am a trained typist.
It would greatly improve my w/u generating speed

9 - I feel that a regular keyboard would be easier to use then the
on-screen keyboard; it is too tedious.

No 1,2,3,4,5,7,8,9

Why not?

1- It will be very inconvenient. Create a lot of problem.

2- On screen keyboard is good

3 - Using a keyboard in the locations that we inspect would not be practical. Laying down or kneeling you could not type

4 - It's awkward & uncomfortable

5 - Flip top could get broken

7 - keyboard already onboard

8 - the more moving parts the more to break

3. Would you prefer to have the pen stylus tethered to the machine rather than loose?

Yes - 1, 2,3,4,5,6,7,9

Why?

1 - This way the pen won't lose so easily.

2 - Keeps the stylus from getting lost.

3 - You know where the pen is.

4 - To eliminate dropping and breakage

5 - Harder to lose

6 - I inadvertently dropped the pen with the Norand unit and was grateful that the pen was tethered. I was in the wheel well and would have had to climb down to retrieve it.

7 - lost or breakage if not

9 - less chance of losing it

No - 8

Why not?

8 - Norand had a tethered pen. It got in the way when writing.

4. Which would you prefer:

Stickers printed on belt printer attached to pen computer 1,2,4,5,7

Why?

1 - easy to use and convenient

2 - how heavy will this printer be?

4 - Easier for others to locate areas

5 - Mechanics are used to looking for stickers; easier to locate w/u's; saves time

7 - Needs RF & would help production locate w/u with w/u #

Hand-made stickers made using masking tape or "dots" 6

Why?

6 - Dots would be good. The mechanic is used to looking for a sticker, plus carrying around dots would prevent us from needing a belt printer on a pen base. P.S. We used dots quite a while ago and they work well.

9 - I think a roll of tape would be suitable because it [printer] would add extra weight & complexity to the machine

No stickers - rely on location information on write-up 3,7

Why?

3 - If charts are available, the information given on the w/u location should be easy to find

7 - maybe a station on the wing and tail docks that would dispense the stickers or none at all. Keep the machine low maintenance.

5. Would you be willing to carry around a heavier machine (1-2 lbs) in order to have a larger screen?

Yes 3,4,7

Why?

3 - The handwriting recognition seems to work better on larger screen. It makes making the w/u easier

4 - Easy to read

7 - Bigger is better???

No 1,2,5,6,8,9

Why not?

1 - will be too heavy to carry around

2 - screen size adequate

5 - Screen sizes are adequate

6 - the smallest of the screens appears to be adequate

8 - The lighter the better. We all as insp. have 20/20 close up.

9 - the screens are adequate already

6. Which would you prefer:

No case

Why?

Shoulder strap only

Why?

Customized case with shoulder strap 1,2,3,4,5,6,8

Why?

1 - Good protection machine and easy to carry

2 - Ease of handling - protects machine

3 - The case is good to protect the unit. But it will not stay clean (i.e., grease, oil, hyd fluid) A skydrol proof rubberized body with a shoulder strap would be good.

4 - Comfortness

5 - Pockets to put jobcards/pen, etc.

6 - The case has a handle plus the strap

8 - A case to better protect unit and a strap to support most of the system when in use.

OTHER 7,9

7 - Case with handle only; strap gets in way, case helps protect

9 - Customized case with hand carrying strap; I prefer carrying the machine this way

7. Would you be willing to carry a small, portable barcode reader attached to the pen computer in order to enter barcode information (e.g., job card #, write-up #, login) rather than write/type it in?

Yes 1,4,6,9

Why?

1- as long as making machine easier to use and convenient will be all right.

4 - for easiness & comfort

6 - A pen type barde reader/stylus can be used while adding very small (couple of oz's) amount to the total weight.

9 - If it makes my job easier & doesn't make the machine too bulky it would be worth it

No 2,3,5,7,8

Why not?

2- How heavy is this barcode reader?

3 - Too much clutter.

5 - More stuff to carry around

7 - Enough is enough

8 - Past experience shows barcode readers to be temperamental and we don't need any extra appendages.