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Survey of Aviation Maintenance Technical Manuals, Phase 3 Report: Final Report and Recommendations

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16. Abstract

This report contains the results from the final phase of a three-phase research effort. Phase 1 of this research effort surveyed the procedures used by five aircraft manufacturers to develop maintenance documentation. Several potential human factors issues were identified in the processes used by these manufacturers to develop their maintenance manuals. The issues included the reactive rather than proactive use of user evaluations, the limited use of user input and procedure validation, no systematic attempts to track errors, and the lack of standards for measuring document quality. In Phase 2, a written survey was used to solicit information about user perception of errors in current manuals, manual usage rates, and general manual quality. On-site interviews of technicians were also conducted to gather feedback about the types of problems encountered with manuals, the associated impact, and suggestions for improving manuals. Feedback was obtained from technicians responsible for maintenance on a wide variety of Title 14 Code of Federal Regulations Part 25 aircraft. Survey results revealed that, although user evaluations of the accuracy and quality of technical manuals are generally good, they rate manuals as having poor usability. Comparing the results of Phase 1 to the Phase 2 survey results supports the need for a higher level of user involvement during the document development process. In this report, a series of recommendations are outlined to address problem areas identified in Phases 1 and 2. It is recommended that (1) manufacturers and operators improve communication between technicians submitting change requests and technical writers to ensure prompt feedback of actions, (2) maintenance procedures be validated using standard human factors techniques, (3) the industry cooperate in the development of a system akin to MSG-3 for identifying maintenance procedures that should be systematically validated, and (4) manufacturers maintain databases with a history of user-reported errors, feedback to the user, and actions taken. By tracking the history of user error reports, manufacturers can then validate maintenance procedures that have the greatest potential impact on safety or economics. Finally, an example is described (using the MSG-3 process) of how these recommendations may be implemented.

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EXECUTIVE SUMMARY

This is a final report of a three-phase project. In this report, a series of recommendations are outlined that address a number of shortcomings in how aircraft manufacturers develop aircraft maintenance documentation. In Phase 1, a number of problems were documented, including the reactive rather than proactive use of user evaluations, the limited use of user input and procedure validation, the absence of systematic attempts to track errors, and the lack of standards for measuring document quality. In Phase 2, a survey of aircraft technicians revealed that, although user evaluations of the accuracy and quality of technical manuals are generally good, the manuals themselves were noted as having poor usability. In light of these deficiencies, it is recommended that (1) manufacturers and operators work to facilitate communication between the technicians submitting change requests and the technical writers making the changes to ensure prompt feedback regarding actions to be taken, (2) maintenance procedures be validated by technicians using standard human factors techniques, (3) the industry cooperate in the development of a system akin to the Maintenance Steering Group (MSG) to identify maintenance procedures that should be systematically validated and, (4) manufacturers should maintain databases with a history of user-reported errors, feedback to the user, and actions taken. By tracking the history of user error reports, manufacturers can target maintenance procedures for validation that have the greatest potential impact on safety and/or economics. This information can also be used to develop more meaningful metrics of manual quality. Finally, an example is described (using the MSG-3 process) of how these recommendations may be implemented.

1. INTRODUCTION.

The Federal Aviation Administration (FAA) has sponsored a number of research projects [1 and 2] addressing issues related to maintenance data and ways to improve the reliability of this documentation. FAA research is motivated by several factors including the FAA goal [3] to "reduce the fatal accident rate for commercial air carriers by 9 percent from a 1994-1996 baseline of 0.037 fatal accidents per 100,000 flight hours" and accident investigations wherein maintenance procedures and documentation were cited as potential contributing factors. Prior to the events of September 11, 2001, it was projected that by 2010, given the forecasted increase in air traffic and the current accident rate, one aircraft accident would occur each day. The current project is a small part of a larger multifaceted FAA research program investigating ways to improve aircraft safety.

The current report summarizes a set of recommendations derived from an FAA-sponsored research project [4 and 5]. The purpose of the research project was (1) to investigate how maintenance documentation is developed by original equipment manufacturers (OEMs) and (2) to investigate user satisfaction and usability problems users encounter when using the documentation. Technical reports describing the Phase 1 and 2 findings of this research project [4 and 5] are available from the FAA.

In brief, the earlier investigations revealed that each manufacturer uses a set of unique procedures, computer applications, and development guidelines for their technical manuals. They each maintain detailed procedures and sophisticated software applications to minimize the inclusion of incorrect technical information in fielded manuals. Once published, each manufacturer has their own established procedures for correcting errors in the published manuals. These procedures include methods for prioritizing user-reported errors, which determine the order in which the errors will be corrected. Errors judged to affect safety of flight are addressed immediately, whereas other errors receiving lower priority ratings may or may not be addressed if more significant issues are subsequently reported. Although unique, no one manufacturer's set of procedures or guidelines was identified by users as resulting in a decidedly better manual.

The manufacturers maintain databases, cataloging user-reported errors. However, these databases are rarely used in any systematic way to identify trends in error reports or what caused the errors. Rather, this information is used to keep track of which errors need to be corrected and as a simple way to measure manual quality (i.e., year-to-year comparisons of the number of errors). The manufacturers perform limited testing of documentation to ensure that maintenance procedures are satisfactory from the user's perspective. The typical document testing or evaluations that are performed are often less than satisfactory, which is based on the judgement of the principal investigator at WSU, for a number of reasons. For instance, evaluations are not systematic, do not employ standard usability techniques, and are often performed using company employees or very experienced technicians which may limit the applicability of the results to other populations of users. The choice of participants for the usability evaluations is important to ensure the results will be widely applicable. Mechanics with different levels of experience may identify different problems with procedures. Experienced users can rely on their knowledge of a system to understand the intent of a writer, whereas less experienced mechanics may rely to a greater degree on the specific step-by-step directions outlined by the writer. The input of experienced technicians may be valuable during the initial development of procedures because they identify critical information and provide insight into the most efficient way to perform a procedure. However, the participation of less experienced mechanics is necessary in later stages of development to ensure the results of the evaluation will apply to the broader population of technicians.

An earlier survey [5] of user experiences indicated that the primary problem with manuals is not the quality of the technical information, or the number of errors in the manuals, but rather the usability (i.e., ease of use) of the manual and the procedures described within. More specifically, users cited numerous examples where maintenance procedures were inefficient and/or failed to consider the demands of the maintenance environment. For example, when working on an electrically powered system the technician might be instructed at different times to remove circuit breakers located in the cockpit rather than instructing them to remove them all at one time. Technicians also gave examples of how instructions could be reorganized to improve workflow and reduce the time to perform a procedure. The results of Phases 1 and 2 [4 and 5] illustrate the need to (1) improve communication between writers and users (i.e., technicians), (2) consider the requirements of the user, and (3) perform more detailed tracking and analysis during the manual development and revision process.

Many of the difficulties that users have with maintenance documentation arise because the documentation reflects the priorities of the manufacturers. The manufacturers are primarily concerned with the production and delivery of aircraft. Matters regarding documentation revolve around the timely development of documentation to ensure delivery schedules are not impacted. This has resulted in a system that is reactive rather than proactive in nature. This is partly due to the lower priority given to technical documentation development by most manufacturers as reflected in their development schedules, budgets, and the limited access technical writers have to the aircraft. With new aircraft, pressures of meeting production schedules force an uneasy balance between two competing demands—manual quality and timely delivery. Manufacturers acknowledge that some problems may exist in newly fielded manuals but that most errors will be identified quickly and addressed in future revisions. Through this process, it is assumed that the manual will be improved as errors or problems are identified and corrected. Simply correcting errors may not improve the manuals. When manufacturers analyze errors reported in fielded manuals they tend to focus on where the errors originated in the development process. Consequently, there is little understanding of the needs of the technicians who must use the documentation, their problems with the documentation, or ways of eliminating those problems. For this reason, usability problems are likely to recur in new and revised manuals. Without performing an analysis of the error reports from the field, there is no way of determining how changes in the writing process would affect development costs. A series of recommendations addressing these and other issues are described in the remainder of this document. In addition, a system for implementing these recommendations is also described.

2. RECOMMENDATIONS.

2.1 IMPROVED COMMUNICATION BETWEEN USERS AND TECHNICAL WRITERS.

The purpose of technical documentation is to support the maintenance of aircraft by providing relevant information to technicians who perform maintenance tasks. As noted above, the current system is driven by the need to meet the regulations, requiring only that information be provided for all procedures necessary to maintain continued airworthiness. The emphasis is on providing the information and not the needs of the user. The fact is, the goal of technical documentation is to support the needs of the technicians performing maintenance on the aircraft. Yet, most manufacturers assume that users will report quality control problems to them when they are identified. This is true despite the fact that the system does little to encourage this behavior. Change requests made by technicians are typically processed by several intermediaries, including company representatives, engineers, and managers from the operator and the manufacturer, before reaching a technical writer. The same occurs when a technician receives a reply from a technical writer. In personal interviews, technicians reported frustration with the current system, citing lack of feedback after submitting change requests and noting that the same errors continued to appear in later manual revisions. The delayed or absence of feedback does not encourage users to report problems. Manufacturers and operators should work together to facilitate the submission of change requests and ensure that users receive prompt responses to their requests regardless of whether or not the procedure will be changed.

2.2 VALIDATION OF MAINTENANCE PROCEDURES.

As part of an FAA-sponsored research program [3], a formatting tool called the Document Design Aid (DDA) was developed to improve the presentation of maintenance information by using workcards. Workcards are documents that are used by a technician or inspector to specify the individual steps required to perform an inspection or repair procedure. This tool serves as a guideline for the development of workcards that take into account how humans read, process, and interpret written information in order to improve their usability. For instance, the DDA provides design guidelines on information readability, context, organization, and consideration of factors affecting the handling (e.g., weight, size, etc., of a manual or card) of the documents. Although the DDA can improve the usability of maintenance documentation, it does not address the content of the procedure or specify how to evaluate the documentation. In light of earlier findings, the lack of a systematic evaluation of the reliability of maintenance documentation is a critical deficiency in the existing manual development process.

A necessary complement to design guidelines is techniques to evaluate the reliability of maintenance documentation as it is developed. The fact that users rate the problem of incorrect data in the manuals as being low is not a surprise given the substantial efforts [4] made to minimize their inclusion in the manual. In order for a technical error to contribute to a maintenance mishap, the error must occur in documentation pertaining to safety-critical systems or processes, and the discrepancy between the correct and incorrect information must be sufficiently large enough to cause a problem, but not so drastic that it is immediately identifiable as incorrect. What is more likely are cases of missing or incomplete data and procedures that are out of order, unclear, difficult to interpret, or awkward to perform. In these cases, the technician must rely on their own judgment and experience to determine the best way to proceed. When interviewing technicians, the most common complaint they had was frequently performing procedural steps out of order because the steps could not be performed as written. The procedure may include all of the necessary information and may be factually accurate; however, it may be difficult for the technician to perform the procedure correctly because of the unclear instructions. In many cases, these problems could be identified during the development process using a variety of techniques ranging from verification by an expert to validation of the procedure.

The term validation refers to a process where a technician performs a procedure as described in the maintenance manual under standard conditions (i.e., at a maintenance base or at the gate terminal using typical tools). The purpose of the validation is to determine whether procedures can be performed in a safe and efficient manner as written. Although some manufacturers have validated procedures in the past, this was normally not performed in a methodical or controlled manner. Typically, a technical writer might observe a technician on the assembly line or at a company service center performing the procedure of interest. The results from this validated procedure may not represent real-world conditions for a number of reasons. First, a company employee may be very familiar with the design and operation of a specific component and may have experience performing this procedure on similar aircraft. Consequently, they may report fewer problems because they have a level of experience and familiarity that other users may not have. Second, the validation may be performed on the assembly line on a new aircraft using special tools available only at the manufacturing site. A technician in the field is faced with the dirt and grime typical of in-service aircraft or poor environmental conditions (low light or poor weather) while using a different or limited set of tools. Under these conditions, it is not surprising that they report more difficulty performing the same procedures.

Not all maintenance procedures may require formal validation. A number of other evaluation techniques may be used, ranging from simple proofreading by a colleague, to a technician reviewing the procedural steps, or simulated performance by a technician. Procedures that are modifications of existing procedures, not safety-related or rarely performed (e.g., procedures for rodent removal or volcanic ash encounters) may be subject to proofreading only. Other procedures that may be more involved or require special equipment and/or parts may be evaluated by having maintenance personnel verify the instructions without physically removing components. Procedures can be evaluated in this way to ensure there are no physical obstructions that prevent the procedure to be performed as described, that the correct tools and part numbers are identified, and that the instructions are complete. Formal validation would be reserved for procedures that are performed frequently, prone to mistakes, or are deemed safety critical.

2.3 DATABASE, TRACKING, AND ANALYSIS OF MANUAL RELIABILITY.

An essential aspect of determining the reliability of a system is the collection and analysis of operating data. To track document reliability, it is necessary to develop and maintain a database consisting of a history of user-reported errors, feedback to their reports, and any follow-up information. The majority of manufacturers use feedback from operators to identify potential problems in their manuals. If it is determined that a revision of a procedure is necessary, then a change is scheduled and the error report is eventually deleted. This purging of feedback data is not necessarily an attempt to hide problems, but rather indicative of a reactive approach toward fixing errors. Documents are released, problems are identified, revisions are made to the document based on those problems, and then re-released. The assumption of this type of reactive approach is that technical documents will improve with age. However, because of the limited depth of data, it is not possible to track trends over time. This approach can be of considerable cost to the manufacturer, operator, and industry as a whole because similar problems may continue to appear. By tracking the number and type of user responses, trends can be identified that can guide efforts to improve manuals and serve as useful metrics of manual quality. Manufacturers could save resources by identifying and validating procedures that have historically been problematic. Operators could also benefit by identifying the personnel, equipment, and environmental variables that contribute to usability problems and respond accordingly.

3. IMPLEMENTATION OF RECOMMENDATIONS.

3.1 DEMONSTRATING THE BENEFITS OF VALIDATION.

The potential impact of poor maintenance documentation on safety is of primary concern to operators and manufacturers. Less widely acknowledged is the cost burden of poor maintenance documentation on the aircraft industry. From the perspective of the manufacturer, poor documentation increases the cost of maintaining the document through manual revision and distribution. This cost includes the personnel time required to process the change request, for engineers and writers to evaluate the change request, to rewrite the procedure, and to publish the manual revision. From the perspective of the operator, poor maintenance documentation may be associated with higher maintenance costs. These costs are a result of slowed maintenance, reduced revenue due to aircraft downtime, resulting wear and damage to components, personal injury, and the increased time required to process revised documentation and ensure that these changes are distributed promptly to maintenance technicians.

When compared to the potential costs (to aircraft operators) associated with a poor maintenance procedure, the costs of validating a procedure are relatively small. For example, it is possible to estimate the cost of reviewing a procedure by making several assumptions. First, assume the review process takes 4 hours and the cost of the personnel is roughly $200 (average salary of $80 for an engineer times the effort of an estimated 2.5 employees). The estimated total cost would equal $800. Next, consider the cost savings to an operator if that review results in changes to a procedure, reducing the total time to perform the procedure by 4 hours. This is time that would have been spent researching the discrepancy in the manual. Assuming an industry labor rate of $60, personnel cost of $150 (average salary of $60 times the effort of an estimated 2.5 employees) and 4 hours, the total cost savings would equal $600. If an operator maintains 25 aircraft of this type, the total cost savings would be $15,000 for just one procedure. The potential costs increase substantially when one considers both the number of procedures in a manual that might be improved to a similar degree and the total number of aircraft in service. Although the costs associated with validating the procedure may be high, in some cases it should be weighed against its impact on safety and cost to the industry.

3.2 ROLE OF THE FAA AS REGULATOR.

It is recommended that industry should be strongly encouraged to adopt an MSG-3 system and logic to identify what maintenance procedures should be validated. Manuals are a required part of the approved maintenance process, but with the exception of the flight manual and the structural repair manual, they do not require certification of the information they contain. Considering the size of the manual and the need to provide timely information to operators, certification of the maintenance manual is not required. Manufacturers should implement a process for identifying critical maintenance procedures and methods for validating the relevant maintenance documentation. This process would include methods for identifying which procedures should be evaluated, identifying which form of evaluation testing would be appropriate, establish standards for performing evaluations, and a system for recording user feedback, and actions taken. This information could be used to justify the validation efforts of each manufacturer. Rather than a generic certification process to which all manufactures would be subject, this would allow each manufacturer to tailor the evaluation process to problems unique to their organization as well as those of their customers. The role of a regulator is to oversee the implementation and periodically review this process to ensure compliance.

3.3. THE MSG-3 PROCESS: A MODEL FOR THE DEVELOPMENT OF TECHNICAL DOCUMENTATION.

In the same way that reliability analysis of components requires tracking the performance of those components over time, an effective usability analysis requires tracking the history of user problems, the attempts to fix those problems, and the outcome of those attempts. The following is a review of how this information can be used as part of larger program to identify procedures that should be validated.

An example of a system similar to that being proposed is the Maintenance Steering Group process for Reliability Centered Maintenance (RCM) [6 and 7]. RCM analysis is used to establish a maintenance and inspection program tailored to the failure history of each aircraft part or system. By matching the inspection and maintenance schedules to reliability data, both the cost of maintenance and the potential for maintainer-introduced damage and error are reduced. Key components of the RCM analysis are the identification of critical systems and components, the tracking of system component failures and replacements, and the periodic review of program effectiveness. When properly implemented, the MSG-3 process provides maximum safety at minimal cost.

While the goal of the MSG-3 logic is to develop a maintenance program and schedule, a similar process could be used to guide a validation program for maintenance technical manuals. Two key components of the MSG-3 process, the decision logic used to identify the potential impact of failures and the tracking of reliability data, could easily be adapted to guide the validation of technical data. By evaluating the level of risk posed by a given procedure (both to safety and economics), the need for validation can be determined. Once the need for validation is identified, the risk potential can be further delineated to determine the most appropriate method of validating that procedure. In addition, by tracking the history of procedure difficulties and validation efforts, any need to modify the program can be periodically addressed. Rather than being limited to an initial requirement of developing a maintenance program, RCM analysis uses the continued accumulation of operating experience to improve the safety and efficiency of the program.

The MSG-3 decision logic begins by assessing each potential functional failure in terms of both safety and economic impact. It is worth noting that this process begins with an acknowledgement of the inherent level of safety and reliability of a system. Just as all mechanical components will eventually fail, so too will human systems fail. Once a lower bound to system reliability is realized, the objectives become the achievement of that inherent limit, the restoration of that level when deterioration occurs, and the redesign of the system when that limit is no longer acceptable. All of which should be accomplished at a minimum cost, both for the completion of the task and for any related failures. Not all procedures have the same sensitivity to usability problems, nor do they have the same potential impacts to safety when problems occur. In order to be efficient and cost-effective, validation must be tailored to the specific task.

Just as maintenance significant items (MSIs) and structurally significant items (SSIs) are identified in the MSG process, usability-significant procedures should be identified in the technical documents. Significance is evaluated based on potential outcomes resulting from a usability problem with the information used to perform the procedure. Usability-significant procedures would be those procedures where a usability problem or error could lead to:

- a safety-critical problem (on the ground, in the air, or threat to maintenance personnel).
- a failure that is not easily recognized.
- a significant operational impact.
- a significant economic impact.

Once the potential risk of a usability problem is evaluated and usability-significant procedures are identified, procedures should be evaluated to identify:

- the range of potential usability problems that could occur.
- the effect of those problems.
- potential reasons for those problems.

The success of the system depends in large part on the collection and analysis of how and when components or aircraft systems fail. By analyzing the details of system failures, trends are identified that allow operators to adjust maintenance schedules, minimizing the potential impact of failures. By analyzing how and when technicians encounter usability problems with a manual, it is possible to adjust the manual evaluation process to focus on those areas that would be most adversely affected by usability problems.

Some procedures may be selected for validation prior to aircraft delivery based on prior experience. Others would be targeted for validation in the event that operational data indicates that it may be the source of usability problems. It follows that manual validation should not be a criteria for aircraft certification. This would allow for rarely performed procedures or those pertaining to repairing damaged components to be validated when first encountered in the operational environment.

4. ADDITIONAL COMMENTS.

4.1 THE TRAINING OF MAINTENANCE PERSONNEL AND TECHNICAL WRITERS.

Although not central to the research objectives of this project, the question of training with regard to technicians and technical writers was raised by manufacturers and technicians. Concern was expressed that newly hired technicians may receive little or no training on using technical manuals and that this may contribute to some of the problems reported with searching for information and navigating technical documents [5]. This matter highlights the broader issue regarding the skills of new technicians. Some concern has been voiced that technicians entering the field have fewer and poorer skills than in the past. For example, the director of maintenance at a major domestic airline reported that only approximately half of some 1600 potential employees passed a basic mechanics skills test [8]. The potential importance of this should not be underestimated. The low accident rate of American aviation is partly a result of the experience level of maintenance technicians, their quality of training, and the quality of the technical information used to maintain the aircraft. A decline in any of these factors may be expected to erode the safety margins we currently rely upon.

Similarly, many of the technical writing groups have reported difficulties finding employees with training in technical writing who are generally familiar with aircraft and their operation. In several cases, manufacturers attempt to compensate for this by hiring a mix of former technicians, engineers, and writers to develop maintenance documents. The aviation technical writing community would benefit from standardized training to ensure a common basic skill level. This training could be adapted to the needs of the company, as well as needs of the users in response to their feedback regarding manual reliability.

4.2 RECENT DEVELOPMENTS.

In response to the findings and recommendations of this research effort, an Associates of Arts (AA) degree program was established at local Wichita area colleges with coordination from WSU. The AA program was developed as a result of a joint venture between local aircraft manufacturers (Raytheon, Lear, and Cessna), educational institutions (Wichita Area Technical College and Wichita State University), the Wichita Chamber of Commerce, and a consulting business (Entrepreneurial Foundations, LLC). This joint venture led to the development of certificate and degree programs for aviation technical writers. Through the collaborative efforts of this group, it will provide an environment for teaching the necessary skills of technical writing, as well as aircraft systems operation and maintenance procedures. Classes began in the fall of 2002.

5. SUMMARY.

A series of recommendations have been proposed that are believed would improve the quality of maintenance technical documentation. In most cases, the recommendations follow directly from suggestions made by representatives from the aircraft industry that participated in the project. Some of the recommendations require minor modifications to existing programs or efforts within the manufacturers, while others, such as the prioritization of maintenance procedures for validation, require the cooperation of manufacturers, regulators, and operators to be realized. These recommendations are an attempt to shift from a reactive, production-centered approach towards a more proactive, user-centered process of generating technical documentation that focuses resources on those aspects of the manual that may have the greatest impact on usability, safety, and economics.

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