Chapter Three
Pen Computers: Evaluations, Recommendations, and the PENS Project

3.0 INTRODUCTION

Pen computer technology has the potential to revolutionize the computer industry. Pen computers are compact, easy to use, and designed for field use. These factors make pen computers ideal tools for field data collection and analysis, even for individuals who do not currently use computers. Galaxy Scientific is working with the Flight Standards Service and the Office of Aviation Medicine to develop a job aiding system that is based on this exciting new technology.

The following is a discussion of the general characteristics of pen computers, a comparison of pen computers available from a variety of manufacturers, and a description of the progress of the Performance ENhancement System (PENS) for Aviation Safety Inspectors.

3.1 GENERAL CHARACTERISTICS OF PEN COMPUTERS

Pen computers are similar to personal computers in that they consist of a display, a central processing unit (CPU), and an input device. Unlike personal computers, however, pen computers put the CPU and display in one small box. Instead of a keyboard and mouse, a pen computer uses a special pen stylus for input. The pen stylus not only functions as a pointing device, it also serves as the primary means for entering data. Figure 3.1 illustrates both a typical personal computer and a typical pen computer.

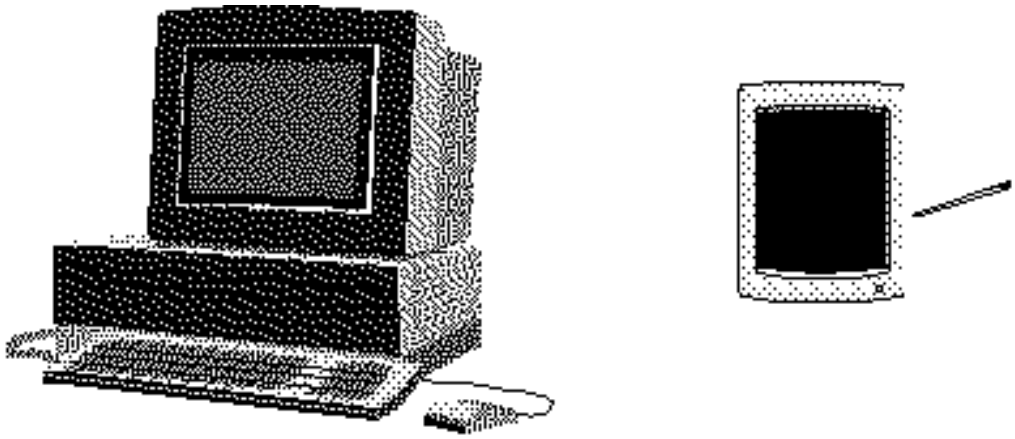


Figure 3.1 Typical Desktop and Pen Computers

Unlike a personal computer, data are written on the screen, rather than typed; a handwriting recognizer translates the printed input into "typed" characters. (Script or "cursive" recognition software is currently being developed by several companies.) Additional gestures are used for editing. Each person customizes the recognizer to her/his handwriting style for improved recognition accuracy. Pen computers also come with "virtual" keyboards (software versions of keyboards), with a connection for an actual keyboard, or with an actual keyboard located beneath the pop-up display.

Pen computers, like notebook computers or laptops, are battery powered. Extending the charge life of batteries is one of the hottest areas of portable computer research. Battery life currently ranges from one hour (with no energy conserving features turned on) to three or more hours (with all energy conserving features in use) on a single charge. While manufacturers take diverse approaches to battery charging and power management, nearly all pen computers come with user-replaceable batteries and ac adapters; several manufacturers also offer automobile cigarette lighter adapters.

Personal Computer Memory Card International Association (PCMCIA) slots also differentiate pen computers. Whereas notebook and laptop computers have seen limited use of these slots (and they're practically nonexistent on desktop computers), nearly every pen computer has at least one PCMCIA slot. These slots can be used for fax/modem cards, network cards, removable storage devices, and memory extension cards. The cards are approximately the size of a credit card and will likely see widespread use in the near future. Such devices allow quick and easy addition of peripherals or personal data. The PCMCIA slots make it easy to have a pool of computers for field workers. When someone needs to go to the field, she/he can grab a computer and a few PCMCIA cards and quickly have a customized machine.

Finally, pen computers are generally lightweight. Units range in weight from approximately three and a half pounds to around seven and a half pounds. This broad range is due to the unique features of each computer. For instance, the lightest computer uses a low voltage power system that reduces battery size (hence weight) and constrains the sizes (weights) of internal components. Two of the computers in the middle weight range come with built-in keyboards that can be stored beneath the displays. At the high end of the weight range are the ruggedized units; these units can withstand environmental extremes, such as cold temperatures and rain, and the general hazards of portable use, such as drops or collisions. The individualizing features of pen computers are discussed later in this document.

3.2 KEY BENEFIT OF PEN COMPUTERS

Pen computer technology capitalizes on the evolution of several branches of computer science and engineering. Graphical operating environments, such as Windows, allow the user to operate a computer almost entirely through pointing and "clicking" (tapping twice in rapid succession with the pointing device). The pen stylus not only supports such pointing and clicking, but when it is combined with handwriting recognition, it allows the user to enter data or issue commands. Thus, one simple device can be used as the sole means of computer operation and data collection. The result of such technological advances is that pen computers offer the promise of empowering field workers with computer technology. Even those people who don't traditionally use computers can be brought up to speed with relative ease.

3.3 POTENTIAL USES OF PEN COMPUTERS

Because pen computers are designed for field use, they have a variety of applications. Some of these application areas include sales, production, health care, census, law enforcement, delivery services, investigation, and inspection.

For example, sales people can make sales calls, assess the customer's needs, quote a price, and even sign up the customer, all on the computer. Production personnel can document production difficulties and track work in progress as they walk through the plant. Health care applications include patient forms, pharmaceutical orders, meal planning, and patient tracking and charting. Instead of using paper forms and waiting months for the data to be entered into a computer database, a census could be taken with on-line forms, thus facilitating quick compilation of a database.

Law enforcement personnel could use pen computers in a variety of ways, from mundane tasks such as writing tickets, to more involved tasks such as documenting and investigating crimes. Personnel in the National Transportation Safety Board could use them for aircraft accident investigations. Delivery services currently use custom pen computers for package tracking, delivery schedules, and recipient signatures. Any regulatory agency could use pen computers for inspections. For example, Food and Drug Administration personnel could use them when inspecting food production and sales facilities (e.g., meat packing plants, restaurants, grocery stores, etc.). Occupational Safety and Health Administration officials could use pen computers for inspections of workplace environments. Aviation Safety Inspectors could use pen computers to speed data collection, information retrieval, information distribution, and certification.

3.4 COMPARISON OF PEN COMPUTERS

Eight pen computer models from a variety of manufacturers were obtained, evaluated, and compared on the basis of CPU type and speed, hard disk capacity, display type, weight, ruggedness, cost, and a number of other factors. (Specific computers are hereafter identified as Computer #1 through Computer #8.) The following specifications, figures, and tables describe the results of that evaluation. While none of the pen computers evaluated could be considered "perfect," some were clearly better than others. While pen computers come in a variety of models and configurations, these units were selected because they are all capable of running Windows for Pen Computing. The models evaluated represent the bulk of the currently available pen computers that will run that operating environment. (Computers that use the NEC V.20 CPU are incapable of supporting Windows; therefore, computers that use this type of CPU were not evaluated.) Pertinent specifications of the evaluated units can be found in Appendix A.

(Two of the units, Computers #4 and #5, were not available in time for a "hands-on" evaluation. The specifications reported here were obtained from printed materials from the manufacturer and from published reports.)

3.4.1 Evaluated Characteristics

Central Processing Unit. Central Processing Unit (CPU) type and speed are central to the response time of a computer. An 80386 CPU should be considered the absolute minimum for portable use, particularly if running Windows. Indeed, one would be hard pressed to find a currently manufactured portable computer that uses an older generation processor. Whereas an 80386 is a minimum, it is difficult to conceive of a unit that is too powerful; many portable computer manufacturers are unveiling 80486-based models. In the future we may expect more powerful CPU s, such as an 80586.

The clock speed of the CPU affects response time nearly as much as the type of CPU. A 20 megahertz clock rate is an effective minimum for portable use, particularly when using the handwriting recognition software that comes with Windows for Pen Computing. While desktop computers now have clock rates of 33, 50, or 66 megahertz, pen computers typically have a 25 megahertz upper limit. However, the higher the clock rate, the better the response time.

Most of pen computers use an 80386 CPU with a 25 megahertz clock rate. However, Computers #2 and #3 have a 20 megahertz clock rate (and both are produced by the same manufacturer). Computer #4 uses an 80486 CPU with a 20 megahertz clock rate; given the increased power of the 80486 CPU, this unit is faster than the units that had 25 megahertz '386 CPU s. Another model from the same company, Computer #5, has an 80486 CPU with a 25 megahertz clock rate. (A 80486/33 megahertz model is to be released later this year.) One manufacturer chose to use a special low voltage 80386 CPU in its computer, Computer #7, because it allows for a smaller battery, thus reducing weight. Figure 3.2 compares the CPU characteristics of each unit.

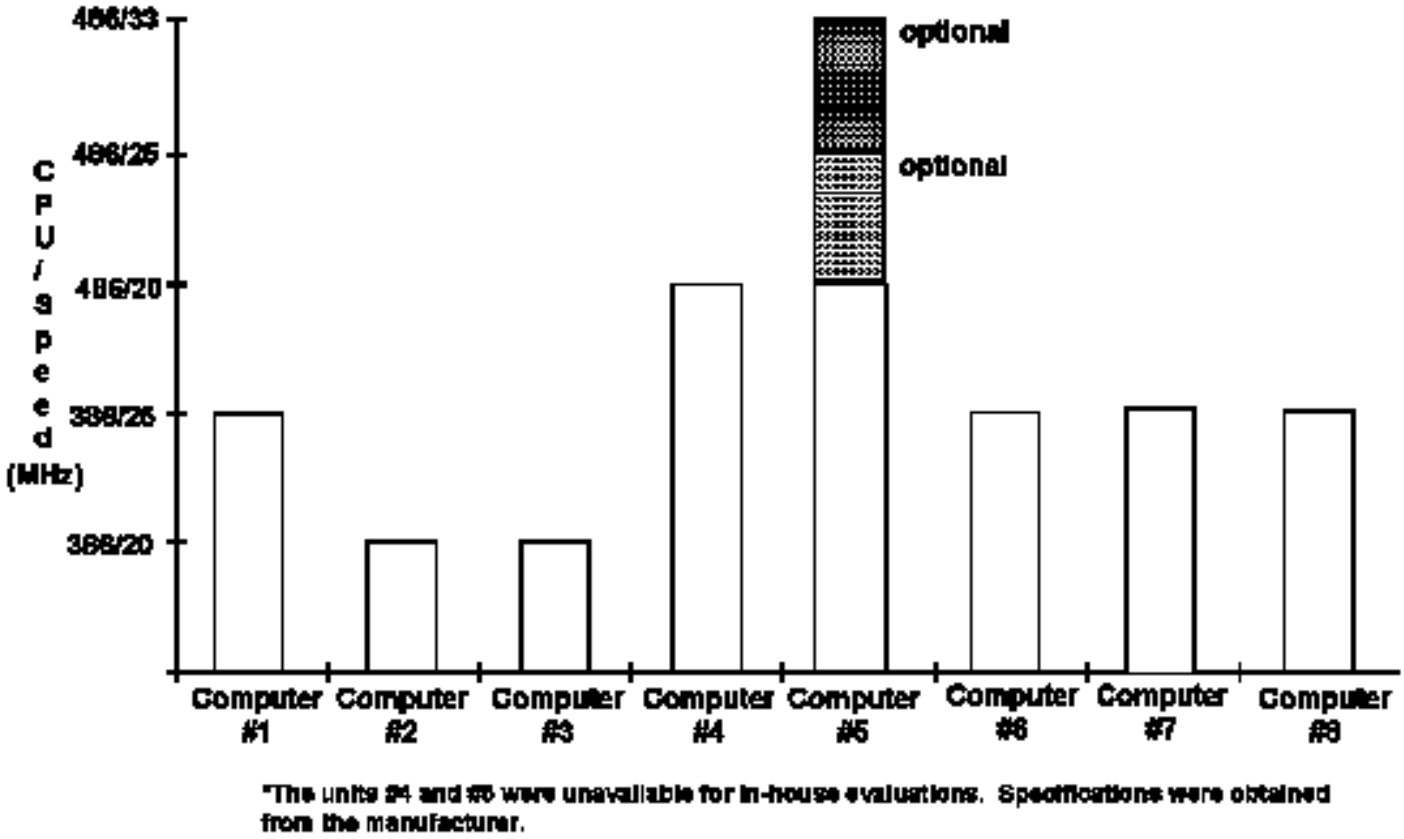
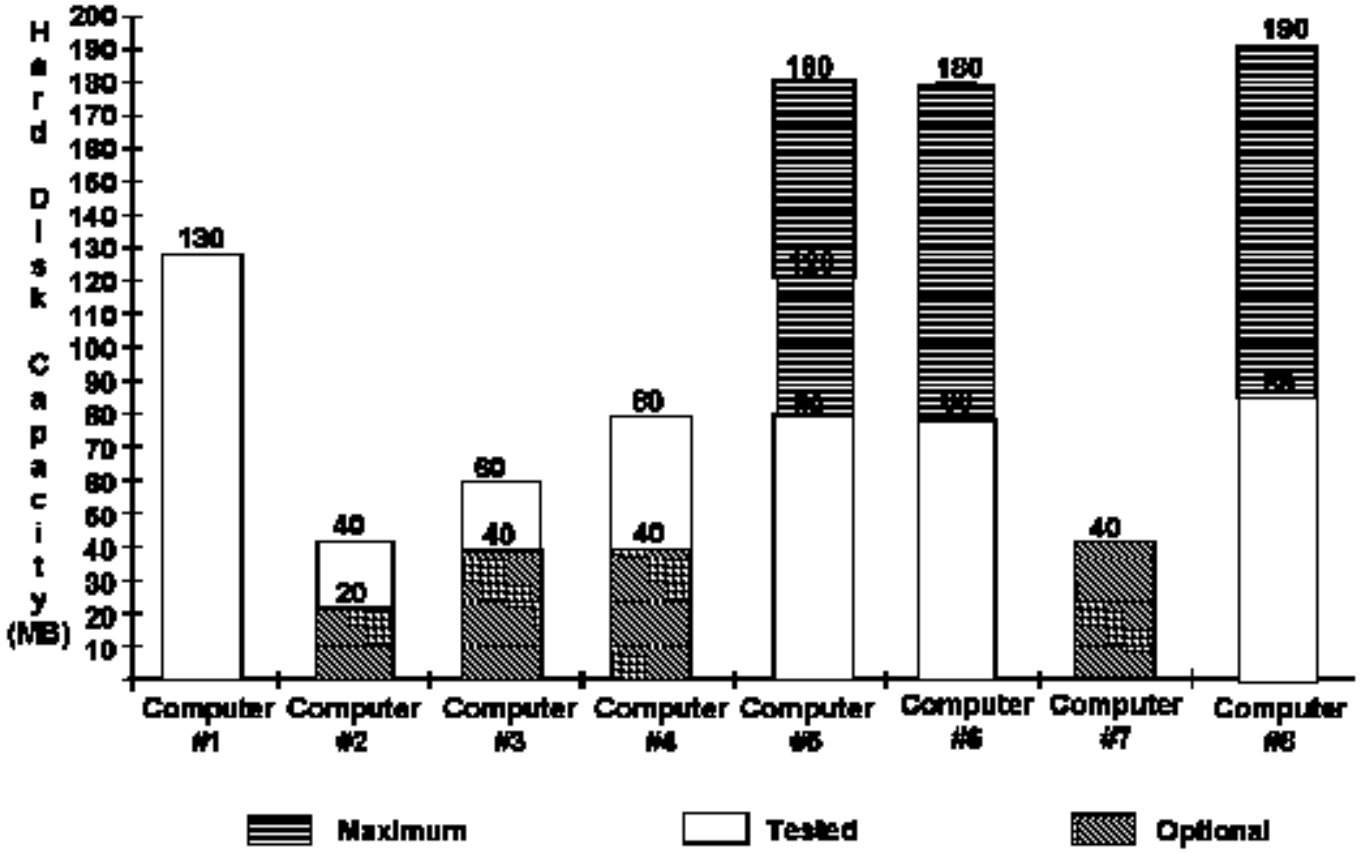


Figure 3.2 Comparison of CPU Type and Speed

Hard Disk Capacity. The hard disk capacity varied greatly across pen computer products. Capacities ranged from 40 megabytes (Computers #2 and #7) to 190 megabytes (Computer #8). Although there can be diminishing returns for large hard disks (in terms of capacity versus cost), software is becoming more space-intensive, particularly with regard to Windows programs. For example, the Windows operating software can use over seven megabytes of disk space, and a typical word processing application can use over 10 megabytes of space. Therefore, 40 megabytes is an effective lower limit on capacity, while 190 megabytes cannot be considered excessive. Currently Computer #7 is limited to a 40 megabyte hard drive because that is the only available size that runs on the low voltage system chosen by the manufacturer. Figure 3.3 represents the distribution of disk capacities for the evaluation units.



*The units #1 and #5 were unavailable for in-house evaluations. Specifications were obtained from the manufacturer.

Figure 3.3 Comparison of Hard Disk Capacities

Display Type. Display type greatly affects the ability to read the display in a variety of lighting conditions. Transflective displays work best in bright light, and they work fine in typical indoor lighting. However, transflective displays are nearly impossible to read in the dark. Backlit displays work best in the dark, and they work fine in typical indoor lighting. However, backlit displays can be difficult to read in bright light (this problem is greatly ameliorated by separate brightness and contrast controls). (It is extremely difficult to describe exactly what transflective and backlit displays are or how they look. One really needs to see these displays to understand more than the facts that one works best in the light and the other works best in the dark.) Computers #7 and #8 are unique in that they have backlit displays that can be completely turned off, in which case the display becomes transflective. Computer #5 is the only unit available with a color display. Figure 3.4 depicts the display types of the compared units.

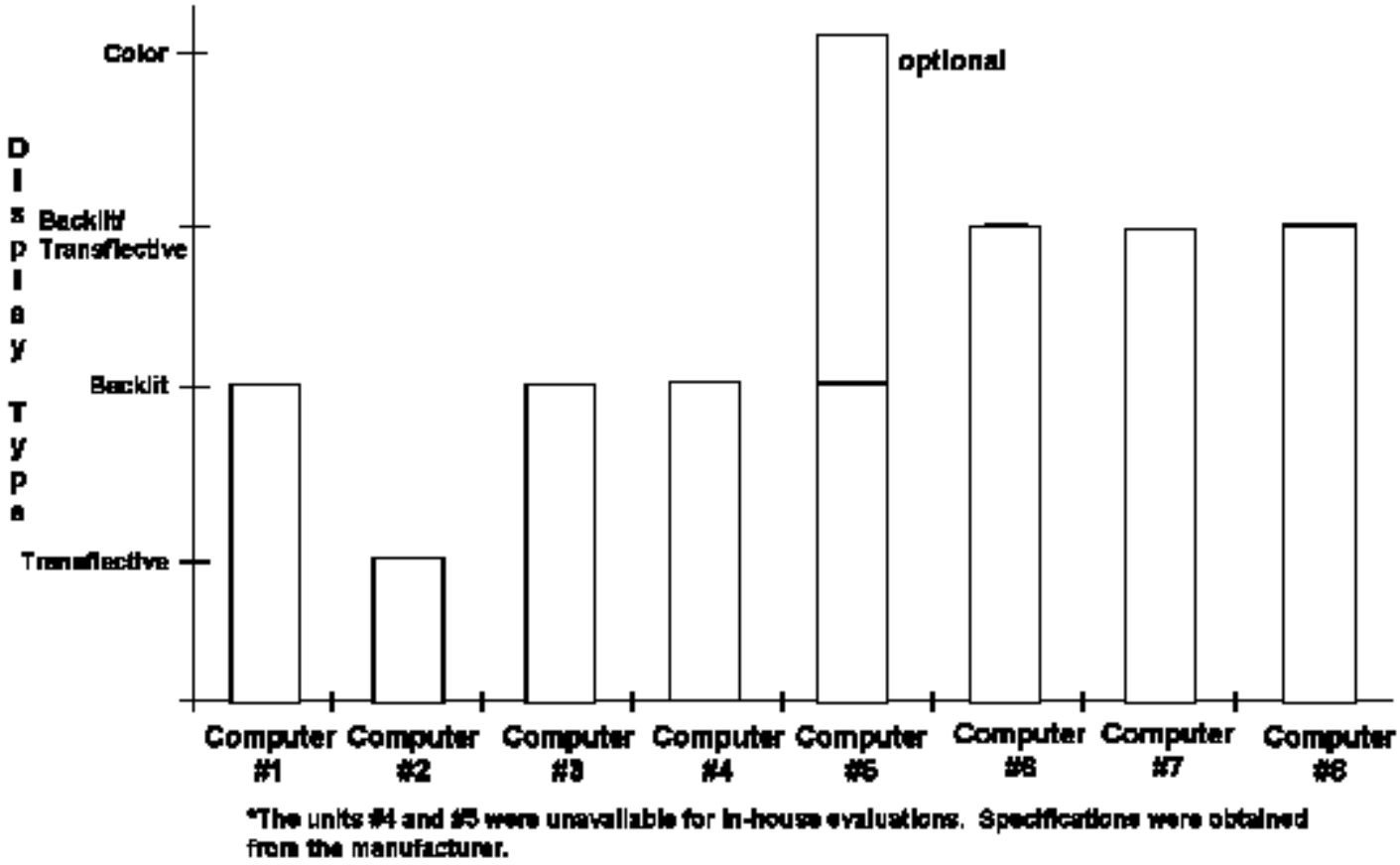


Figure 3.4 Comparison of Display Types

Weight. Weight is a critical factor when evaluating computers for field use. The computer must be easy to hold and carry for a significant portion of the workday. The weight of pen computers is highly correlated with ruggedness; the more rugged a machine, the heavier it is likely to be. Computer #7 was the lightest evaluated unit at 3.3 lbs. Computer #8, which is ruggedized, was the heaviest unit at 7.5 lbs. (The unit evaluated was a pre-production unit; production units are supposed to weigh 6.5 lbs.--which would still make it the heaviest pen computer.) Computer #1, because of its built-in keyboard, is toward the upper end of the weight range. Computer #5, which also has a built-in keyboard, weighs 7.0 lbs., which is also at the upper end of the weight range. However, the pen tablet can be removed from the keyboard base unit to lighten the load. Figure 3.5 shows the weights of the evaluated units.

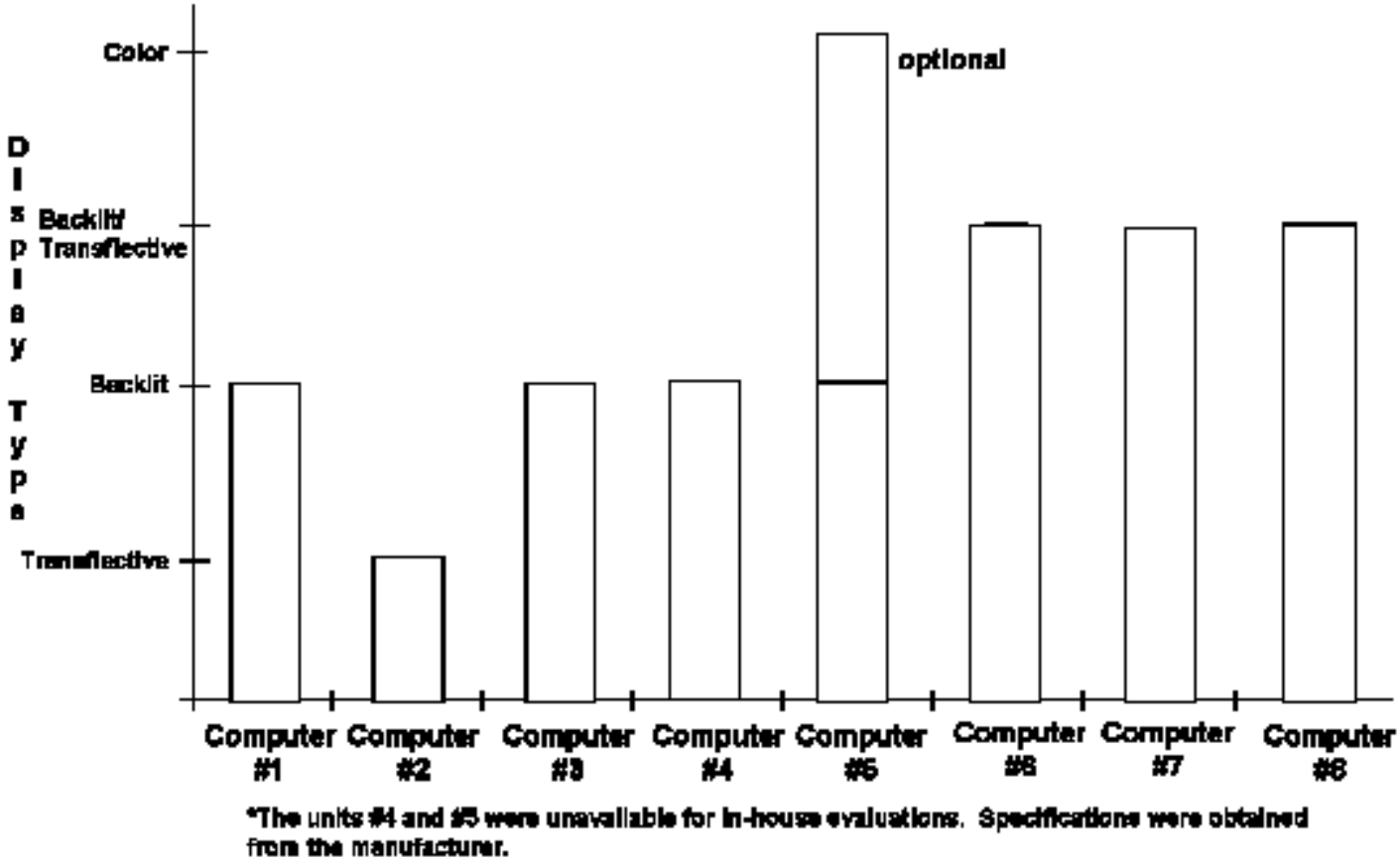


Figure 3.5 Comparison of Weights

Battery Life. Another factor that affects the utility of a portable computer is battery life; that is, how long can the computer be operated before it is necessary to change the battery or recharge it. Battery life can be extended by incorporating various energy-saving features into the computer. One of the most common energy-saving features is to shut off components that are idle. For example, if the hard disk has not been used for a period of time, say 30 seconds, it can be shut down to conserve power. Similarly, the screen and the CPU can be turned off when not in use. The amount of time that passes before a component is shut down is usually adjustable by the operator. While pen computer manufacturers tend to specify long battery lives based on all energy-saving features enabled, real use tests indicate that a standard pen computer battery will last about an hour of continuous use when none of the energy-saving features are enabled. (This assumes the display is backlit; a display that is not backlit consumes considerably less power. For example, Computer #2 will run approximately two hours on a single charge.) Computer #8 is an exception to this rule in that it will run approximately two hours on a single charge with the display on. The pen computer manufacturers are combating the problems associated with short battery life in several ways: the manufacturer of Computer #7 supplies two batteries as standard equipment with their product; Computer #8 uses a quick-charge battery that recharges in an hour; the manufacturers of Computers #7 and #8 both use non-replaceable backup batteries that allow the operator to change main batteries without shutting down the unit; Computer #1 has an optional heavy duty battery that gives two hours of continuous use. All of the manufacturers have designed their units such that a dead battery can be quickly replaced with a fully charged one. Figure 3.6 compares the battery lives of the evaluated units, with and without energy conserving features turned on. The manufacturer's specifications should be taken with a grain of salt.

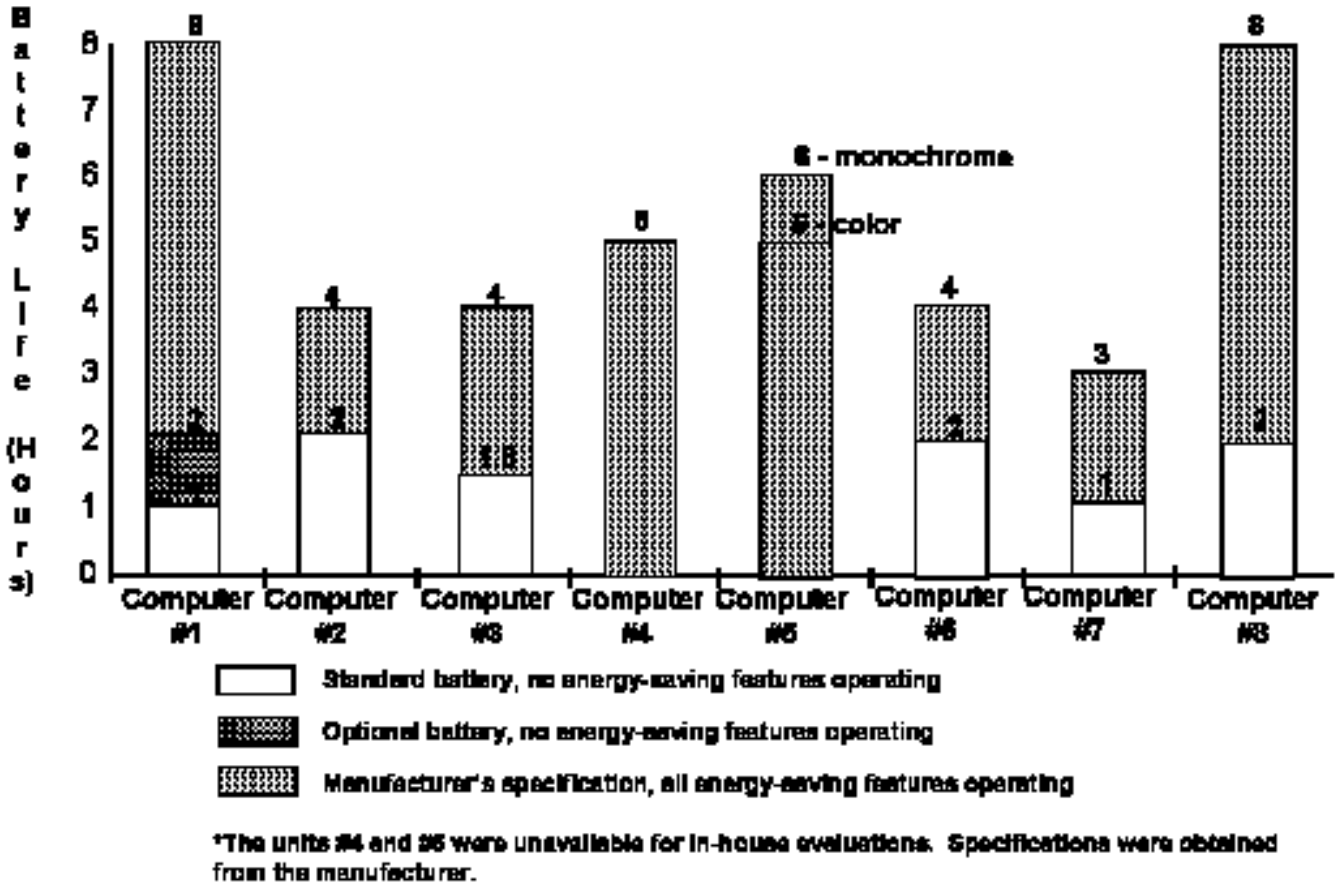


Figure 3.6 Comparison of Battery Life

Ruggedness. Ruggedness, or the immunity from damage due to drops, collisions, water, extreme temperatures, etc., can be an important criterion on which to evaluate pen computers. Most field environments are rather harsh compared to the typical office environment. Instead of sitting quietly on a piece of furniture, as would a desktop computer, a field computer will (at a minimum) be subjected to a lot of handling. In the course of such handling, it is likely that: the computer will be dropped; the operator will bump into things while operating the computer; it will rain or snow on the computer; or, the computer will be left on the dash of a locked car on an August afternoon. All of these things can take a toll on the hardware if it is not designed with such factors in mind. While Computer #8 is specifically designed to handle such environments, most of the other evaluated units were designed to be semi-rugged. Instead of making ruggedness a fixed aspect of their units (thus making them heavy all of the time), the manufacturers of these units have opted for ruggedized carrying cases. These cases improve impact and water resistance, and they have straps and handles to ease carrying the computer. Table 3.1 summarizes the ruggedness characteristics of the evaluated units, along with a number of other factors.

	Computer #1	Computer #2	Computer #3	Computer #4	Computer #5	Computer #6	Computer #7	Computer #8
Rugged	Optional Case	Optional Case	Optional Case	Optional Case	Optional Case		Optional Case	Yes
Built-in keyboard	Yes	No	No	No	Yes	No	No	No
Number of Brightness and Contrast Controls	2	1	1	2	2	2	2	2
External floppy disk drive standard	Yes	No	No	Yes	Yes*	No	Yes	No
Number of PCMCIA slots	1	1	1	2	2	1	2	0
Built-in fax/modem	Yes	No	No	No	No	No	No	Yes
Dimensions	1.6"H x 11.5"W x 9.3"D	1.2"H x 11.7"W x 9.4"D	1.2"H x 11.7"W x 9.4"D	1.2"H x 10.9"W x 9.8"D	2.1"H x 11.7"W x 9.3"D	1.3"H x 11"W x 11"D	1.5"H x 10.6"Wx 8.3"D	2.0"H x 12.5"W x 10.1"D

* internal

Table 3.1 Miscellaneous Pen Computer Characteristics

Other Factors. Other factors that contribute to the desirability of a given pen computer over another include such things as a built-in keyboard, separate brightness and contrast controls, a standard internal or external floppy disk drive, the number of PCMCIA slots, a built-in fax/modem, and the size of the unit. There are tradeoffs involved with many of these factors. For example, a computer that has one PCMCIA slot and an internal fax/modem is nearly equivalent to a computer that has two PCMCIA slots but no internal fax/modem. (One of the PCMCIA slots can be used for a fax/modem. A fax/modem can be very important to remote field workers who need to communicate with others in other field locations or at a central office.) Table 3.1 lists the factors and their presence on the units.

Price. For many people, the determining factor on purchasing a pen computer will be price. It is important to realize that although the initial cost of a pen computer is likely to be higher than an equivalently equipped notebook computer, pen computers also weigh less and are smaller. Furthermore, pen computers were designed to speed data collection and reduce reliance on data-entry personnel. In other words, many agencies who use paper forms rely on data entry clerks to read the data off those forms and transcribe them into a computer database. Data entry clerks are an intermediate step in the data collection and distribution process; such intermediate steps can reduce data integrity and slow assimilation of the data into databases. Pen computers allow data to be directly entered in the proper database format at the time of collection. This method ensures that data are entered correctly and it reduces reliance on data entry personnel. While price is highly correlated with capabilities, it is not a reliable indicator. Price should be one factor used to choose between pen computer models, but it should not be the sole factor. The prices of the pen computers evaluated are shown in Figure 3.7.

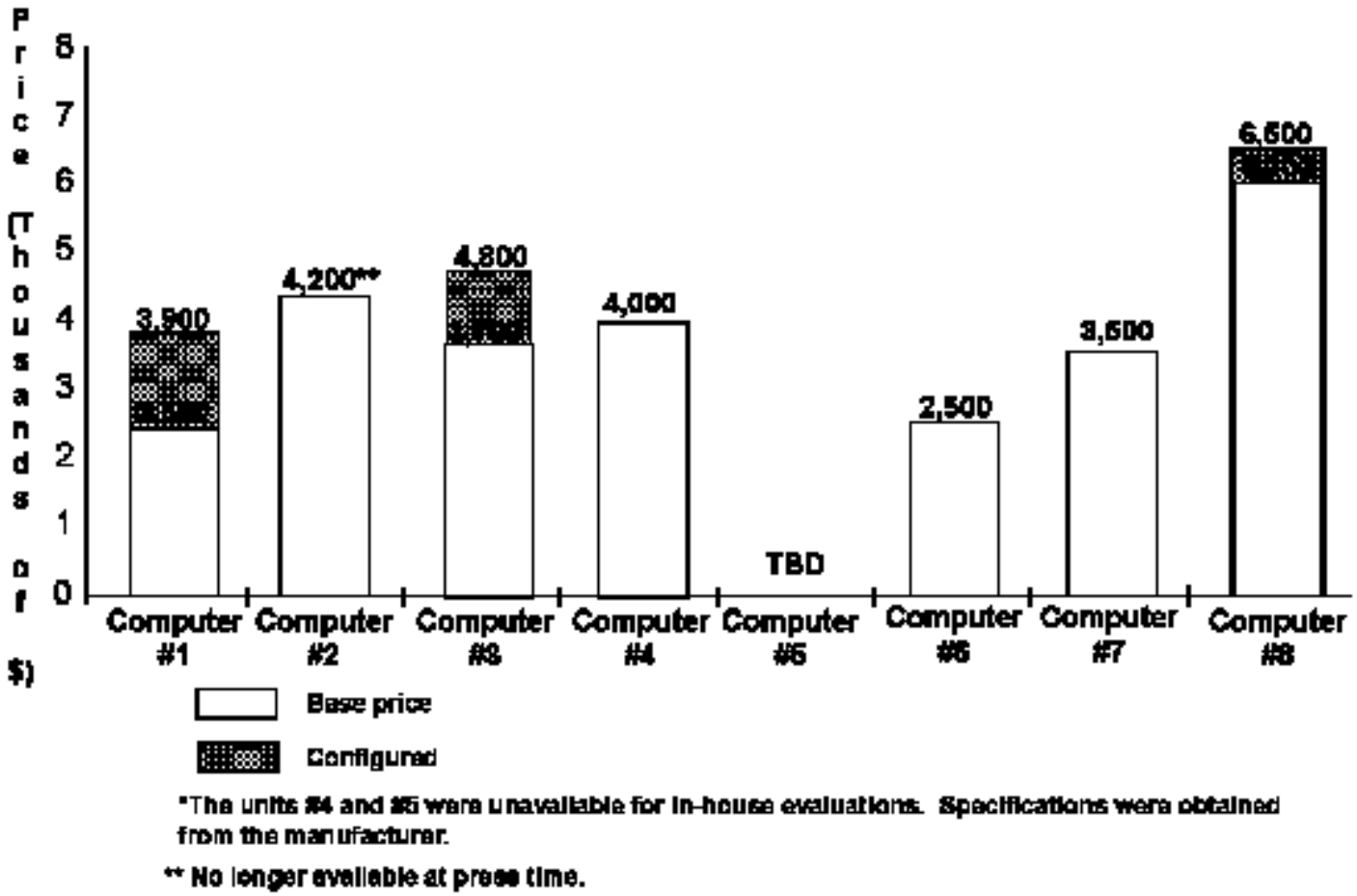


Figure 3.7 Comparison of Prices

3.4.2 Common Features of Pen Computers

All of the evaluated pen computers had an external keyboard port (with the exceptions of Computer #1 and Computer #5, which had built-in keyboards). The units also had serial and parallel ports; on computers other than Computers #2, #3 and #8, the parallel port doubled as a floppy disk drive connector. Serial ports are often used for communications (including loading software onto the pen computer) and a mouse (which, of course, is unnecessary when using a pen stylus as a pointing device). Parallel ports are also used for communications, but their primary use is for connecting printers. Computer #7 was the only model that did not have a VGA port; a VGA port is a convenient feature if the operator wants to display items on a large monitor instead of the pen display. All of the units were configured with eight megabytes of RAM; this is an effective minimum for running Windows for Pen Computing.

3.4.3 Common Limitations of Current Pen Computers

As mentioned above, a current common limitation to pen computers is the short battery life. Batteries also make significant contributions to the weight of a unit. Several manufacturers are working to improve battery life, while maintaining lightweight batteries. Many current pen computers use nickel-cadmium (NiCad) batteries, which appear to have an upper limit on battery life of one hour (given a backlit display and current technology). Nickel-metal hydride batteries are now beginning to appear; these batteries appear to have longer lives than do NiCad batteries. It is only a matter of time before compact, lightweight, long-life batteries are available.

On the subject of batteries, a limitation of all current pen computers, except Computers #2 and #3, is that the pen stylus requires batteries. Unless there is an accompanying keyboard, there is no way to operate the computer if the pen stylus batteries die. The pen stylus batteries are typically readily available (and inexpensive) calculator or hearing aid batteries. It is probably a good idea to carry a spare set of pen stylus batteries in the field. The pen styli for Computers #2 and #3 use internal inductors that are sensed by the radio frequency grid on the computer. Other manufacturers are probably moving in the inductor direction.

The biggest limitation of pen computers is the handwriting recognition software. Recognition accuracy is unacceptably low when using the recognizer that comes with Windows for Pen Computing. The standard recognizers that run under other operating environments, such as PenPoint and PenRight, do not perform any better. However, there is a third-party recognizer, Nestor Writer, that has very high recognition accuracy. According to a recent publication (Bachus & Weston, 1993), a novice user can get initial accuracy rates above 80%. The authors reported rates above 90% after one hour of training. This software is currently available for PenPoint and should be available for Windows within six months. While all currently available recognizers require printed text input, several companies are working on cursive recognizers.

3.4.4 Tradeoffs Between Pen Computers

It should be apparent that the perfect pen computer has not yet been invented. As mentioned above, there are several tradeoffs between the features of pen computer models and each model has features that make it unique. Computer #1 is modestly priced and has a built-in keyboard, but the keyboard makes the unit heavy. Computers #2 and #3 have the benefit of not requiring batteries for the pens, but they are more expensive than similarly configured units. Computer #4 has an 80486 processor and is lightweight. Computer #5 also has an 80486 processor, a color display, and a built-in keyboard. However, these units are rather expensive. Computer #6 has a handle that doubles as a stand and it has a "hot dock." The hot dock allows the unit to be quickly placed in a docking station that supplies power and connects the unit to a network. Computer #6 falls in the middle of the group in terms of overall performance. Computer #7 has two PCMCIA slots, is the lightest unit evaluated, and has a backlit/transflective display. Unfortunately, it has a small hard disk and the evaluated pre-production units had very short life main and pen batteries. Computer #8 is very rugged and has quick-charge batteries, but it is heavy and expensive.

Such tradeoffs make it difficult, if not impossible, to dictate which unit to purchase for a given application. When implementing any application, the designer must perform an extensive field evaluation to fully understand which features are most important to the people who will actually be using the equipment. Just such an evaluation is proposed in the next section.

3.5 PENS: A PERFORMANCE ENHANCEMENT SYSTEM

The Performance ENhancement System, PENS, is a tool to aid Aviation Safety Inspectors in performing their tasks. Aviation Safety Inspectors (ASIs) make up the inspection team for the FAA. Aviation Safety Inspectors perform a variety of tasks, in both commercial and general aviation areas, including: inspecting aircraft and equipment, reviewing manuals and records, certificating pilots, and evaluating training programs.

There are 2600 ASIs in the nine regions of the FAA. The initial target of PENS is an ASI performing an airworthiness (safety) ramp inspection. (A ramp inspection consists of inspecting an aircraft, while it is at the gate, before a scheduled departure.) PENS is an electronic performance support system (Gery, 1991) that consists of two components: a "smart" forms application and an on-line documentation system. PENS capitalizes on the recent advances in pen computer technology outlined above.

3.5.1 Improved Forms

As is typical with regulatory agencies, there are several forms that must be completed while performing an ASI task. Currently, these forms are on paper and require that redundant information be recorded on each form. After completing the forms, the ASI either types the data into a local computer database or he/she submits the forms to a data entry clerk. There are several drawbacks to such an approach. First, redundant recording of data on multiple forms takes time that could be devoted to more productive activities. Second, the two-step process of recording data on paper and then entering the data into a computer is inefficient. Third, one is either paying an inspector to do a task for which he/she is over-qualified, or one is paying for a staff of data entry clerks. Fourth, a data-entry clerk may make transcription errors (due to misreading the inspector's handwriting) or errors due to incomplete knowledge and understanding of the inspector's activities. Such errors mean that the database is an unreliable source of information. Finally, the current process takes considerable time, which means there is a delay in getting safety data into the national database where it can be accessed by other members of the FAA.

Pen computer technology can be easily applied to such tasks to minimize the number of steps required to collect data and assimilate it into the database. Forms will be linked together so that an entry in one form propagates to the other forms, thus eliminating redundant data entries. Furthermore, the data will be collected so that they are ready for direct downloading into the database. This method of collecting data reduces the need for data entry clerks and it reduces data transcription errors. At the end of the work day, the inspector will return to the office, connect the pen computer to the network, and initiate a downloading procedure that will be carried out overnight.

3.5.2 On-line Documentation

The second major contribution of PENS is an on-line documentation system. Whereas ASIs currently must carry two briefcases full of books (including Federal Aviation Regulations, ASI Handbooks, and other regulatory documents), the necessary data will be stored on the hard disk of the pen computer or on a CD-ROM (compact disc, read-only memory). Not only is the computer media more lightweight and compact, it also facilitates quick retrieval of specific information. For instance, an ASI will be able to search the regulations for the word "corrosion" to answer a question on reporting defects. PENS would then indicate all of the instances of the word corrosion. The ASI could then ask PENS to retrieve the relevant documents and display the pages that discuss the term.

Besides the bulk and inefficiency of the books, inspectors must deal with problems of information currency. One complaint made by inspectors is that they will tell an operator that it is not in compliance with the regulations, only to be shown a more recent edition of those regulations. That is, sometimes the operators get the most recent editions of the regulations before the inspectors do. This problem could be dealt with by distributing updated documents to the pen computers when they are connected to the database computer network. Thus, a new edition of a document could literally be published one day and in the inspector's hands the next.

3.5.3 Additional Benefits

A side benefit of using a computer to support inspection activities is that it opens the door to other types of activities and methods for documenting an inspection. For example, an inspector could follow an on-line checklist for an inspection. The checklist would then become the focus of interaction with the computer; by completing the checklist, all of the necessary forms would be automatically completed. We could even develop a scheduling component that would remind the inspector to follow up on an inspection. When documenting an inspection, ASIs currently must record their findings verbally. However, because the bulk of a ramp inspection is conducted by visually inspecting an aircraft, sketching is a more natural method for recording the results of such an inspection. Thus, if an inspector found a leaking seal on the wing of an aircraft, the inspector could annotate a line art drawing of that aircraft on the computer. This graphic could then be stored along with the completed form.

Another important benefit of giving ASIs computer-based inspection tools is that it would greatly ease inspection of air carrier records. Nearly all air carriers keep their records in computer files, as well as paper files. (At least one airline has only computer records.) Whereas searching paper files for specific data can be tedious and cumbersome, computer databases were designed for just such activity. Indeed, some industry officials are promoting the notion of allowing the FAA to inspect their records:

"We're not taking advantage of the data systems airlines have in place," [a] senior vice president of technical operations at [an airline], said. Those systems could be the foundation of a new surveillance system "that penalizes bad behavior and rewards good behavior." (McKenna, 1992)

The proposed concept would consist of reducing the frequency of inspections for operators who consistently meet airworthiness standards, while increasing the frequency of inspections for those operators who do not meet those standards. (A similar concept is already applied to other types of activities.) This approach should benefit the airlines by streamlining maintenance (thus reducing costs due to out of service aircraft) and reducing the amount of company time spent on inspections.

3.6 EVALUATION AND IMPLEMENTATION

There are a number of issues that can affect the success of introducing new technology into the ASI work environment. Many inspectors do not have experience using computers. Of those inspectors, some are willing to try the new tools based on promised increased productivity, while others are hesitant to embrace a new method for performing their work. Some inspectors are even concerned with how they will be perceived by the operators when they are carrying a pen computer.

Perhaps the most significant hurdle to widespread implementation of PENS, however, is the adequacy of the handwriting recognition software. The difficulties involved with handwriting recognition (writer independence, print vs. cursive writing, intraindividual variations in writing style) are directly analogous to difficulties with speech recognition; however, handwriting recognition is five to ten years behind speech recognition. Although much research and development is going in to new methods for handwriting recognition, we cannot wait for such advancements before fielding a system. Therefore, we are capitalizing on constraints built into the forms and data to reduce dependence on handwriting recognition. For instance, because many fields on the forms require one item out of a finite set of possible entries, one can display that set and select an item from it. This approach has the added benefits of reducing memory demands on the inspectors and of increasing data reliability.

Pen computer configurations and durabilities must also be considered, as there are significant tradeoffs in these areas. Questions that should be asked include: Is it better to have a lightweight unit without a keyboard, or a slightly heavier unit with a keyboard? Which is more important to inspectors, weight or ruggedness? Is battery life sufficient to even consider using such a device? Appendix B lists these questions and others, along with our recommendations. These recommendations are based on very informal evaluations, however, and should be considered only as preliminary guidelines.

3.6.1 Evaluation Plan

Given the above concerns, the following evaluation is proposed as a means to assess the utilities of various hardware configurations and the effectiveness of the software. We expect to modify the software based on inspector feedback, but the field evaluations will largely determine which models of pen computer hardware will be put into actual use. Although we expect the hardware to withstand most environmental conditions, it is possible that some extreme conditions will preclude the use of computer hardware. The following experimental plan will provide inspectors with experience with a range of models and it will subject the hardware to a range of operating environments.

3.6.2 FAA Regions

We will field units in six to nine Regions, in a variety of locations. This will give the project broad exposure to field inspectors and it will subject the hardware to a range of environmental conditions. The six Regions identified below are suggested based on the worst-case environmental conditions present in those regions.

Suggested location:	Reasons:
Alaska	Cold, snow
Northwest Mountain	High humidity, low temp., rain
Central	Average temp., average humidity
New England/Eastern/Great Lakes	Cold, snow
Southwest	Low humidity, heat
Southern/Western Pacific	High humidity, rain, heat

3.6.3 Pen Computer Models

We will field four different models, each from a different manufacturer; this will reduce reliance on one manufacturer and it will help identify design factors important to the inspector population. From this evaluation, it is likely that two of the models (or subsequent versions of them) would be chosen for final implementation. However, all of the purchased units would remain in service after the evaluation.

Each unit would have nearly identical hardware configurations, so as not to bias the results.

Seventy-two computers (and peripherals) will be purchased; this will provide each Region with two units from each manufacturer.

Suggested Computer:	Reasons:
Computer #1	Built-in keyboard
Computer #4	80486, medium weight
Computer #7	Lightest
Computer #8	Rugged

(Note: Computer #5 is also an 80486 unit with a built-in keyboard; this may be used instead of Computer #4.)

3.6.4 Experimental Design

A team of eight inspectors in each Region will evaluate these units. These inspectors will represent a cross-section of the inspector population in terms of age, sex, work experience, and computer experience. Each inspector will use one of the computers for a week and then switch to a different model. The rotation would be counterbalanced to eliminate order effects. This rotation will continue until each inspector has had an opportunity to use each model. At the end of the rotation, each inspector will complete an evaluation form (sample attached) that requests him/her to rate each unit and answer some general questions. The inspectors should still have access to the units at this time to refresh their memories of the specifics of each unit. From these data, we will recommend two of the models (or their subsequent versions) for final implementation.

3.7 SUMMARY AND CONCLUSIONS

As discussed above, pen computers use handwriting recognition software and a pen stylus for input, rather than a keyboard. The operator writes on the screen and the handwriting recognition software translates the written characters to typed characters. The pen stylus also acts as a pointing device, much like a mouse. When combined with graphical user interfaces, such as Windows for Pen Computing or PenPoint, the pen stylus and handwriting recognition software hold the promise of making computers easier to use than traditional desktop computers. Many pen computer models from a variety of manufacturers have undergone preliminary in-house evaluations. These evaluations have identified several differences in the design of such devices and have identified some tradeoffs involved in these design choices. While such evaluations are valuable, they should be seen as only a first step in selecting equipment; final selections must be made based on field evaluations by the actual user population.

As with the introduction of any new tool into an existing system, the effects are widespread (Chapanis, 1982; Helmreich, 1987; and, London, 1976). The potential for enhancing the productivity and job satisfaction of Aviation Safety Inspectors is great. However, with that potential comes the possibility of either having no effect (because of rejection of the tool) or, worse yet, actually decreasing performance. The PENS project is taking a cautious, iterative approach to design and introduction of the tools. Only through careful cognitive task analysis, rapid design and prototyping, and empirical evaluation will PENS be seen in the eyes of the inspectors as a beneficial cognitive tool, rather than another doorstop or paperweight.

3.8 REFERENCES

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Appendix A, Computer Specifications

Computer #1

Features

Dimensions--1.6" H x 11.5" W x 9.3" D

80386/25 MHz CPU

8 MB RAM (2 MB Std., 6 MB upgrade)

130 MB Hard Drive

Built-in keyboard

External floppy drive (parallel port) standard

Sidelit (backlit) 9.5" 64 shade VGA LCD display (blue) with brightness and contrast controls

Optional built-in FAX/Modem (2400 baud modem/9600 baud fax or 14.4 kbaud modem/9600 baud fax)

Serial port

Parallel port/floppy disk drive port (requires adaptor for parallel port)

Monitor port

1 PCMCIA slot

Battery-operated pen

Computer battery is replaceable

Operating temperature range 41 to 104 degrees F

Storage temperature range -4 to 140 degrees F

Operating relative humidity 10% to 80% noncondensing

Storage relative humidity 5% to 80% noncondensing

Shock tolerance--operating 5g, nonoperating 80g

Vibration tolerance--3-200-3 Hz at 0.4g (operating); 3-200-3 Hz at 1.5g (nonoperating)

Altitude--operating 10,000 ft; nonoperating 40,000 ft

Electrostatic discharge 15kV

Die-cast magnesium and injection-molded thermoplastic case

5 1/2 lbs.

$2796 base price; $4070 configured

Drawbacks

1 hour battery life with standard battery and energy conservation features disabled.

Pen ink is "noisy"; abated somewhat by supplied filtering software.

Keyboard only usable in landscape display rotation.

Other Factors

Pen "feel" simulates a felt tip pen on paper.

Screen is good indoors and outdoors (but has some glare).

Optional heavy duty battery.

Optional cigarette lighter power adaptor.

Opinion

One of the favorites until handwriting recognition produces near 100% accuracy. Even then, it will be a good unit because the keyboard gives the unit more flexibility and because many people can type faster than they can write.

Computer #2 and Computer #3

Features

Dimensions--1.2"H x 11.7"W x 9.4"D

80386/20 MHz CPU

8 MB RAM (4 M Std., 4 M upgrade?)

40 or 60 MB Hard Drive

Transflective 16 shade VGA LCD display (green)--Computer #2

Backlit 16 shade VGA LCD display (blue) with single brightness/contrast control--Computer #3

Serial port through docking strip

Parallel port through docking strip

Monitor port through docking strip

Operating temperature range 41 to 104 degrees F

Storage temperature range -4 to 122 degrees F

Operating relative humidity 5% to 95%

Altitude--operating 9800 ft; nonoperating 40,000 ft

No battery in pen

Rechargeable computer battery is replaceable

Optional FAX/Modem.

4 1/2 lbs.

$5350 configured

Drawbacks

Choice between Flash Disk and hard drive.

Pen "feel" is very slick, uncomfortable.

Parallel port does not support floppy disk drive; one must choose between a fax/modem and a floppy drive controller.

Other Factors

A favorite pen stylus because of slim design, out-of-the-way button.

Battery life of Computer #2 is longest of tested units because display is not backlit.

Terrible sales support.

Opinion

Computer #2 was discontinued while this report was being written. Computer #3 is probably in the bottom third of 386-based machines in terms of features, performance, and price.

Computer #4

Features

Dimensions--1.2" H x 10.9" W x 9.8" D

80486/20 MHz CPU

8 MB RAM (4 MB Std., 4 MB upgrade)

40 or 80 MB Hard Drive

Optional external keyboard

External floppy drive standard

Backlit 9.4" 64 shade VGA LCD display (blue) with brightness and contrast controls

Optional PCMCIA FAX/Modem (2400 baud modem/9600 baud fax or 14.4 kbaud modem/fax)

Serial port

Parallel port/floppy disk drive port (requires adaptor for parallel port)

Monitor port

2 PCMCIA slots

Battery-operated pen

Computer battery is replaceable

Operating temperature range 0 to 45 degrees C

Storage temperature range -20 to 60 degrees C

Operating relative humidity 0% to 85%

Storage relative humidity 0% to 95% noncondensing

3.9 lbs.

$3999 base price; $5770 fully configured MSR

Drawbacks

TBD

Other Factors

TBD

Opinion

TBD

Computer #5

Features

Dimensions--2.1" H x 11.7" W x 9.3" D

80486/20 MHz or 80486/25 MHz CPU

8 MB RAM (4 MB Std., 4 MB upgrade)

80, 120, or 180 MB Hard Drive

Built-in keyboard

Internal floppy drive standard

Backlit 9.4" 64 shade VGA LCD display or 9.4" 256 color Super VGA active matrix display

Optional PCMCIA FAX/Modem (2400 baud modem/9600 baud fax or 9600 baud modem/14.4 kbaud fax)

Serial port

Parallel port

Monitor port

2 Type II or 1 Type III PCMCIA slots

Battery-operated pen

Computer battery is replaceable

Optional second battery

Optional docking station

7.0 lbs.; but display can be removed to function as pen-only tablet

Price TBD

Drawbacks

Keyboard only useable in landscape display rotation.

Other Factors

TBD

Opinion

TBD

Computer #6

Features

Dimensions--1.3"H x 11"W x 11"D

80386/25 MHz CPU

8 MB RAM Std. (up to 20 MB)

80 MB Hard Drive (up to 180 MB)

Backlit/Transflective (backlighting can be turned off) 64 shade VGA LCD display (blue) with brightness and contrast controls

Serial port

Parallel port

Floppy disk drive port

Monitor port

Built-in 9600 baud FAX/2400 baud Modem

"Hot Dock" docking port for power and/or other connections.

Battery-operated pen

Rechargeable computer battery is replaceable; 2 batteries std.

4 lbs.

$2500 base price to VAR; $3500 MSR

Drawbacks

Screen needs constant adjustment; screen is not evenly lit. Pre-production problem?

Pen scratches screen coating. Pre-production problem?

Pen is difficult to retrieve from holder.

Slow hard disk drive.

Other Factors

No button on pen (pen buttons hinder more than they help).

Nice built-in, adjustable handle.

Units manufactured by under contract by large computer manufacturer.

Designed for landscape display rotation, but usable in portrait rotation.

CPU battery life is 2 hours hard use, 4 hours normal use. Well above average.

Opinion

Unit is relatively well-designed, but unspectacular.

Computer #7

Features

Dimensions--1.5" H x 10.6" W x 8.3" D

80386/25 MHz CPU

8 MB RAM (4 MB Std. vs 4 MB upgrade)

40 MB Hard Drive

3.3 Volt "Low Power System"

External floppy drive (parallel port?) standard

Backlit/Transflective (backlighting can be turned off) VGA LCD display (gray-brown) with brightness and contrast controls

Serial port

Parallel port/floppy disk drive port (requires adaptor for parallel port)

Keyboard port

Monitor port

2 PCMCIA slots

Battery-operated pen

Computer battery is replaceable

3.3 lbs.

$3499 base price; $???? configured

Drawbacks

Pen batteries need frequent replacement (e.g., weekly).

Hard disk is largest available for given dimensions, but is still too small.

Other Factors

Screen is good indoors and outdoors.

The 2 PCMCIA slots will allow a data card and a fax/modem card simultaneously.

Not rugged, but 3rd party is designing a "wetsuit", rubber, ruggedized case.

Tested unit was early production.

Opinion

Assuming they can solve the pen battery problems, this will be a nice, small, lightweight, pen-only unit.

Computer #8

Features

Ruggedized

Dimensions--2.0"H x 12.5"W x 10.1"D

80386/25 MHz CPU

8 MB RAM Std.

85 MB or 190 MB Hard Drive

Soft keys built into bezel of display

Backlit 64 shade VGA LCD 10" display (green) with brightness and contrast controls; optional 11.6" SVGA 64 shade display

Built-in 9600 baud FAX/2400 baud Modem Std.; optional 9600/9600 FAX/Modem

Serial port

Parallel port

Keyboard port

Monitor port

Optional docking station

Ballistic-composite main housing with aircraft aluminum and stainless steel fittings

Battery-operated pen

Quick-charge 3 hour computer battery with backup battery.

6.5 lbs.

$5995 base price; $6495 configured w/o docking station; $6990 w/docking station

Drawbacks

Weight.

Although battery monitor indicates over 2 hours of charge, it is closer to 1-1 1/2 hours.

Other Factors

Start-up company; company's only product; difficulty in bringing it to the market.

Optional keyboard unit has floppy drive, ports.

Getting a demo unit was extremely difficult; units received were pre-production. Company started production in 11/92.

Opinion

Ruggedness is continually mentioned as a key criterion for field units; this is a good example.

Appendix B, Evaluation/Implementation Questions

The following questions need to be addressed when specifying a pen computer for the Flight Standards Service:

Environmental Immunity--How resistant is the unit to temperature extremes (e.g., Anchorage in the winter to Puerto Rico in the summer), humidity, rain, etc.?

Ruggedness--Can the unit be dropped? How susceptible is the screen to damage from collision? Will the paint chip from minor collisions? Is a ruggedized case necessary and available?

Harness--Is there a harness or strap to alleviate carrying the unit and preventing damage if dropped?

Weight--Are the units light enough to be carried for an entire work day?

Lighting Conditions--Will current units work in lighting conditions ranging from bright sunlight to absolute darkness?

Display--Is the display monochrome, grey scale, or color? How many shades or colors can be displayed simultaneously? What is the resolution?

Pen--Is there a provision for tethering the pen so that it won't get lost? Will the pens allow user replacement of the batteries, rather than buying a new pen? Is the location of the button on the pen such that it is not accidentally depressed while writing?

Pen Feel--Does the feel of "writing" with the pen on the computer simulate a pen on paper?

Storage Capacity--What is the capacity of the hard disk, in Megabytes?

Speed/Computing Power--What are the fastest and most powerful CPUs available? 80386? 80486? 80586?

RAM--What are the available RAM capacities and speeds? At least 8 Megabytes are required; can more be put in?

PCMCIA card slots--PCMCIA (Personal Computer Memory Card International Association) cards allow peripherals, such as FAX/Modems, CD ROM controllers, and ROM (read only memory), to be easily added to and removed from the unit. These cards are revolutionizing the portable computer industry. How many PCMCIA slots are available?

Keyboard--Is there a keyboard built into the units? Is there a lightweight standard keyboard as an accessory to the units?

CD-ROM Players--Do the units currently support CD-ROM (compact disc, read only memory) players?

FAX/Modem--These allow for communication with computers and other parties over the phone lines. Are they available for the pen computer?

Connectivity--Is the unit capable of supporting a network connection, either through a serial port or a dedicated port? What about wireless connections?

Upgrades--Are there user-replaceable CPUs or other upgrade paths?

Based on in-house evaluations, we recommend field evaluations. However, we can make the following conservative recommendations:

Environmental Immunity and Ruggedness--A ruggedized case that allows one to use the computer while it resides in the case will improve ruggedness and environmental immunity. Most currently available products will function in mist to very light rain. Current pen computers will operate in temperatures ranging from about 20 degrees to 110 degrees Fahrenheit. Because pen computers tend to be very susceptible to damage from dropping, the best approach may be to choose one that is itself semi-rugged, but which has a ruggedized case. A ruggedized case will also allow an inspector to use the unit in the rain, snow, etc. Only one company currently manufactures a unit that is already ruggedized.

Harness--Either the unit itself or a ruggedized case should be equipped with a carrying strap or harness. The currently available ruggedized unit comes with a carrying case that has a strap.

Weight--This is the primary drawback to ruggedized units and becomes a problem when adding a ruggedized case to other units. We think that a unit that does not allow one to remove the ruggedized case will be too heavy for general acceptance. A removable case will allow a minimum weight configuration for most uses, with the flexibility to add the case (and, hence, weight) when required. Current weights range from approximately 3.5 lbs. to approximately 7 lbs. (for the ruggedized unit). A weight of approximately 5 lbs. is probably acceptable, initially.

Lighting Conditions/Displays--Most currently available 80386 based pen computers come with backlit, grey scale, VGA (16 to 64 simultaneous shades of grey, 640 x 480 pixel resolution) displays. Such units allow one to use them in the dark and in bright sunlight. The best such units allow independent control of contrast and brightness. A monochrome display is unacceptable (regardless of resolution); a grey scale, VGA display is acceptable; while color, Super VGA (greater resolution, 256 colors) displays are not currently available, they would be preferred.

Pen--A tethered pen is a little more difficult to use, but it is much more difficult to lose. Given the cost of replacement pens ($75-$100), we would recommend tethering the pen. Again, given pen cost, we recommend that the pen allow user replacement of the batteries. A pen that has a button that prevents one from accidentally depressing it while writing is preferable, but not mandatory (because the pens can usually be rotated such that the button is out of the way).

Pen feel--Ideally, writing on the pen computer would simulate writing with a pen on paper. Some of the available products are better than others in this regard.

Storage Capacity--Current hard disk storage capacities range from 40 Megabytes to 120 Megabytes. While 40 Megabytes could be considered the absolute minimum, the more capacity one can get, the more software programs/tools and data can be stored and used. We would recommend a 120 Megabyte hard drive for now, while keeping in mind that larger capacity hard disks will be available in the future.

Speed/Computing Power--Currently, 80386, 25 Megahertz CPUs are used in most pen computers. However, 80486 and 80586 CPUs with faster clock rates should be available in the near future.

RAM--Because it is likely that the pen computers will be using Windows for Pen Computing as their operating environment, 8 Megabytes of RAM should be considered the absolute minimum requirement. Some manufacturers allow 16 Megabytes or more of RAM. The availability of RAM greatly affects processing speed and response times.

PCMCIA card slots--Most manufacturers offer one PCMCIA slot. Because many desired features of the pen computer could be addressed through the use of PCMCIA cards, two or more slots would be better, although not mandatory.

Keyboard--We recommend that a concealable keyboard be built in, similar to standard notebook or laptop computers; however, the pen computer must be fully functional when the keyboard is concealed. That is, the screen must be visible and allow pen input, even when the keyboard is concealed. The built-in keyboard would allow one to readily enter large amounts of text. Pen computers with built-in keyboards are compact and convenient, whereas detachable keyboards tend to be inconvenient and cumbersome.

CD-ROM--It is becoming increasingly clear that the pen computer will need to support a portable CD-ROM player. For the foreseeable future, a PCMCIA card or a parallel port will support this function. Ideally, a PCMCIA SCSI interface card will be used to drive the CD-ROM because they are faster than parallel port devices. Portable CD-ROM players that use parallel ports are currently available.

FAX/Modem--Most manufacturers offer FAX/Modems either as standard equipment or through a PCMCIA slot.

Connectivity--All pen computers currently supply a parallel port, which would allow connection to a network. We do not recommend that a wireless network connection provide the sole access to networks; a wired connection should be available.

Upgrades--No manufacturer currently supports upgradeable CPU s, but this will likely change. Such upgrades would allow Flight Standards to take advantage of the most recent technology without scrapping the computer itself.

Appendix C, Example Evaluation Form

Please rate the following on a *relative* 1-5 scale, where *1 is worst* and *5 is best*:

	Computer #1	Computer #2	Computer #3	Computer #4
Weight	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Size	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Speed	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Display--inside	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Display--outside	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Pen Responsiveness	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Pen Feel	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Handwriting	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Comfort	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Which product do you prefer?

Computer #1 Computer #2 Computer #3 Computer #4

Which orientation do you prefer?Horizontal Vertical

Do you prefer to have the pen tethered to the unit? YesNo

Do you think you could carry any of these units for a normal work day? Yes No

If a neck, shoulder, or waist strap were available, would you use it? Yes No

Which would you prefer? Neck Shoulder Waist

Would you prefer a rugged unit to one that is less rugged, even though it weighs more? Yes No

What are the three largest drawbacks to all of these products?1. _____

2. _____

3. _____

Would you prefer using a smaller, more lightweight product (e.g., less than 4 lbs.) with fewer software tools (e.g., no word processors, spreadsheets, etc.) available or a heavier product with more tools?

Lightweight, Few tools Heavy, More tools

Would you prefer using a smaller, more lightweight product (e.g., less than 4 lbs.) if software tools available on the pen computer (e.g., word processors, etc.) were very different from those used in the office or a heavier product that used the same software as used in the office?

Lightweight, Different tools Heavy, Same tools

Would you prefer using a smaller, more lightweight product (e.g., less than 4 lbs.) or a heavier product with a built in keyboard?

Lightweight, No keyboard Heavy, Built in keyboard

Would you prefer using a smaller, more lightweight product (e.g., less than 4 lbs.) with an operating environment (e.g., DOS) that was different from the office computer operating environment (e.g., Windows) or a heavier unit with the same operating system?

Lightweight, Different environment Heavy, Same environment

Would you prefer using a product that was light, but not rugged, or a heavy, rugged product?

Lightweight, Fragile Heavy, Rugged

Would you prefer a standard laptop computer, without a pen (ie. no handwriting input), to the pen computers?

Yes No

Appendix D, Summary Minimum Hardware Specifications

Currently, two different pen computer specifications are appropriate; one specification describes what is available today, while the other describes what may be cost effective in the future.

Specification for available equipment:

Pointing device (e.g., pen, mouse, trackball)

Keyboard input device (either affixed, detachable, or "virtual")

Storage device (e.g., 40 Megabyte or greater capacity hard disk, PCMCIA card)

20-25 Megahertz, 80386 CPU

Display device: grey scale, backlit, VGA

Adjustable screen brightness and/or contrast

8 Megabytes RAM, minimum

Serial, Parallel communications ports (allows network connection, for example)

Replaceable, rechargeable batteries with at least one hour of operational capability without power-saving options in effect

Battery charger/power supply

Weight less than 8 lbs.

Floppy disk drive (external)

External CD ROM drive

Optional:

FAX/Modem

Docking station--should include: card cage, keyboard, floppy drives; may also include: color Super VGA monitor, large capacity hard disk, tape backup drive

External monitor connector

Additional PCMCIA slots

Ruggedized carrying case/strap

Specification for equipment available within 1-2 years:

Pen pointing device

Attached keyboard input device that accommodates either a horizontal or a vertical display orientation

100 Megabyte or greater capacity hard disk

2 or more PCMCIA card slots

33-50 Megahertz, 80486 or 80586 CPU

Color Super VGA monitor

Adjustable screen brightness and contrast

16 Megabytes or more RAM

Serial, Parallel communications ports on the unit

Replaceable, rechargeable batteries with at least three hours of operational capability without power-saving options in effect

Battery charger/power supply

Weight less than 3 lbs.

Bar code and/or magnetic strip reader

Internal floppy disk drive

CD-ROM drive (possibly internal)

FAX/Modem

Wireless LAN ("WaveLAN")

Internal card slot (e.g., for a network card)

Docking station--including, but not limited to: card cage, keyboard, floppy drives, color Super VGA monitor, large capacity hard disk, tape backup drive

External monitor connector

Ruggedized carrying case/strap