Chapter 1
ADVANCED TECHNOLOGY IN AIRCRAFT MAINTENANCE: THE TURBINE REPAIR AUTOMATED CONTROL SYSTEM (TRACS)

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1.1 INTRODUCTION

Repair shops form a critical component of the maintenance and inspection environment. The increasing complexity of information demanded by mechanics as well as the accuracy required for accountability necessitates the use of computerized job aids. Such a system has a potential to reduce error, mitigate such error if it occurs, and generally promote safety and efficiency in repair shop environments.

Under grant from the FAA Office of Aviation Medicine, Galaxy Scientific Corporation conducted task analysis and job aiding research to identify the human factors issues related to communication and information flow in the turbine repair shop at Delta Airlines. Implementing advanced technologies used and proven in earlier FAA projects, we have created prototype software running on a pen-based computer designed to support maintenance technicians working in the repair shop environment. The Turbine Repair Automated Control System (TRACS) was designed to assist the mechanics and technicians with a number of traditionally separate tasks. The features include:

- Automation of the current paper-based system of sequencing repair steps.
- Aiding in the decision-making process during sequencing of steps.
- Full hypertext manual documentation with links directly within the repair sign-off process.
- Graphical methods of selecting parts on a turbine module for repair and rebuild.
- Ability to carry the pen computer easily to the point of repair for direct entry of critical. measurements and other data, reducing the possibility of error.
- Friendly, easy to use interface in a point and click window environment.
- Full tracking of parts through the entire repair process, with access to all time and cycle limit information.

1.1.1 Research Goals

The maintenance and repair of aircraft has a direct impact on flight safety. The systems which airlines use to maintain aircraft are frequently inspected by the FAA for obvious reasons. However, recent technological changes have provided a means by which airlines can significantly improve these systems. Many airlines are embarking on implementing new technologies for documentation, process control, compliance, and cost control. ACs which govern these new technologies are slowly being created, but not fast enough to keep up with the pace of change.

The current research attempts to evaluate some of the newer technologies to identify what will and will not be useful to the Airline Maintenance Technicians (AMT) who must use them. The research also addresses the regulatory and safety issues that will be involved during the implementation of new technologies in the maintenance workplace.

To that end, the following research agenda was followed:

- Delineation of the research scope by identification of target shop and parts.
- Task analysis of the AMT job to identify potential redundancies and error-prone situations.
- Information needs analysis so informational requirements of the AMT will be known.
- Collection of all relevant forms and documentation required for maintenance of target parts.
- Three phase, iterative development of a prototype software system to aid AMTs.
- Final evaluation of the prototype system.
- Communication of results to industry and the scientific community.

1.2 METHODOLOGY

The methods used for the present study involved three steps. The first step was a fairly high-level task analysis which helped us to identify the major divisions of labor within the rotor shop. The task analysis gave us a good idea of the general tasks which each category of worker was responsible for completing.1

The next step was a detailed information flow analysis, which involved the collection of all of the types of documents used by the workers in the rotor shop and the routes those documents followed. We also analyzed how the documents were appended and updated during the repair process.2

The final step in our research was to design a prototype software system using human-centered design principles. We developed the prototype with the continuous feedback from the technicians who would eventually be evaluating the usability and utility of the system.

The following subsections describe the environment in which we conducted our research, the results of the task analysis and information flow analysis, issues raised during these analyses, and a diagram of the repair process. The final subsections describe the consequent user requirements and scope of the prototype design.

1.2.1 Description of the Maintenance Environment

After presentation of the research objectives to Delta Air Lines, members of the engine planning group agreed to allow researchers to use the Rotor Repair Shop as a test bed for the prototype technology. The rotor shop services turbine and compressor modules of jet engines manufactured by General Electric. The rotor shop is housed in the Technical Operations Center, Atlanta, GA. This is Delta's primary maintenance and repair facility. The rotor shop occupies about the space of a football field, including areas for administrative paperwork, mechanical repair, inspection, and storage of parts. The shop is surrounded by many support shops responsible for cleaning, machining, plating, heat-treating, and other jobs related to the repair of jet engines.

One of the reasons for the choice of the rotor shop was because of the historically difficult methods of routing parts for repair, sometimes resulting in rejected parts. The difficulty in routing parts stems from a complex method of repair which must be configured separately for each part. Any system which could simplify or make easier the routing process would potentially decrease human errors as well as improve overall flight safety.

1.2.2 Task Analysis

Because the final objective of the project was to build a prototype system to aid mechanics in repairing parts, we first needed to understand the job as thoroughly as possible. During May and June 1996, we traveled multiple times to the work area and interviewed the AMTs as they were completing tasks. We identified five job classes in the rotor shop. Following is a task description of those jobs.

Work Center Personnel

Major duties of the work center person are:

- Locating parts
- Scheduling parts
- Assembling paperwork needed to repair parts
- Ensuring compliance with regulations by checking for necessary sign-offs
- Controlling part inventory

Inspector

Major duties of the inspector are:

- Visually inspecting parts for flaws and service needs
- Taking and recording measurements to determine whether a part is within limits
- Final inspecting of all parts returning from repair and rework
- Routing parts that require additional rework

Lead Mechanic

Major duties of the lead mechanic are:

- Keeping time and attendance for team members
- Assigning mechanics to jobs
- Checking in all rotors
- Checking compatibility of parts
- Completing daily scheduling for rotors
- Attending rotor repair workscope meeting
- Monitoring manuals
- Originating non-routine repair paperwork
- Inspecting and ordering parts for rebuild of modules
- Final checking and assignment of parts for assembly

Mechanic

Major duties of the mechanic are:

- Following current methods of repairing parts
- Maintaining knowledge about parts
- Routine cleaning of parts
- Servicing parts
- Signing off when steps are completed
- Logging time for repairs

Mechanic Assistant

Major duties of the mechanic assistant are:

- Cleaning parts as required
- Checking and sorting hardware
- Assisting with job duties of the inspector, lead, mechanic, and work center

1.2.3 Repair Process Diagram

Following is an illustration of the process by which modules and parts enter the rotor shop, are disassembled, inspected, routed for repair, and reassembled. It represents the process by which a module is serviced, and the moments at which information is accessed for decision-making. Included in the illustration is the information used during particular steps. These sources of information are contained in boxes resembling gray slips of paper.

The modules are broken out of the engine in the engine shop. A meeting is held to determine the level of repair or maintenance needed for the module. The module is sent to the rotor shop, where it is checked in by the work center, inspected, cleaned, and broken down to component parts. The parts are inspected again and routed for repair. An intermediate inspection takes place to determine whether all repairs have been effectively implemented. The parts are put back together to form the module, and final inspection occurs which allows a module to return to service.

In the diagram, double dotted lines represent the imaginary fence we placed around the rotor shop. Inputs from the cleaning and testing of the part are included in the repair process, but these shops were not involved in the development of the prototype.

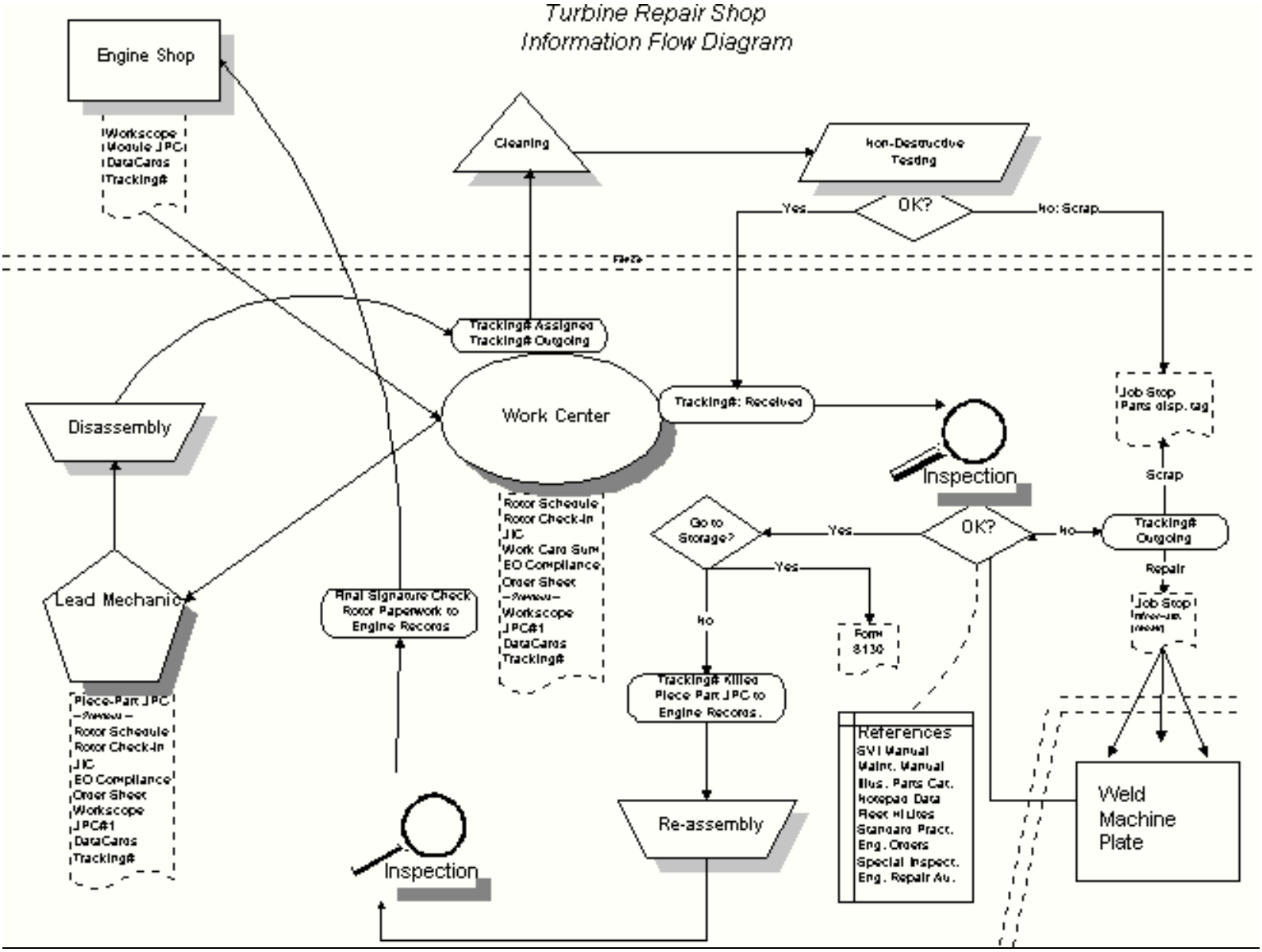


Figure 1.1 Process and Information Flow in the Rotor Shop

1.2.4 Information Analysis

The next item on our research agenda involved an information analysis. This process goes beyond observing what the AMT does during normal work time, but finding out what information is needed to get the job done, and how information flows within the repair system. This was a critical analysis, since the technology we chose to implement would depend on the type of information used in the job. We first identified all of the documents used in the repair shop (such as manuals, orders, repair routing sheets, etc.) and then closely monitored the way the documents were used, processed, and updated.

Table 1.1 describes most of the documents required for the repair of parts and modules in the rotor shop. The interested reader should refer to the help system contained in the prototype for a more thorough treatment of the forms and documents used in the rotor shop.

Table 1.1 Forms and Documents Related to the AMT Rotor Repair Shop

Job Instruction Card	The Job Instruction Card (JIC) controls the assembly and disassembly of the High Pressure Turbine module and its component parts. Mechanics and Lead Mechanics must follow and sign off each step.
Order Sheet	When a module enters the repair shop and is visually inspected, the inspector or lead mechanic determines which parts must be taken out of the module to be serviced. The order sheet is the method by which parts are requested to replace the parts that are pulled from the module for repair.
Shop Order	After a part has been ordered on the Order Sheet (indicating the part needs to be serviced), a Shop Order is generated for the repair of that part. The Shop Order controls many aspects of the repair of a part. The Shop Order begins as a template for a standard repair of the part. To customize the shop order for a specific repair, the lead mechanic must configure the template. This process is called Stamp Steps, because on the traditional paper-based Shop Order the mechanics actually used a rubber stamp to indicate which steps were required for repair.
Job Stop Card	Sometimes a part becomes so damaged that it cannot be repaired, or it will be delayed for an extended period of time. When this happens, a Job Stop Card must be completed in order to let people who may be waiting on the part know that the part has been delayed.
Engineering Order	An Engineering Order (EO) is a required repair of a specific part type, usually mandated by the manufacturer or the FAA. This may occur because of some defect or other event related to the performance of the part.
E.O. Compliance	A form requiring a signature which indicates that a regulatory Engineering Order has been complied with correctly.
Engineering Repair Authorization	An Engineering Repair Authorization (ERA) is a specific, one time authorization of a repair.
Engine Manual	This reference document provides exact instructions for the repair of a particular part or process. It includes tables and technical diagrams.
Process Standard	These are FAA approved standard operating procedures which are specific to individual airlines.
Illustrated Parts Catalog	This reference document gives information about the configuration of various engine parts, allowing mechanics and inspectors to determine the proper compatibility of components.
Form 8130	An internationally recognized standard form for the documentation that a part has been serviced by an authorized repair station. Parts can be resold to other airlines by using this form.

Issues Observed from Information Flow Analysis

Based upon our analysis of the documents used in the rotor shop and the methods by which they were updated, we observed some potential areas that could be improved with the use of a job aid system. The following paragraphs describe those broad areas that were identified.

Gathering Information

Because of the many sources of reference information that AMTs require to complete their work, a great deal of time is lost gathering that information. In the repair shops, time is a critical factor in maintaining commercial viability while at the same time maintaining a proper level of safety. These two forces are opposed to one another. Providing the information necessary in a timely fashion would greatly increase the overall safety of the operation. Most repair stations keep their reference manuals on microfiche or paper. Providing the same information at a single location in a digital format would greatly increase the speed of information retrieval.

Recording Information

At the time of the analysis, we noted that all of the recording of data such as part measurements, serial numbers, historical cycle information, etc. was accomplished on paper forms. These forms are eventually stored in the engine records area after a part has been serviced. Therefore, logged data is unavailable during later repairs and previous part servicing histories are not utilized. Accessing the data during FAA inspections is also cumbersome, though within regulation. Providing electronic forms for logging data would eliminate the need for the deep storage of paper records, and would provide the AMT with historical records on demand.

Redundancy

Since most of the repair system is recorded on paper, the process of customizing that system for each part is extremely tedious. Part routing is accomplished by stamping the appropriate steps required for repair if the part requires a standard repair. If the part requires additional rework, the routing process becomes significantly more complex. A large part of the handwritten information is redundant, such as the numerous times a technician must write the same serial number on multiple forms. Time could be saved and errors could be reduced if electronic forms were provided which automatically transferred information across multiple forms. Data sharing would reduce routing errors, allowing AMTs to focus on safe, quality work.

Information Loss

AMTs must handwrite all changes to the standard repair process (this process is called rerouting) and are not allowed to reuse previous routing work from similar repairs by federal regulation. This represents a type of expert information loss. Creating a new routing document is necessary for a paper based process of repair; allowing technicians to use copies of previous reroutes would present a safety risk because copied information could not be altered to fit the current repair. However, if the technicians were allowed to create an electronic "master copy" of reroutes (also known as a template) and had the ability to quickly make changes to this master copy, there would be no reason to create new routing documents whenever there was a deviation from the standard routing. In fact, this would significantly improve safety by allowing the AMT to utilize the latest knowledge in completing the job. This information could also be made available to technical publishers as well as regulators, increasing the likelihood that the information is current.

1.2.5 User Requirements

Based on the observations listed above, we identified a set of challenges for designing the prototype:

- Provide all reference information needed by the AMTs in a digital, searchable format.
- Provide easy links to reference information at the moment it is needed.
- Create an electronic system for part repair which corresponds to the paper-based system.
- Make the electronic system intuitive and easy to use.

- Implement the electronic system on portable computers so that AMTs can record critical data at the point of measurement.
- Eliminate redundant data logging.
- Give the user the ability to track part status and comments from other shops at any time in the repair cycle.
- Provide a method of updating process control information.
- Give experts the ability to save routing knowledge and routing templates for use in future repairs.

1.2.6 Research Scope and Target Parts

Since the research objective was to develop a proof-of-concept prototype, we decided to limit the scope of the prototype to include only two parts that are repaired by the rotor shop. The two parts selected were both from the General Electric CF6-80 jet engine, High Pressure Turbine (HPT) module. We selected the Stage 1 Shaft/Disk and the Thermal Shield because these parts are two of the most expensive and difficult to route parts in the shop. The selection of parts was made primarily by the AMTs who assisted us in our research.

The scope of the project was also limited by the beginning and endpoint of the repair process. Although theoretically we could have followed the parts from the moment they are removed from the aircraft to the time they return, we made the conscious decision to define our research universe more narrowly. This gave us the opportunity to better control the inputs and outputs of the system, as well as maintain a strong focus on the actual repair of the parts. Thus we drew an imaginary fence around the rotor shop and its support shops (Figure 1.1). The prototype software tracks HPT modules from the time they are delivered to the rotor shop, disassembled into components like our target parts, repaired, put back together, and sent out of the shop again.

1.3 PROTOTYPE DESIGN

The design of the prototype occurred in three distinct stages which we called initial test, intermediate test, and final evaluation. The iterative nature of the design allowed us to get continuous feedback from the same group of AMTs who had given us information about their jobs and repair process. By giving the technicians the chance to make suggestions for the software, we had a much better chance of creating software which was properly functional and user friendly. This iterative process of creating software, in which the end user has a great deal of power in determining interface and functionality, is termed user-centered design.[3,4,5]

1.3.1 Initial Designs

The first major function we decided to develop for the prototype was the repair process of the two target parts. This process was primarily controlled by the Shop Order, which is simply a sequence of steps for the repair of the HPT parts. We gathered together the Shop Orders for the Thermal Shield and the Stage 1 Shaft/Disk and created an electronic version of this sequence with the ability to sign off each step.

The Main Menu (Figure 1.3) of the program allowed technicians to move between various functions of the program. The Order Sheet (Figure 1.4) allowed technicians to graphically identify which parts of the module need to be removed for repair. In addition, we created a version of the Data Cards which described time and cycle limits for the parts. These data cards assist the technicians as they are routing the part. Part routing refers to the task of identifying which repair steps are required to make the part serviceable. The method by which a technician routes a part is by "stamping steps" on the shop order with a personalized rubber stamp. These stamps flag the mechanics who will be completing the work.

The Shop Order (Figure 1.5) was significantly improved based on recommendations to include inserting, moving, changing, and deleting steps. The ability to short sign a step was added. Digital reference documentation was included as well for both of the target parts (Figure 1.2). The ability to view the appropriate reference from within the Shop Order form and to click on a button and retrieve the actual document, was seen as a great improvement. With this fairly simple addition to the software, feedback from the AMTs was extremely positive. In fact most of the AMTs asked when the system was to be implemented on the shop floor. We continued to point out that the prototype was designed for proof-of-concept, and that the airline partner would have to be the managers of any change to its current system.

1.3.2 Final Design

At the time of the final evaluation, we had implemented all of the suggestions for improvements given during the initial phases of design. The Repair Code Editor was the most recent change to the software. This feature allowed the AMT to configure templates for the repair of a particular part. There were two components to the editor -- Presets and Repair Codes.

The Presets window (Figure 1.6) allows the AMT to "stamp steps" within the original Shop Order and save that series of activated steps for future use. A menu of saved Presets is available at the time the AMT needs to stamp steps. By choosing one of the Presets, the technician automatically stamps all steps for that configuration rather than having to stamp each step individually.

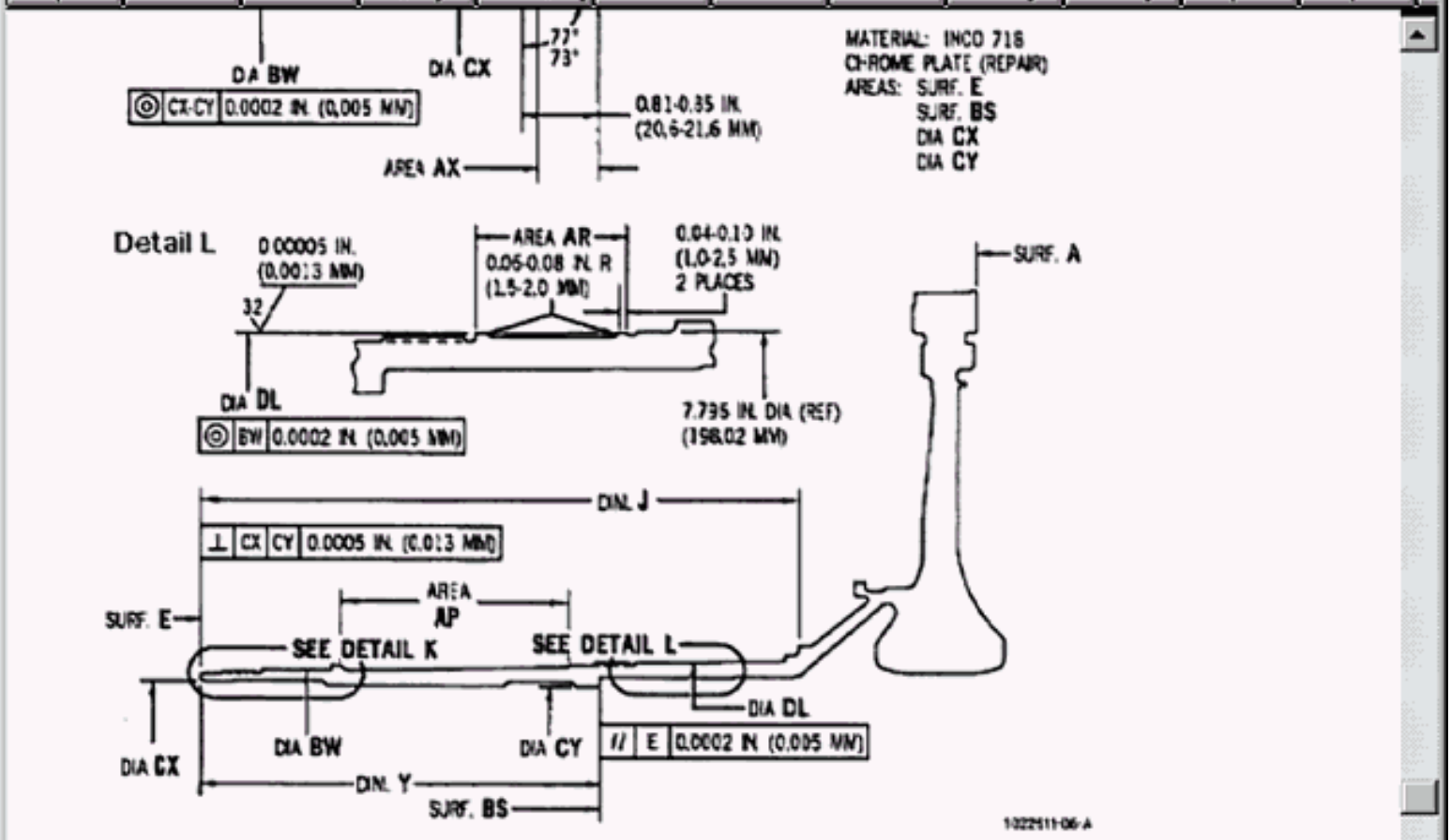
The Repair Codes window allows the AMT to create a customized sequence of repair steps which could be saved for later reroute work. For example, rather than creating and inserting steps one at a time on a shop order, the AMT can simply choose a previously saved Repair Code, and insert the whole batch of steps at once.

The interface was significantly altered as well to include such features as editable fields for part information on the Header window of the Shop Order. Use of panes within windows was another feature added to the software to increase the legibility and organization of individual screens. Buttons were changed to maintain consistency throughout the program, and a full help system was added. These features improved the overall usability of the software. Following are some sample screens from the TRACS software.

Folio VIEWS - [Turbine Online Manual]

File Edit View Search Layout Customize HitList Window Help

Open Save Contents Query Clear Query Hits Codes Level Para Style Char Style Jump Dest Jump Link



Chrome Plate and Machine Diameters DL & BW

Record: 792/953 Hit: 0/0 Query:

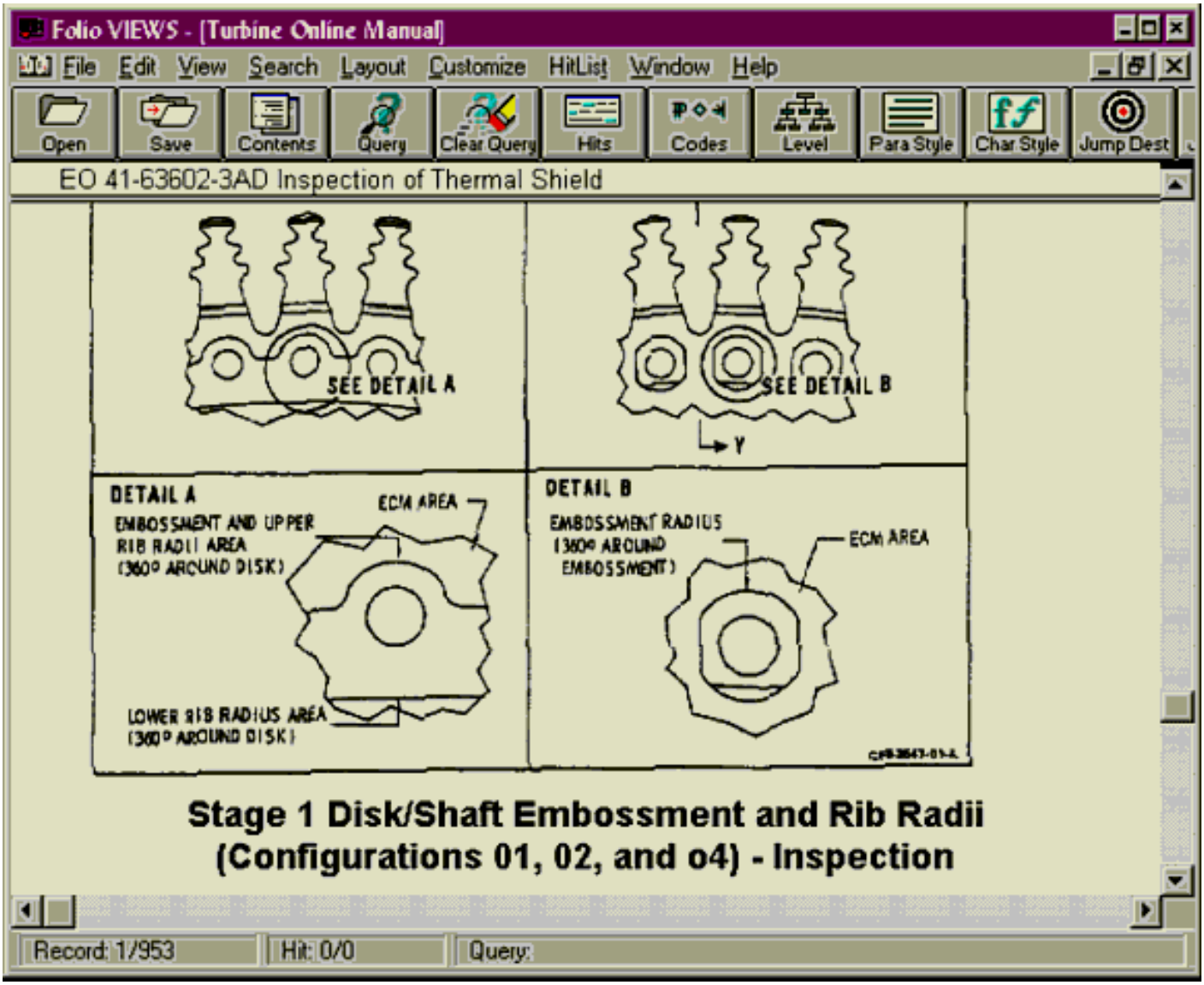


Figure 1.2 Example Screens from the Digital Engine Manual

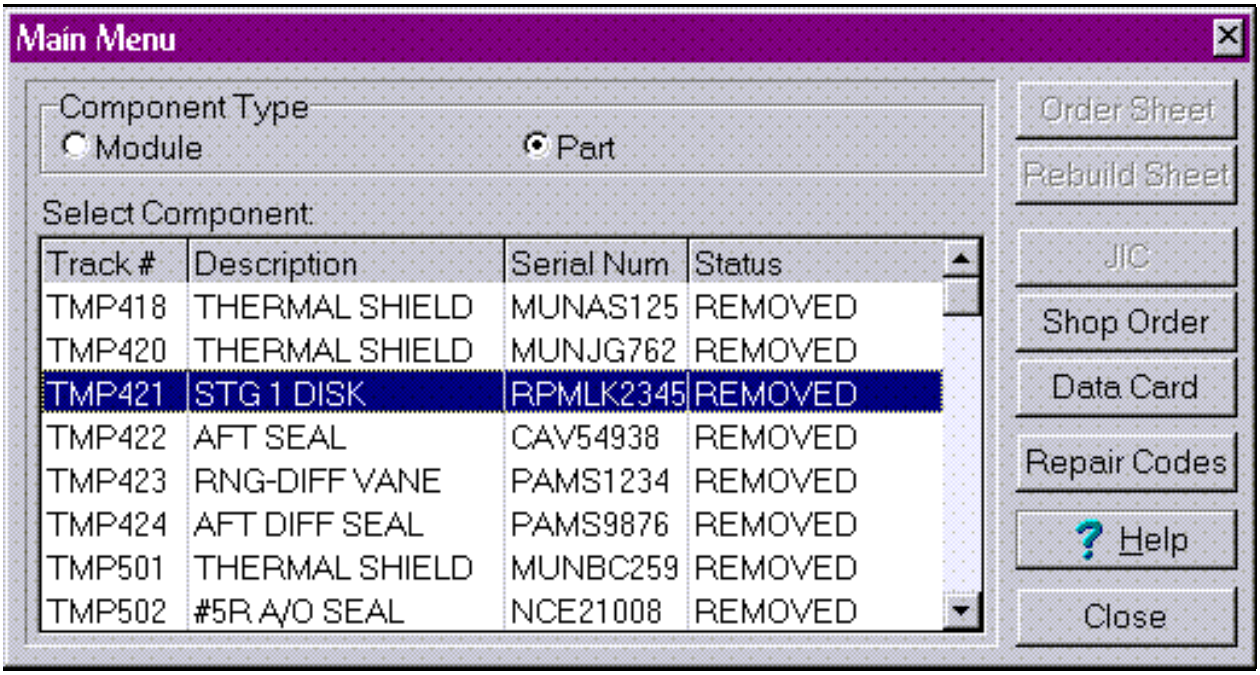


Figure 1.3 TRACS Main Menu

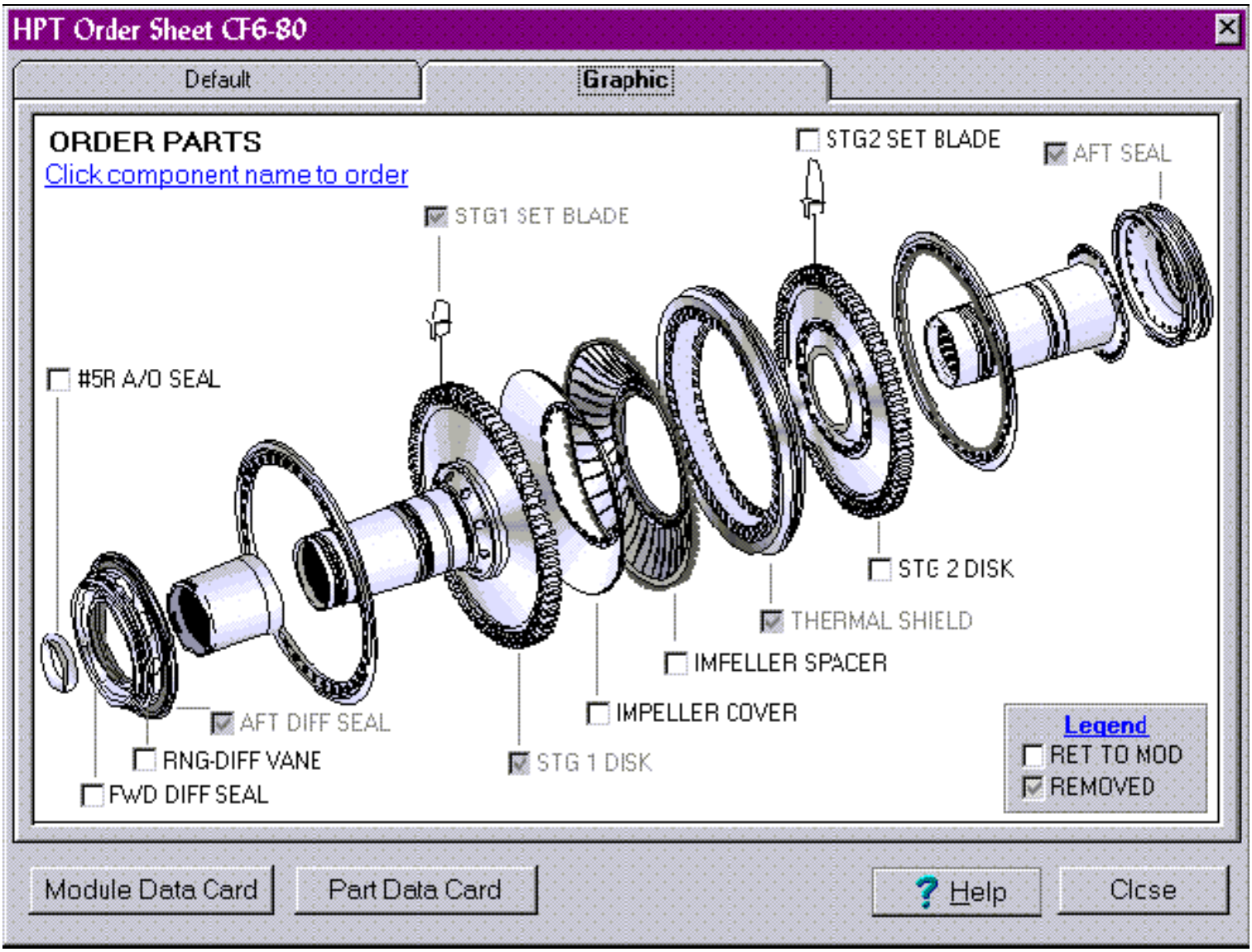


Figure 1.4 High-Pressure Turbine Module Order Screen

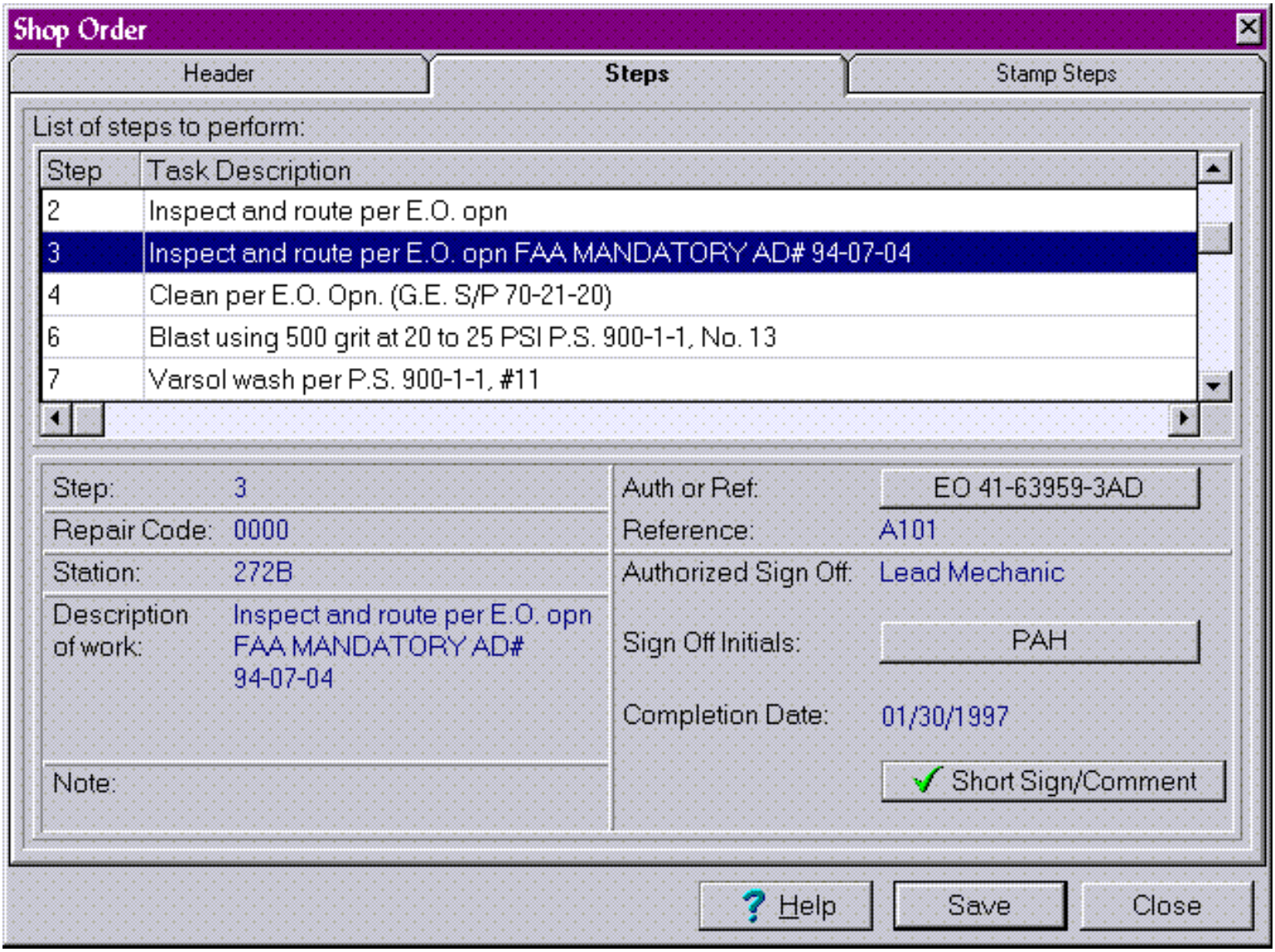


Figure 1.5 Shop Order with Active Repair Steps

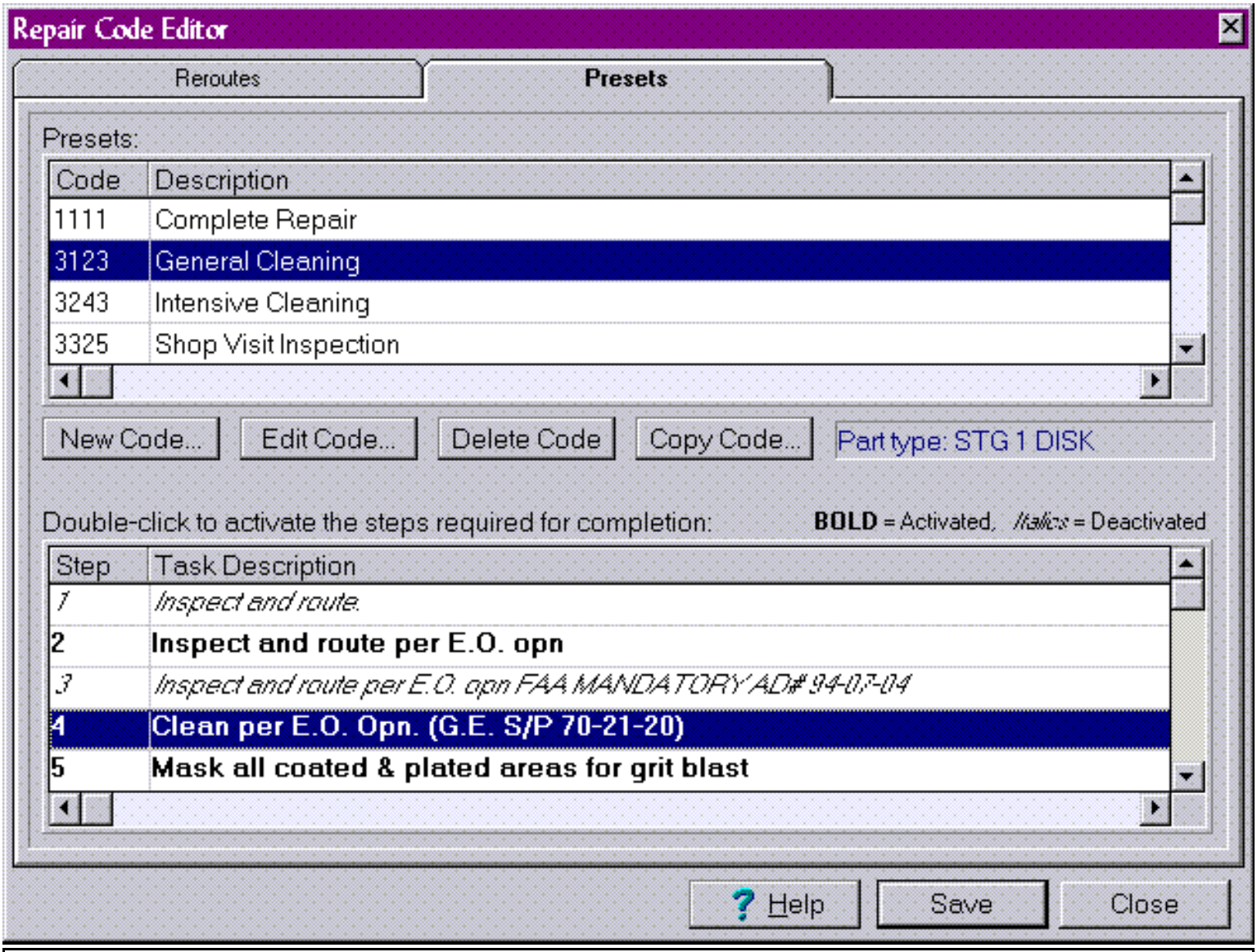


Figure 1.6 Repair Code Editor: Presets

1.4 PROTOTYPE EVALUATION

The evaluation of the software took place from December 12 through December 18, 1996. On the first day of the evaluation, the morning was spent demonstrating the features of the software to the technicians, and providing them with time to get familiar with the hardware and software. The software was provided on a Fujitsu Stylistic 500 pen computer, which contained a 50MHz Intel 486/DX processor. One pen computer with pen, keyboard, carrying-case, and portable printer was given to the technicians for evaluation over the next four days. Technicians were asked to use the software for a period of one or two hours during the course of a normal workday, and simulate an actual repair of a module and parts.

Short evaluation forms were completed after the first morning of the demonstration to get initial impressions of the software usability and functionality. Longer evaluation forms were left with the technicians for completion after they had finished the simulation of repairing a part. A verbal feedback session was conducted on the morning of December 18 in order to capture information that would not be elicited on evaluation forms. The session was taped with the permission of all present at the meeting. The forms and the hardware were picked up on the afternoon of December 18.

1.4.1 Results and Discussion

Both written and verbal feedback was collected concerning the usefulness and usability of the software. Evaluations also included comments about the pen computer hardware. The following sections describe the feedback received from technicians and work center personnel.

Usability Analysis

It should be noted that the present research should be considered a case study, since only one shop was chosen for the design of the prototype, and within the shop only one representative of a particular job class could participate in the evaluation. This was due to real world constraints on production and turnaround time for the technicians. Even with this limitation, results of the evaluations were very encouraging.

Results from the preliminary evaluation form were divided into two categories: Work Center responses and Mechanic/Lead Mechanic/Inspector responses. This was due to the fact that the task analysis and the software were focused primarily on the mechanics, lead mechanics, and inspectors. Functions for the work center personnel were only included if they related directly to the other jobs. Therefore, many of the work domains for the work center personnel were not represented in the software and many questions on the survey did not apply to their job. Responses from this group should be considered with caution.

All questions were rated on a scale of 1 to 5, with 1 being strongly disagree, and 5 being strongly agree. All questions (except three, which were reverse coded) were worded in such a way that a response closer to 5 was a positive evaluation. For example, the first question was "Having reference information (Engine Manuals, EOs) available within the program would make routing parts easier."

Results of the initial evaluation and final evaluation are presented in Figure 1.7. Responses indicate that in most domains, evaluation of the software was highly positive. This is demonstrated by the fact that average responses to domain questions were well above the midpoint of the scale in the majority of the domains.

In Figure 1.7 the leftmost pair of bars show the results of the evaluation given immediately after the demonstration. The remaining pairs represent domains of the final evaluation, which occurred one week later. Lighter colored bars are average responses from the work center personnel, and darker colored bars are average responses from the technicians. The domains of the final evaluation were:

- Utility Impressions - the "usefulness" of the software.
- Hardware - the usefulness and usability of the pen computer in relation to the job at hand.
- Productivity Enhancement - the ability for the software to meet objectives and increase personal productivity.
- Speed/Look and Feel - the time it takes to move between areas of the program, and the aesthetic design.
- Usability - the ease with which individual functions and screens are used.

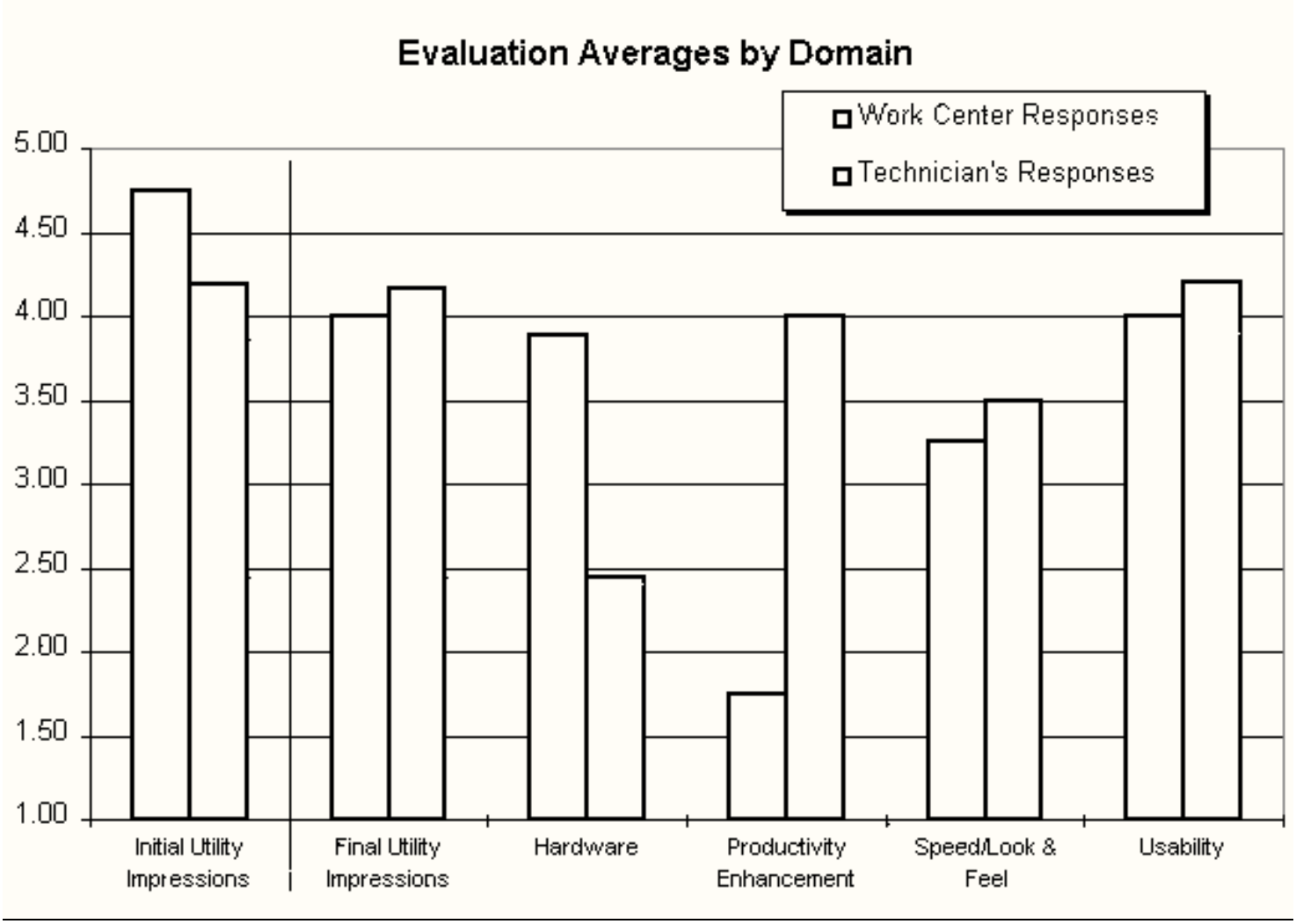


Figure 1.7 Results of the Evaluations

Results indicate that users found the software to be highly useful and usable. The only areas in which the average response fell below the midpoint (average) of the scale were the technicians' ratings of *hardware* and the work center personnel's ratings of *productivity enhancement*. Because verbal feedback explained both of the results, these issues will be addressed in the verbal feedback section.

These results are clearly positive and indicate that participants overwhelmingly viewed the software as an improvement to their current method of completing work.

Verbal Feedback

According to the surveys, technicians rated the pen hardware poorly. The reason for this was discussed at length in the follow-up meeting. Technicians discovered that the handwriting recognition software was not able to understand their handwriting on many occasions. This is a common complaint about handwriting recognition, and studies have indicated that users become more proficient with practice. Given the brief span of time for evaluation, this result is predictable. Mechanics and inspectors both agreed that a better hardware solution would be a desktop or a laptop computer, since keyboard input is preferred. This group also made the comment that their jobs mostly occur in a single area or workspace, and that having to move back to a workbench to enter data would not be problematic.

It should be noted that the work center personnel gave a much better rating for the pen computer. This is because they tend to move around the work facility much more than inspectors or mechanics. They are responsible for locating parts and modules in various storage areas, and believed that the use of a pen computer would be helpful. However, they also noticed difficulty with handwriting recognition. The tentative conclusion from these results is that pen computing devices can be implemented successfully so long as the job requires high mobility, and the amount of handwriting recognition necessary for inputs in minimized.

Other comments expanded on the fact that TRACS was not specifically designed for the work center personnel. The researcher's focus was on the mechanic, lead mechanic, and inspector jobs. One comment pertained to the method of rerouting and saving routing work, which was seen to be especially useful and well implemented. The ability to point and click to sign off and stamp steps was seen as a great benefit. Some improvements suggested were the creation of a menu containing all of the process standards required for routing, and also a digital version of the workscope.

1.5 CONCLUSION

Overall, the development and testing of the prototype was viewed as a success. There are many issues to confront when moving from a prototype project to a real-world implementation. The most complex issue is the connection of many sources of data. Users receive information from at least 10-12 different databases or sources during the course of a normal workday. Creating links with this information, making sure it is current, and presenting it in a format that is usable is not an easy task. With the constant push toward reduced repair cycle times, these issues will continue to surface. Developing prototype software which attempts to address the issues is a good method of learning the difficulties associated with making the transition to a paperless workplace.

1.6 FUTURE STEPS

A great deal of interest was generated following the testing of the prototype, and Delta Air Lines is currently embarking on their own pilot project which implements many of the concepts identified and developed in the rotor shop. During the course of the work, other airlines were identified who are moving in similar directions.

In the coming year we are planning to present the results of this research to a number of industry conferences. Capitalizing on some of the ideas from the project, we are planning to do a benchmarking study to determine the extent to which airlines are implementing these types of technology in their maintenance environments. This will provide us a rich context to explore solutions to the complex problems associated with automation and information delivery, with the explicit intention of increasing safety in aviation maintenance and repair.

1.7 ACKNOWLEDGMENTS

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Thanks to all of the people who advised me on how to get started with the project. I must also commend the hard work of all members of the TRACS team, each of whom did an excellent job.

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