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Human Factors Survey of Aviation Technical Manuals, Phase 1: Manual Development Procedures

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Human Factors Survey of Aviation Technical Manuals Phase 1: Manual Development Procedures

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Interim Report

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16. Abstract

This report contains the results from Phase 1 of a three-phase research effort. Phase 1 examines aviation industry procedures for developing maintenance technical data. Phase 2 will document user problems with maintenance technical data. Phase 3 will identify maintenance technical data development improvements by applying human factors principles. Five aircraft manufacturers were surveyed regarding company policy, communication, data tracking, user feedback, and error reduction efforts. The five industry participants represent both regional and large commercial transport manufacturers. Phase 1 survey results revealed three significant maintenance technical data issues: inconsistent development process guidelines, reactive rather than proactive response to user feedback, and inadequate assessment of errors involving usability as opposed to accuracy. Phase 1 results will later be compared to Phase 2 surveys of user problems with maintenance technical data to identify the impact of development procedures on the users perception of manual quality.

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EXECUTIVE SUMMARY

Until recently, little attention has been paid to the procedures used to develop and revise aircraft maintenance technical data. Studies of maintenance errors have tended to focus on the actions of the mechanic, job culture, and work procedures. More recently, attempts have been made to document the source of maintenance errors and improve maintenance procedures. One of the identified contributing causes of errors is the documentation used to guide maintenance tasks. As a result, efforts have been made to establish guidelines for the design of maintenance job aids. A question that remains is how the procedures used by manufacturers to develop maintenance data may contribute to user error.

In this document, the results of Phase 1 of a three-phase research effort to (1) examine the procedures used by industry to develop maintenance manuals, (2) document the problems encountered by users of these documents, and (3) identify ways in which human factors principles can be used to improve the development of these documents are reported. Phase 1 is a survey and report of the procedures used within the aviation industry to develop maintenance technical data. A cross-section of manufacturers was surveyed regarding company policy, communication, data tracking, user feedback, and error reduction efforts.

1. INTRODUCTION.

1.1 BACKGROUND.

A little known fact is that aircraft manufacturers rank among the largest publishers in the world. With each aircraft they produce, they provide the technical documentation needed to maintain the aircraft in working order. Aircraft manufacturers provide a wide range of documentation including the maintenance manual itself, an illustrated parts catalog, wiring diagrams, structural repair manuals, and a host of other related documents. The development and revision of aircraft maintenance technical manuals is no small task. The amount of information is staggering, with manuals being measured more appropriately by the feet of shelf space they occupy rather than the number of pages they contain. For aircraft that have any degree of customization, the manufacturer may need to develop different, operator-specific manuals to include only the information relevant to the aircraft they maintain. The Boeing Company estimates that if all manual pages published in 1998 were stacked one on top of another, the resulting tower would reach approximately 103,000 feet in the air [1].

The size and complexity of a modern technical manual requires the integration of information from multiple sources, making it increasingly difficult to verify the accuracy and clarity of the information maintenance manuals contain. Each company has developed their own techniques and procedures to deal with these issues, but there is little documentation in the public domain or industry dialogue about the different procedures employed. While manufacturers may be hesitant to openly share this information, the potential benefits include the reduced cost of developing manuals and improved manual quality. Considering that the goal of a technical manual is to facilitate the safe and efficient maintenance of an aircraft, it is important to continually evaluate the degree to which the applied procedures meet these objectives. The goal of this effort is to document the unique ways companies have addressed the problems of manual development and to encourage a dialogue between the manufacturers, operators, and regulatory bodies within the industry.

The task of developing manuals has become a more critical part of aircraft maintenance in recent years as the demands being placed on those manuals increase. The continued growth in worldwide air traffic has resulted in increased production of new aircraft and older aircraft remaining in service much longer than originally expected. While the number of aircraft has increased, the number of maintenance technicians has not; consequently there is greater pressure on aircraft maintenance in general. A 1993 Blue Ribbon Study, “Pilots and Aircraft Maintenance Technicians for the 21st Century: An Assessment of Availability and Quality,” found that although there were enough aircraft mechanics at that time, the projected demand was increasing at a faster rate than the number of new mechanics. Amid the favorable economic conditions experienced globally in the years since that study was released, the situation has worsened more quickly than predicted and air traffic continues to increase. The growth of air carrier operations combined with a retiring maintenance workforce and a worker-friendly job market has resulted in a critical shortage of qualified aircraft mechanics. The Labor Department reports that approximately 140,000 mechanics work in the aviation industry today and 40,000 additional mechanics will be needed by 2008. In order to fill the positions necessary to support larger fleets, maintenance facilities are being forced to lower hiring requirements for maintenance personnel. As an example, American Airlines has recently been forced to lower experience requirements from 4 to 2 years. At the same time, there appears to be a general lack of skilled applicants. In 1997, responding to concerns about the skill level of newly hired mechanics, United Airlines incorporated a basic skills test into their interview process for maintenance technicians. This skills test involves tasks required of any aircraft mechanic, including rivet installation and safety wiring of bolts. In an interview with *USA Today*, the United Airlines Director of Maintenance reported that from the end of 1999 to mid-2000, 1,600 potential employees were interviewed, and only 45% of those could pass the basic skills test [2]. United is one of only five airlines that include a skills test in their hiring process. The experience of United Airlines may indicate a need for long-term changes in the training of new mechanics, but the short-term reality is that the qualification of the maintenance workforce appears to be declining.

Lesser-trained and lesser-educated maintenance personnel will rely much more heavily on the content of maintenance manuals. They will also lack the knowledge that comes with experience to determine when a manual may be in error. In some cases, in order to meet demand, work has been offloaded to foreign maintenance facilities that bring with them the added concern of the translatability of documents. Growing liability and regulatory pressures have also increased the scrutiny of technical manuals and, in some cases, have forced the inclusion of corporate lawyers into the manual development process. Because of these pressures, decisions regarding reading level, writing style, clarity, and the degree of detail to be used when writing maintenance manuals are even more important now than in the past.

The way a particular manufacturer may handle these content decisions is often a matter of established company history. Manufacturers develop a writing style that is propagated from veteran writers in the company to the newly hired writers, and users come to expect a certain style from a particular manufacturer. Style consistency may have the benefit of a perceived familiarity across manufacturers models, but it may not be appropriate for the changing face of the maintenance workforce.

In 1994, a review of major aircraft accidents found that approximately 12% could be attributed to maintenance [3]. According to the Boeing Company's summary of commercial airplane accidents worldwide for the years 1959-1999, the figure is a more conservative 5.9% [4]. Regardless of which figure one chooses to use, there has been an apparent increase in maintenance-related aircraft accidents in recent years. While aircraft accidents capture headlines, the truth is that few maintenance errors ever result in accidents. Analysis of maintenance errors indicates that the majority of incidents involve omitted or incorrect execution of tasks, incorrect installations, and the use of incorrect parts (Boeing research cited in reference 5). Such events can potentially lead to accidents if left uncorrected, but these are rare events, and to focus on accidents alone is to underestimate the actual number of errors and their impact on safety and operating costs.

A Human Factors approach to reducing maintenance error requires that causal attribution be extended beyond just the offending mechanic. If the search for error sources is extended to environmental influences, causal attribution may include latent errors introduced by management policy, organizational communication, or corporate culture of the maintenance facility. Another potential factor in maintenance error that is easily overlooked is the technical information used to guide maintenance operations. The potential contribution of technical documentation to maintenance error is not a new concern [6]. However, previous attempts at improving maintenance documents, such as Drury and Sarac's document design aid [7], have yet to be adopted by aircraft manufacturers on a large scale.

Maintenance manuals can contribute to maintenance error if they contain misleading information, insufficient information, or unclear procedures. Not only must the information be technically sound, it must also be presented in an effective manner. A term common to the computer industry most applicable in this case is "usability." The Institute of Electrical and Electronics Engineers (IEEE) defines usability as "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" [8]. Applied to aircraft manuals, usability includes the user experience of those manuals; how easy they are to use, how well they match the mechanic's representation of a task, and how useful the information is they contain. The user experience of the manuals will also impact the ways and degree to which mechanics will use them. In a study conducted for the Australian Transportation Safety Bureau, 67% report having been misled by maintenance documentation, 47% report having opted to perform a maintenance procedure in a way they felt was superior to that described by the manual, and 73% of mechanics surveyed reported failing to refer to maintenance documents either occasionally or often [9].

These findings raise concerns about the perceived usability of manuals and the quality of information exchange between mechanics and the writers of maintenance materials. The fact that mechanics report instances of failing to refer to maintenance manuals may be indicative of familiarity with the task or prior experience with manuals that were hard to use or not very helpful. If user comments are relied on as the final check of manual quality, the usage pattern becomes a critical issue. A lack of user complaints may be indicative of a well-crafted manual or one that users have simply stopped using and see no point in bringing these issues to the attention of the developer.

The task of developing and revising maintenance manuals requires the coordination of multiple information sources across a number of departments within the management structure of the manufacturer. Engineering, technical support, customer service, and technical writing must integrate the most recent information from their respective sources to provide the technical base necessary to produce a technically sound document. Technical writers have the ultimate responsibility of verifying that they have the most recent and accurate information available on which to base technical manuals.

The accuracy of the information contained in maintenance manuals is of paramount importance, and manufacturers have implemented multiple safeguards to protect against the inclusion of erroneous content. Document checklists, peer review, and software formatting have all been implemented to reduce the number of errors present in fielded maintenance manuals. Once released, each manufacturer has procedures for addressing problems that users encounter while using the manuals. The accuracy of maintenance manuals gets considerable attention from manufacturers and operators, and the continued application of computer technology to the technical writing task promises greater ability to verify the accuracy of technical information.

1.2 REGULATORY REQUIREMENTS.

The current procedure for developing maintenance manuals is an integral part of satisfying the Federal Aviation Administration (FAA) requirement for operators to develop and support an ongoing maintenance program. More specifically, manuals are designed to help operators meet the requirements outlined by the following Federal Aviation Regulations (FAR).

- FAR Part 121.363 establishes the operators responsibility to maintain the airworthiness of its aircraft fleet.

- FAR Part 121.367 requires each certificate holder to have programs for aircraft inspection, preventive maintenance, and oversight of alterations that ensures these tasks are performed in accordance with the certificate holders manual. The certificate holder is further required to ensure that these tasks are performed by competent personnel with adequate facilities and equipment. Finally, the certificate holder is ultimately responsible to ensure that each aircraft released to service is airworthy and properly maintained.

- FAR Part 121.373 requires each certificate holder to establish and maintain a program to monitor the performance and effectiveness of its inspection and maintenance program. The certificate holder is responsible for correcting any identified deficiencies in those programs.

- FAR Part 121.379 establishes the authority of an air carrier to perform aircraft maintenance in accordance with an FAA-accepted maintenance manual. The maintenance can be performed by the carrier itself or another approved facility. If maintenance requires a major repair or major alteration, the work must have been accomplished in accordance with FAA-approved technical data.

Manufacturers are likewise required to provide the technical instruction necessary to support continued airworthiness of their aircraft. This obligation is outlined in FAR Part 25.

- FAR Part 25.1529 requires instructions for continued airworthiness as part of type certification. The instructions may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first airplane or issuance of a standard certificate of airworthiness, whichever occurs later.

- FAR Part 25: Appendix H elaborates on specifications for the technical information required by FAR Part 25.1529. The instructions must be written in English, providing for practical arrangement, and in a form appropriate for distribution. Instructions must include information about all equipment installed on the aircraft, including equipment made by third party manufacturers. Manual content requirements are outlined for system descriptions, maintenance and inspection procedures, required schedules, and information about system tests and service points.

While the FAA has established a need for airframe maintenance manuals in a required maintenance program, exact regulatory requirements for those manuals are not outlined. The manuals must be accepted as part of the maintenance program, but the manual data itself is not approved. Only portions of the maintenance technical information require direct regulatory approval (e.g., Structural Repair Manual) while the majority of maintenance information does not. Considering the massive amount of maintenance information and the potential degree of variation in manuals from one operator to another, direct regulatory approval of all procedures is not desirable. From the regulatory perspective, the intent of a maintenance procedure is more important than the particulars of its execution. However, the lack of detailed standards underscores the responsibility placed on the manufacturer and, to a lesser extent, the operator to develop and maintain the quality of information contained in manuals.

2. DISCUSSION.

2.1 MAINTENANCE TECHNICAL MANUAL CONSIDERATIONS.

2.1.1 Development.

New manuals begin development during the early stages of the aircraft design process. During the design and development stages of a new aircraft program for FAR Part 121 operators, the manufacturer produces a Maintenance Planning Document (MPD) outlining the inspection and maintenance schedules that will be required by the airframe and system components. The development of the MPD is guided, in part, by the Maintenance Review Board (MRB) document developed by the FAA and industry to aid in establishing initial inspection and maintenance schedules. The process is further aided by logic developed through the Maintenance Steering Group (MSG), an industry collaboration of manufacturers, airlines, and regulatory authorities. The MSG allows for the adaptation of the MRB process to meet the unique requirements of a particular aircraft while conforming to the original intent of FAR inspection and repair regulation. The MSG logic has gone through several iterations and is now referred to as MSG-3. The entire MRB process is required for the aircraft to receive a Type Certificate and serves as an initial check of the integrity and accuracy of maintenance information.

With the required inspection and maintenance schedules established, the manufacturer must begin the task of outlining those procedures. In addition to the required scheduled maintenance, procedures must also be developed for the removal, installation, and repair or replacement of all components installed in the aircraft. It is in the outlining and description of these procedures that technical writers have the greatest freedom and it is in this area that manuals vary the most.

A guiding force in the style and appearance of technical manuals is the Air Transport Association (ATA), through the document guidelines they develop. The ATA specification 100, and the new *i*spec 2200 that replaces it, provides direction for the format and layout of technical manuals. Although not regulatory nor mandatory in nature, manufacturers, operators, and regulatory agencies have come together through the ATA to standardize the format of technical manuals. This standardization extends from chapter organization to headings and fonts. The goal is to make navigation and use of manuals as consistent as possible across the industry. Once again, although there is considerable structure imposed by the ATA specifications, decisions about the content are left to the discretion of the technical publications group. For example, manuals can differ greatly in the use of constrained language (i.e., restricted vocabulary set and/or sentence structure). Technical writers have used constrained languages in an attempt to improve usability by addressing the effects of differences in reading level and language fluency among maintenance personnel. Some manufacturers use the United States Air Force dictionary that limits the vocabulary to words that should be understood by a person with an eighth grade reading level. Other manufacturers use more restrictive standards such as simplified English, to control both vocabulary and sentence structure. The simplified English standard has writing rules and a list of acceptable words, noun phrases, and verbs. The use of simplified English is meant to eliminate slang and create concise sentences. Because maintenance documentation is authored in English and normally not translated into the native language of an international operator, simplified English may make it easier for non-native English speakers to use technical manuals. Given all of these factors, two manuals, both conforming to ATA specifications, may differ greatly in clarity, reading level, degree of detail, and writing style.

2.1.2 Time.

The underlying time and budget pressures that drive the manufacturers of aircraft need to be kept in mind when examining the scope of the task facing the writers of technical maintenance information. Safety is of ultimate concern to anyone in the aviation industry, but there are often trade-offs between ideal safety practices and the real-world compromises adopted. One of the single greatest factors in determining the amount of money made on an aircraft is time. An airplane sitting on the production line is not making money. The longer it takes to deliver an aircraft, the longer the delay until it begins earning revenue. Operators pressure the manufacturer to meet an established contractual delivery schedule because, in most cases, the new airplane has already been scheduled for revenue service. This economic reality is crucial to the full appreciation of the environment surrounding the development of technical documents.

The time in production determines the number of aircraft that can be produced in a year and may be the deciding factor in a customer's choice of a manufacturer. In theory, delivery could be delayed to ensure that maintenance manuals are completed. In reality, the technical publications department within manufacturers is rarely given authority commensurate with engineering, production, or flight test departments. Delivery will not occur until all final assembly on all systems have been installed and tested, but it is unlikely to ever be delayed for the technical documentation that refers to those systems. When budgetary concerns arise, the technical publications department is often faced with funding cuts and time limitations. In most cases, the technical publications department is aware of the problems they face but lack the perceived importance within the company hierarchy to command the time and resources to implement changes.

2.1.3 Variations Between Manuals.

During the production life of an aircraft model, engineering and equipment improvements continue to be made. Vendors supplying parts for that aircraft are also constantly working to improve their products. These improvements are incorporated into production aircraft as they become available. Because of the evolution of the aircraft design, different serializations of the same aircraft model may include different parts and, therefore, require different maintenance procedures. For any given aircraft model, there is also a variety of optional equipment that can be installed. For smaller, regional aircraft, configuration differences may be limited to interiors and avionics options. For large transport aircraft, configuration options can be extended to accommodate any desire of the customer including engines, environmental systems, and in-flight entertainment equipment. The result is that any two examples of a particular aircraft model may vary significantly. The mechanic responsible for maintaining those aircraft must be provided with the necessary information to make the distinctions between the aircraft and adjust accordingly to the task of repairing each of them. To make this as easy as possible, the manual must contain all of the information relevant to the aircraft the mechanic is working on, while at the same time not require sorting through a lot of nonapplicable information.

For smaller aircraft, or those with fewer customization options, it may be acceptable to include all information into every manual and give the user the necessary data to determine what applies to their particular aircraft. For more complex aircraft, or those with a large number of customization options, it becomes necessary for the manufacturer to tailor a customer's manual to the particular configuration of their aircraft. When a large transport aircraft has a maintenance manual numbering in the tens of thousands of pages, unnecessary information is not tolerated by the operator. For these aircraft, manufacturers are forced to provide manuals customized to each operator. The way this is handled depends on the manufacturer.

The task of the manual technical writer is to obtain all of the information necessary to incorporate both the constantly changing engineering information and any necessary customization information into the finished manual. Several sources within the organizational structure of the manufacturer need to coordinate their respective data in order for this information to make it into the manual. Significant design changes affecting the form, fit, or function of the aircraft must be communicated to all affected internal organizations. When notified of a significant design change, technical writers must modify the applicable maintenance data and incorporate that information into a manual revision. The burden is on the technical writer to ensure that the data presented in the manual reflects the actual configuration of the airplane.

Individual writers are assigned to writing tasks based on their expertise with aircraft subsystems. A writer that is assigned to avionics, for example, must not only be knowledgeable about each of the avionics systems available, but also how those systems interact with other subsystems. When writing the documentation for an aircraft that has system A, they are actually writing the documentation for the hundreds of aircraft with that same system. The document must not only reflect the data applicable to that system, but it must also address any potential interaction between combinations of installed subsystems.

2.1.4 Document Lag.

As new data becomes available, the writers must review that data and make any required additions or changes to the manual. If multiple changes are necessary, they are worked in order of importance and safety relevance. Source data continues to evolve throughout the writing process, but at some point in time, a decision must be made to finish authoring activity for the manual. Additional time is then needed to compile all of the information, format and/or print it, and send it to the operators. Once the decision point is reached, the document is said to be "locked" and no changes will be made. The "lockup" date is usually 3 to 4 weeks before the intended release of the manual or revision. Revision schedules are either driven by the amount of accumulated content or a calendar cycle.

At the point of lockup, the process of developing the next revision begins, starting with any data not included in the previous revision. Even though writing has ceased for that release of the manual, engineering continues to progress during the lockup period. The airplane manufacturer tries to synchronize the release of maintenance data with the delivery of a new airplane, but in some cases, design engineering data or supplier data is released after the lockup period for the current revision. Consequently, this late engineering or supplier data can cause a "document lag" in which the released maintenance data does not match the delivered airplane configuration. Maintenance data not included in the current revision of the manual will be prioritized for inclusion into a later revision. If safety-sensitive data or maintenance significant data (causing an operator economic or technical difficulty) emerges between the release of the current and next planned revision, manufacturers have established a process to provide a temporary revision until the next release becomes available.

2.1.5 Distribution.

Once a manual or manual revision is completed, it must be converted to the deliverable format requested by the operator and distributed. For domestic operators, the distribution is straightforward. Postal delivery or parcel service can have a hard copy of the manual to a maintenance facility in a few days or less. From that point, it is the responsibility of the respective maintenance personnel to assure the new information is added to the manual and disseminated to mechanics.

For international operators, the distribution process can be slowed weeks or even months depending on the efficiency of customs procedures it needs to pass through. Non-English speaking facilities may slow down the process further by translating the information into their native tongue.

2.1.6 Multiple Manual Formats.

Although the size of the published manual gives a good indication of the magnitude of the task required to develop one, in practice, the manuals are frequently distributed to users in other media formats. Microfiche or microfilm cassettes are common media options for distributing manuals without the physical space requirements of paper. Mechanics can view film versions of the manual in the appropriate viewer and print the pages pertaining to the job they are assigned. Although they are smaller and easier to store, film versions of the manual are identical to the paper manual and differ only in the presentation media. Although the manual can be distributed on whatever media preferred by the operator, the paper copy of the manual remains the master reference.

Digital data formats are slowly replacing other media formats. Large operators prefer the ease and flexibility of digital manuals. Large amounts of electronic data can be easily transferred via network or distributed on CD-ROM. Computerized maintenance data can be easily manipulated by the operator and integrated into company manuals. If desired, electronic maintenance data can then be downloaded to a notebook or hand-held computer for use by a field mechanic at the aircraft. Digital data does not suffer from delays associated with printing and distribution of paper manuals and manufacturers could conceivably distribute daily updates via the Internet. Computerized data allows for the inclusion of multimedia enhancements not available in paper-based manuals. In spite of its potential advantages, the implementation of computerized data is inconsistent across the industry.

To avoid potential problems arising from different revision schedules for paper and electronic data, electronic data is synchronized to the slower paper publication schedule, eliminating the potential distribution time savings. As a result, the full benefits of the electronic medium are currently not being realized.

Aside from the problems of digital versus print data, supporting multiple data mediums requires additional effort to verify that document formatting is compatible with each type of media supported by the individual manufacturer. Each aircraft operator may request the manual in a different media to match existing hardware base (e.g., microfiche viewer, tape, CD-ROMs). Interactions between new and legacy systems (i.e., data maintained on older computer databases) can cause unforeseen irregularities in the appearance of the finished document. Finding and correcting these problems may at times require manually reviewing each new page.

2.1.7 Document Customization.

Depending upon the size of the operator, maintenance manual data may be modified for the purpose of integrating into company manuals. In some cases, these operators receive the manual data in an electronic format (tape, CD-ROM, native SGML code) and then modify it to adhere with company procedures. Alternatively, the operator may provide details to the manual developer and have them produce the manual in a format consistent with approved company manuals. Customization in this case may include company procedures for handling parts, completing paperwork, or reporting problems. In other cases, customization may extend to the way procedures are carried out. When an operator specifies a procedure that is different than that outlined by the manufacturer, the manufacturer will examine it to determine whether it is consistent with what it considers to be safe procedures. If the operator requests procedures to be entered that have not been approved by the manufacturer, those procedures may be included in the manual with a notation indicating that it is customer-originated data.

Operator customization of the manual can create problems for both the manufacturer and the user of that manual. From the mechanics perspective, manufacturer-generated data and company-generated data are often indistinguishable. Likewise, it is sometimes difficult for the manufacturer to have a clear idea of the quality of their procedures when they have been modified by the operator. Another example of this mismatch is the generation of the work task cards or job aids generated from the manual for use by mechanics. Many manufacturers provide job aids automatically generated directly from the manual, however many operators develop their own version of job aids. User experience and feedback may be quite different depending on the source of this data and it may not be immediately apparent which party is responsible for an identified problem.

2.1.8 Feedback.

Once a manual or revision is released, further changes may be required to address user feedback. The user is the ultimate check of the quality of maintenance information. If the user thinks the manual contains erroneous data, unclear directions, or difficult procedures, they can report such problems back to the customer service department of the manufacturer. In the case of larger operators, concerns raised by mechanics are typically channeled through the operators engineering department before they are passed on to the manufacturer.

The integration of user feedback is primarily a reactive process, in which the data is released, and remains unchanged unless problems are reported. Except in the case of safety of flight, responses to user feedback may differ based on the unique requirements of an operator. In the case of customized manuals, if one operator wishes to change the way a particular procedure is performed, they will make a request and only their manual will be changed. The requests of an operator will reflect the efforts of their own engineering departments and are typically not shared with potential competitors. Manuals for a new aircraft may start out very similar, but over time the unique feedback generated by the mechanics and engineering departments of each operator cause them to diverge. Many operators invest large amounts of time and resources into customizing their manuals and do not wish that information to be shared with potential competitors, so this process is repeated with each operator, requiring the manual developer to continually address similar issues. As a result, manufacturers are not only providing manuals to support each aircraft they produce, but multiple variations of that manual to address the unique desires of each individual operator. Another downside of this practice is that potential improvements in the manual are not being disseminated throughout the industry. The requirement for unique user feedback is primarily true of operators of large aircraft, but regional operators may make similar requests.

In an attempt to prevent the repeated occurrence of similar errors in the manual development process, some manufacturers have developed methods for receiving, categorizing, and cataloging identified problems. Once recorded, problems can be tracked to identify trends in errors that point to potential shortcomings in a manufacturer's manual development process. Whether or not a database of errors is maintained, continual monitoring of customer feedback is a critical part of providing a document that meets user expectations.

2.1.9 Aircraft Customization.

Once an aircraft leaves the factory, it will continue to be modified throughout its operating lifespan. Operators make changes and updates to avionics, interiors, and passenger comfort equipment. In some cases, changes can be more drastic, such as structural modifications or cargo conversions. There is considerable variation in the degree to which maintenance information is updated to reflect those changes. If the aircraft was returned to the manufacturer or a factory-authorized maintenance center for modification, a fully integrated manual update is often included in the total cost of the job. For in-house changes, or work done by third-party modification centers, very little maintenance information may be available. If the operator wishes to have these changes integrated into their existing manuals they can, but because the rework was not due to a factory-initiated change, the operator must shoulder the cost. Many times the operator elects not to pay to have the information incorporated in the original manual. In such a case, the operator may be given a generic manual supplement pertaining to the modification. This supplement may contain detailed maintenance information or be limited to a basic technical description.

The manufacturer may be impacted by the continued customization in two ways. First, if the operator wishes to integrate the new information in their manual, the manufacturer must communicate with the modification center to gather all the necessary information pertaining to the operation and maintenance of the new system. This can often be very difficult, depending on the quality of the engineering provided by the modification center. Secondly, if the operator chooses not to involve the manufacturer, the manufacturer may still be impacted because they are not aware of the actual configuration of the aircraft. Consequently, future attempts by the manufacturer to improve the aircraft or manual will not consider the potential interaction between factory-originated changes and modifications performed by a third party. When revising manuals, the author will write procedures based on the known aircraft configuration, usually the configuration at time of delivery. If a writer changes a procedure based on original equipment manufacturer (OEM) procedural or engineering changes, it may be inappropriate for the unique configuration of the customized aircraft.

2.1.10 Older Aircraft.

The high cost of providing maintenance manual updates and revisions has led most manufacturers to implement some form of revision subscription service. In order to continue receiving updates to maintenance manuals, operators are usually required to pay for a subscription to that manual. A subscription entitles the operator to receive all revisions and updates as they are released. Most manufacturers also include a regular newsletter that includes information about pending revisions and model information. Operators that opt not to pay for a subscription receive only information considered to directly impact the safety of flight.

By far, the greatest numbers of maintenance manual changes come early in the life of a new aircraft. The time pressures of delivery often result in the latest engineering changes being left out of early versions of the manual. The largest numbers of problems with the manual are usually identified soon after its release, and those problems are addressed in early revisions. At some point, the number of changes begins to decline and level off. It is at this point that an operator may feel that the cost of maintaining a manual subscription is not warranted by the small amount of change in each revision and may choose to suspend the manual subscription. Unless the operator chooses to later pay to have the maintenance manual updated, the manual will reflect the condition of the aircraft at the time of suspension regardless of future changes to parts information, vendors, or recommended procedures. With the age of some aircraft still in service, it is not unheard of to find operators with manual subscriptions that have been suspended for 20 or 30 years. In most cases, these aircraft are being flown by foreign airlines or have been leased to smaller operators. Because these manuals have been suspended, it is unclear whether these operators are using old manuals or newer documents purchased from a third-party manual developer.

From the perspective of the manufacturer, older aircraft present a particularly costly challenge. Once an aircraft model is released, the maintenance information is open to scrutiny and must continue to be supported until the last aircraft is retired. Unlike most departments within a manufacturer, technical writers must remain knowledgeable about the design and function of systems in both production and out-of-production aircraft. For an established aircraft manufacturer, this may require them to support manuals for aircraft that have been out of production for decades.

2.2 MAINTENANCE TECHNICAL DATA ERRORS.

When asked about ways of improving technical manuals most writers/developers emphasize the development of procedures to eliminate the accidental inclusion of incorrect technical information. Although accidents attributed to correctly following maintenance procedures that turned out to be erroneous may capture public interest, other more frequent and potentially more significant sources of errors receive comparatively little attention.

It is important to note the difference between the academic and popular definitions of error. In academia, error is understood to encompass a wide variety of forms, including lack of clarity and the omission of information. However, when technical writers are questioned about errors, their definition of an error is typically limited to the inclusion of incorrect technical information in the manual. Quality control procedures tend to focus on identifying incorrect information, formatting irregularities, errors in grammar, and aircraft configuration errors. Using this narrow definition of error may lead one to overlook other important factors that impact the user's perception of the usability of a manual.

Although they may garner considerable attention when they occur, the cases of blatantly incorrect information being incorporated in a manual are relatively small when one considers the size of the document and the amount of detailed information it contains. The possibility of a procedure being written that is unclear, difficult to follow, or fails to represent a mechanics mental model of the task is more likely and has the potential to be of equal or greater consequence than incorrect information. Poor usability of documents introduces a systemic potential for error due to the unpredictability of how a mechanic interprets the manual and how closely this interpretation adheres to the intent of the writer.

If an incorrect procedure is outlined, the error will presumably be identified and corrected in the first few attempts at doing that task. The effect of a poorly written procedure however may be much more subtle; for example, a mechanic may think they are performing a task correctly when, in fact, they are not interpreting the procedure in the way intended by the writer. In this case, an unclear procedure may lead to similar mistakes being repeated each time the offending procedure is attempted.

In cases where difficulties with a procedure may be more salient, the user may be more apt to abandon the documented procedure and rely on their own judgment to perform the task.

Because the procedure may be technically sound, a problem resulting from confusion with or failure to use the manual is likely to be attributed to incompetence on the part of the mechanic. Ultimately, a mechanic may be reprimanded or fired for committing actions they thought were correct in light of documentation that was difficult to follow or understand.

When attempting to assess the degree of error present in maintenance manuals, it is important to have a clear understanding of what constitutes error. Reason's model of active and latent error [10 and 11] has been given considerable mention in the maintenance error research literature [7 and 12]. The term active error is used to describe an erroneous action or violation committed by an individual, while latent error refers to environmental factors that may contribute to error. The oft-cited "Swiss Cheese" model of error illustrates the way latent errors caused by working conditions, management policy, and organizational communication can contribute to a situation that results in an active error on the part of a mechanic. Manuals can indeed be a source of latent maintenance error, but this model is not particularly well suited to the study of errors in maintenance manuals. Maintenance error investigations focus on the failure event or inappropriate action of the maintenance personnel. Attempts at reducing active errors require an understanding of all possible errors, so that either the individual or the system can be changed to protect against those possibilities. Because the number of possible errors is potentially infinite, likely errors are usually determined by examining previous error occurrences [12]. Once an error is identified, investigators must work backward to examine all of the potential contributing effects that lead to its occurrence. They must determine how far to track the source of error and estimate a degree of influence for each contributing factor [13]. Errors in maintenance manuals are different from the erroneous action of an individual and attempts at identifying, cataloging, tracking, and reducing errors in technical information need to take a different approach.

As Rasmussen points out [14], the goal of generating a taxonomy for classifying, analyzing, and addressing existing errors in a system, based on previous failures, is best suited to systems that remain reasonably static for long periods of time. Tracking the reliability of a system requires an accumulation of data over time, and if a change is introduced into the system without being controlled, the accuracy of the resulting reliability measure will be suspect.

The procedures used to develop maintenance documentation have been relatively stable for a long time. However, these procedures have recently experienced substantial changes resulting from the application of new technology and changes in the demographics of the user population. From the earliest aircraft until the advent of computers, manuals were assembled by hand through cutting and pasting of text and hand-drafted illustrations. Even early applications of computer technology to the development process operated merely as a more efficient version of the cut and paste, paper document assembly. Technology is changing so rapidly that in many cases legacy information is not migrated to new systems before those systems are replaced by the next version. Consequently, the way manuals are developed today is not the same as they were last year or will be a year from now. Traditional attempts at cataloging and reducing process errors may have worked well with the transfer of blueprint information to paper documents, or even early computer-based authoring systems, but are inadequate to address the problems caused by rapidly evolving technology and a changing user workforce.

Because the process of developing manuals is now so dynamic, any attempt to develop a reliability measure must take into account both the changes in the development process and the target audience. Attempts to measure reliability using static measures such as recording the number of typographical errors or incorrect part numbers are necessary but no longer sufficient. Simple reliability measures may provide information about the integrity of the process but it will not indicate how well the manual meets the needs of the user [14]. The user population is not static, and as the development process continues to evolve, the manual writers must repeatedly verify that it continues to meet the needs of the user population.

The information contained in the manual must be correct but to focus on technical accuracy alone is to inappropriately simplify the issue. Focusing attention on matching the task to the user would go beyond process error to include the cognitive and psychological processes guiding the task and user. Reason outlines a process for developing a framework of error that includes "contextual error sources" introduced by the task and situation and "basic error tendencies" of the individual [10]. As Reason points out, while there is no universally applicable classification for error that will meet all needs, a general framework of error can be defined from repeated user testing that can predict the majority of problems.

The technical writers responsible for maintenance manuals are professionals who take seriously the potential safety impact of their work. It is fair to assume that their intention is to produce the best manuals possible, but in spite of these intentions, errors occur. This is important to note at the outset, as error cannot be separated from intention. The notion of intention is based on two things: (1) an expressed goal to be attained and (2) a clear procedure for how to reach that goal. Volition is fundamental to the definition of error, and therefore, the term error can only be applied to intentional actions. Intention, in this case, includes intention in action as well as prior intention. Errors then fall into one of two broad categories: (1) a failure of actions to go as intended (Norman's slips and lapses or Reason's execution failures) or (2) a failure to choose the appropriate actions to achieve the desired outcome (Norman's slips or Reason's mistakes failures) [15 and 16]. In either case, the intended outcome is not reached.

While the terms used in the error research literature generally refer to an individual, they could effectively be applied to the processes of industry. In the process of developing maintenance manuals, there can be failures of execution (printing mistakes, formatting errors, etc.) or failures of planning (difficult procedures, overlooked information, etc.). Failures of execution are reduced through proofreading techniques, technical monitoring, and software document checkers. Recently, efforts intended to reduce process error in manufacturing have been applied to the development of technical documents. For example, ISO 9000 certification was originally conceived as a method of improving the consistency and quality of manufacturing processes but is now being applied to the development of data as well [17]. The reduction of failures of execution requires tightly controlled procedures for data transfer and error checking. If procedures are in place to eliminate error in the transfer of data from its point of origin to its entry in the manual, the task is reduced to one of verifying that the procedures were indeed followed. If execution errors do occur, it then becomes a matter of determining whether the procedures were adequate or whether they were violated. The error source can be quickly identified and eliminated. Execution failures are the most visible type of error and the easiest to control. ISO 9000 certification seeks to eliminate execution error by documenting all procedures and then enforcing adherence to those procedures by all personnel. In its simplest form, ISO 9000 certification can be reduced to documenting what is done and doing what is documented. If problems arise, then the procedures must be adjusted to correct the problem.

Just as latent error is the more difficult type of maintenance error to address, planning failures are the more difficult type of error to identify and eliminate in document creation. In the case of a planning failure, an action is executed as intended, but when the action is followed to its outcome, it fails to produce the desired result. As it applies to maintenance manuals, a planning failure would mean that a procedure is technically sound but is misunderstood by the mechanic or fails to match the way the job is actually performed. Format checkers and peer reviews may not identify planning failures because the information may be accurate and appear to follow a logical sequence but cannot be performed by the mechanic (due to physical constraints, available tools, etc.) or may be misinterpreted by the mechanic.

Planning errors can be further separated by their ultimate outcome. Although the development process may suffer from planning and execution errors, a flawed procedure might have little negative impact due to some level of forgiveness or error tolerance within the system. In the case of maintenance manuals, this tolerance is afforded by the experience, skills, and knowledge of the mechanics. Experience allows a highly skilled mechanic to overcome minor problems using their expert knowledge to identify what the writer intended or to find a way to perform the described task. If the user lacks this expert knowledge, the tolerance for error is decreased and smaller errors have a greater potential for negative impact on the system.

In short, any attempt to improve the way in which manuals are developed requires a thorough understanding of the processes used by the manufacturers and the problems encountered by the users. In Phase 1, the focus is on the procedures used by the manufacturers to develop aircraft maintenance manuals.

3. EVALUATION.

3.1 SURVEY METHODS.

This phase sought to gain a working knowledge of the issues surrounding the development, revision, and distribution of aircraft maintenance technical manuals and the current industry procedures that address those issues. This information was gathered through the cooperation of multiple aircraft manufacturers and their personnel, including:

- Technical writers
- Customer service representatives
- Engineers
- Illustrators
- Department managers
- Manufacturer representatives

Information was collected through informal interviews and directed discussions. The topics covered in these interviews included:

- The process of developing and revising maintenance manuals.
- The systems and procedures used to coordinate information from numerous sources within the organizational structure of the manufacturer.
- The solicitation and inclusion of user feedback into the development of technical manuals.
- The means used to identify, track, and reduce error in fielded technical manuals.

In addition to these direct contacts, participation in industry conferences provided an opportunity to discuss additional industry perspectives.

Site visits were conducted at each of the participating organizations. These visits consisted of a series of meetings over the course of several days. To the extent possible, site visits included demonstrations of procedures and technology used in the technical publication process. Visits were normally arranged through a technical publications manager. In addition to the hosting manager, interviews included employees from a variety of areas in the technical manual process. Researchers were provided with copies of procedure guidelines, organizational charts, and related documents as appropriate.

The industry sample included five aircraft technical manual producers. The five organizations included manufacturers and modifiers of FAR Part 25 aircraft, representing both regional and large commercial transport models. For the purposes of anonymity, the participating organizations will be referred to throughout this report as companies V, W, X, Y, and Z. Because of the limited information available from manufacturers concerning the types and number of identified errors, data supplied by third-party maintenance facilities was used to supplement the review of problems identified in fielded manuals.

3.2 INDUSTRY ANALYSIS.

3.2.1 Who Writes Manuals?

The manufacturers differ considerably with regard to what they consider appropriate qualifications for a technical writer. For example, company X hires mostly engineers while companies V, W, and Z hire a composite of certified mechanics, writers, and technicians, while company Y hires equal numbers of engineers and former mechanics. The make-up of the technical writing staff is potentially important, as the knowledge base of the writer may not match that of the user. In some cases, an engineer's cognitive representation of a mechanical system may be very different from that of a mechanic.

3.2.2 New Manual Development.

The procedures used by the surveyed companies to develop manuals differed primarily with regard to the systems used to communicate between engineers, writers, and operators. This section is summarized in table 1.

TABLE 1. NEW MANUAL DEVELOPMENT

Company V	• All communication and transfer of engineering information is handled through a centralized computer database. • Engineering and technical publications are separate departments.
Company W	• Engineers and technical writers are collocated for new projects. • Computers are used for authoring, but integrated team meetings are used to facilitate communication.
Company X	• Engineers and technical writers are collocated for new projects. • Multiple computer systems are used for authoring. • The majority of information transfer is handled through centralized computer systems. • Integrated team meetings are also used to facilitate communication.
Company Y	• Multiple computer systems are used for authoring. • Information transfer is handled through centralized computer systems and face-to-face meetings.
Company Z	• Computers are used for authoring. • Memos, face-to-face, and electronic communications are used to transfer data.

For each of the reviewed manufacturers, the process of writing a new manual begins during the early planning stages of aircraft development. As the preliminary details of the aircraft systems are established, descriptions of aircraft systems are developed for use in the manual. To the extent possible, a framework is then developed with the anticipated information required to maintain those systems. This framework is based on established MSG logic and any similarity with existing models. From this point on, any differences between the organizations in the initial development of manuals reflect their unique approaches toward communication between various groups including writers, engineers, and customer service.

At company W, the initial development of the aircraft concept involves technical manual writers. When a new project is first proposed, a senior writer is assigned to lead manual development and is involved in the decisions regarding budget, systems, and component vendors. The senior writer has the opportunity to set requirements for the data that vendors and suppliers must provide. The senior writer is also part of an integrated product team that tracks deadlines, changes to engineering, or potential problems. The product group is a means for immediately communicating any pertinent information to all affected parties. Communication between engineers and writers is facilitated by first assigning a writing team to the new project and then having them physically move their offices to collocate with the development engineers. In this way, technical writers are aware of proposed engineering changes and can anticipate how those changes may impact their schedules. A more subtle effect of this arrangement is that technical writers are aware of the issues driving engineering changes that might be used to improve the maintenance procedures. The approach used by company W is in contrast to the computer-based solutions adopted by other manufacturers. Computers are an integral part of the writing process at company W, but greater importance is placed on maintaining face-to-face communication between the individual involved in the aircraft development process.

Companies V and X employ centralized computer databases to coordinate the writing process. When an engineer at company V develops new data, that information is entered into the centralized database along with the identity of the responsible engineer. The information entered into the database identifies all technical drawings that were modified as a result of the change. The technical writer is responsible for identifying what systems may need to be modified to reflect the change. When a writer begins work on new engineering data, their name is also added to the database. Along with the identities of the writers, information is entered about the work hours required and expected completion date. One of the primary advantages of computerized database tracking is the ability to have a real-time status report of work in progress. If a writer needs information about the way in which an engineering change will interact with the system they are responsible for, they need only consult the database and call the engineer responsible for the change data. If there is a potential interaction between systems, all of the related engineers are easily identified. The system used by company V not only tracks the development and distribution of data; it is also used to track inventory. A side benefit of this use is that, in the event that a writer has a question about the look or operation of a part, they need only consult the database with the part number and they can identify the actual bin location of the part and retrieve a sample part for inspection.

During a new airplane program, company X also has its technical writers collocate with design engineers to facilitate accurate and rapid maintenance data development. The operators are also asked to provide feedback concerning the usability of the maintenance data. Although they use face-to-face communication, much of the information exchange between writers, engineers, and operators is handled via electronic communication.

Company X uses multiple computerized databases based on a variety of electronic formats to process technical data. Engineering data, configuration data, illustrations, change requests, and workload assignments are all transferred via centralized computer systems. When an individual job is completed, the information is formatted and compiled into the manual automatically by the computer. If any formatting problems are encountered, the computer reports those problems and does not include that information until it is corrected. The software used by company X is a combination of in-house and contractor-developed systems. Multiple versions are concurrently in use as a result of the need to develop software to support new aircraft programs while maintaining existing systems to continue supporting older programs. Because of the inefficiencies resulting from multiple incompatible systems, company X is attempting to migrate to a single new system thus eliminating the problems of maintaining and integrating information from multiple platforms.

3.2.3 Configuration Management.

Configuration management within the surveyed companies differed in the degree of manual customization they provide. This section is summarized in table 2.

TABLE 2. CONFIGURATION MANAGEMENT

Company V	Manuals include all maintenance information for a model and are not customized to a specific aircraft.
Company W	Manuals include all maintenance information for a model and are not customized to a specific aircraft.
Company X	Manuals are customized to a specific operator.
Company Y	Manuals are customized to a specific operator.
Company Z	Manuals include all maintenance information for a model and a one-time manual supplement is published for each specific aircraft.

A primary reason that companies may be confronted with maintaining older and incompatible databases is due to the need to support aircraft that have remained in service longer than anticipated. These databases contain the configuration information for each airframe produced by the manufacturer. Before any change is made to a manual, the configuration information must first be referenced to determine how that change may impact each aircraft. For companies V, W, and Z that offer relatively few configuration options for each aircraft, the impact of configuration differences on manual development is minor. They produce a single manual that addresses all aircraft of a particular model type. Equipment differences are identified by aircraft serialization, and call-outs are used in the manual to identify these differences. Company Z also provides a manual supplement limited to cabin interiors and passenger amenities. This manual supplement was developed primarily as a customer courtesy and is not updated with the rest of the manual. Errors identified in the configuration management often stem from small differences between very similar systems not being identified through serialization changes.

In order to satisfy their customers, companies X and Y will produce an aircraft meeting almost any requested configuration. Therefore, unlike companies V, W, and Z, they invest a considerable effort in configuration management and support. This requires the maintenance and support of large databases and associated software. In practice, this means that not only do they produce a unique manual for a particular model but also for each operator and in some cases each aircraft.

3.2.4 Error Tracking.

The surveyed companies differed considerably in the attempt to track and identify the source of manual errors. This section is summarized in table 3.

TABLE 3. ERROR TRACKING

Company V	• Error is tracked internally but not traced for the purpose of source identification.

	• A database is maintained for errors identified by external sources.
Company W	• An error-tracking program is being developed.
Company X	• Internally and externally identified errors are recorded and tracked. • Error tracking is used as a measure of production performance.
Company Y	• Internally and externally identified errors are recorded and tracked. • Error tracking is used as a measure of production performance.
Company Z	• Error tracking is limited to manual revision history. • No attempts are made to trace error causation.

Because of the amount and specificity of the technical information, all manufacturers invest considerable effort in verifying the accuracy of new maintenance procedures. The basic proofreading process is similar across manufacturers; however, the manufacturers vary markedly in the way they handle errors once they are identified. These differences stem from what point in the development a manufacturer chooses to track errors. The first point for tracking errors is at the time of inclusion in the manual. If the development process includes a formal proofreading, errors can be recorded and tracked to identify trends. If there appears to be a pattern of errors, new procedures or training can be developed to eliminate this trend. Errors identified at this stage are limited to problems in the execution of the writing process.

The second point in the process at which errors can be tracked is after the document is released to the user. User feedback allows the tracking of not only execution errors such as incorrect part references but also planning errors such as confusing language or difficult procedures. Identifying and tracking errors in a fielded manual requires formal procedures for customer communication and feedback.

All of the surveyed manufacturers have systems for proofreading new data before it is cleared for publication. For written procedures, the first level of proofreading usually consists of a peer review. Depending on the manufacturer, the next level of proofreading includes either a review by a group lead or a document checker. Illustrations are presented to the requesting writer to verify that the drawing meets the intention of the writer. Illustrations are then checked for nontechnical errors such as line weights and call-outs. The level of formality with which these procedures is performed may differ between companies, but the basic tasks are the same. Where companies differ considerably is in the tracking of the errors identified during the proofreading process.

While all of the surveyed companies have error-checking procedures, only companies V, X, and Y attempt to catalog the errors. At the time of survey, company W was attempting to establish an error database. For those that catalog errors, it is generally limited to process errors, or errors found before the release of manual data. Even for those companies that do attempt to catalog errors, there is little systematic source tracking of the errors. Company V maintains a database of customer service reports, cataloged by aircraft model, but does not attempt to identify the error source. Only company X maintains a detailed database of the errors and attempts to track their source.

For each of the companies, there is a reluctance to maintain detailed records of past errors because of fear of how that information could be used. Employees are wary of errors being traced down to the level of the individual for fear of punitive repercussions affecting pay or promotion. The companies are also wary of maintaining a detailed error history because of exposure to liability or regulatory action.

3.2.5 Customer Feedback.

All of the surveyed companies have systems for receiving and responding to customer feedback. This section is summarized in table 4.

TABLE 4. CUSTOMER FEEDBACK

Company V	• A customer service hotline is maintained. • Customer feedback is entered into a database and tracked by comment, aircraft model, and planned response. • A website is available for customer feedback.
Company W	• A customer service hotline is maintained. • Users are solicited through written and phone surveys. • A website is available for customer feedback.
Company X	• Customer service is handled through a network of field representations, telephone hotline, and teletype communications. • Customer site visits have been used. • A website is available to customers that allows for customer feedback, access to all maintenance documents, and aircraft information.
Company Y	• Customer service is handled through a network of field representations, telephone hotline, and teletype communications.
Company Z	• A customer service hotline is maintained. • A website is available for customer feedback.

The handling of customer feedback in most companies is similar to new engineering data. After a customer reports a problem, their complaint is checked for (1) accuracy (2) if the complaint involves factual data or practicality, or (3) if it involves rephrasing or modifying a procedure. Customer support personnel are usually trained mechanics that are well acquainted with the aircraft they support, so they are often responsible for evaluating the content of a customers comment. Next, the data is routed to either engineering or technical publications for comment. For those manufacturers that utilize Integrated Product Teams, the information is brought to the team for review. Once it is determined that a change is warranted, the task is assigned a revision schedule. Manufacturers have procedures for triage of revision data based on the manual chapter affected, the extent of the change, the perceived importance, and budget considerations. Regardless of the manufacturer, exceptions are made for information directly impacting the safety of flight. Safety of flight data is handled immediately and will often result in the issuing of a temporary revision.

Each of the surveyed companies maintains customer support networks that gather feedback from users and answer questions. Customer feedback can be gathered through mail, telephone hotlines, fax, Teletype, and e-mail. In addition to direct contact with the manufacturer, factory representatives and service centers are available. Typically, problems reported through hotlines or customer support pertain to a specific issue associated with the manual (e.g., a question about a specific procedure) and reveals little about the users perception of the overall quality of the technical documentation. Companies have attempted to use surveys to solicit more general information about how they might better meet the needs of the users. Phone solicitations and mass mailing have been used to obtain user feedback. The quality of this information is often suspect because the feedback is usually not very specific and is frequently limited to blanket statements of like or dislike. In an attempt to improve the quality of feedback gathered through user survey, on-site surveys and interviews have also been performed. Whether it is a function of the unexpected nature of the unsolicited contact, the lack of salient examples of problems, or low motivation, the average response to manufacturer-initiated surveys adds little to the information already gathered through user-initiated contacts.

3.2.6 Validation.

Procedure validation is only used to a limited degree within the surveyed companies. This section is summarized in table 5.

Rather than relying solely on user feedback to identify problems with new or significantly changed procedures, the aircraft manufacturers have used validation techniques to evaluate the quality of the procedures. Validation involves actual users attempting to complete a procedure and reporting any difficulties encountered. The validation is performed under conditions that replicate the working environment as closely as possible so that performance can be expected to be similar to the real world. Validation is an excellent means of testing the maintenance data without the potential for costly mistakes. Procedure testing has the added benefit of encouraging communication between the user and writer. A procedure may appear to be accurate and sound, but when a user attempts it, they find an easier way, or suggest information that might aid a mechanic in completing the procedure. In some cases, safety or economic limitations preclude the validation of a procedure through user performance. For example, many troubleshooting procedures cannot be validated unless a specific component is damaged. To simulate a damaged component, or to actually damage a component, may not be economically feasible or may impose a potential safety risk. In these cases, validation procedures can be extended to include simulated task performance and user analysis of instructions. Simulation would involve a user working through a task in accordance with the maintenance instructions without actually performing the task. The analysis involves a user reading through the maintenance instructions with the purpose of identifying potential problems or concerns. Analysis, simulation, and performance can be thought of as a set of validation “tools” to be applied as appropriate in light of the constraints imposed by the task to be evaluated.

TABLE 5. VALIDATION

Company V	• Writers, with the aid of service center mechanics, can verify written procedures or descriptions.
Company W	• Writers have access to aircraft during production if they want to verify a

	written procedure or description.
Company X	• All scheduled maintenance procedures pertaining to two of the newest models are validated.
Company Y	• Procedures are evaluated through analysis, simulation, and performance. Validation is applied to procedures identified as problematic.
Company Z	• An attempt has been made to validate new procedures but is often based on prototype aircraft.

All of the companies surveyed have used some form of procedure validation, but most use it in an unsystematic fashion. Companies V, W, and Y will validate procedures that a writer is unsure of or that have gotten negative comments from field users. In most cases, validation testing at these companies is done by the actual writer or the writer and a company service center mechanic. Company X has been validating all scheduled maintenance procedures for two of its latest airplane models. The choice to validate maintenance procedures was part of a customer support strategy, aimed at improving the quality of new aircraft models. Company X has not retroactively applied the extensive validation process to existing airplane programs. Company Z has initiated an effort to validate new procedures, but has found that development schedules have forced testing to take place early in the prototyping stage, resulting in much of the information becoming irrelevant as the engineering changes. In reality, access to an actual aircraft is limited and procedures are usually written using engineering documents alone.

3.2.7 Measures of Document Quality.

Each of the surveyed companies lacked an objective method for measuring the quality of manual data. This section is summarized in table 6.

Each of the surveyed manufacturers reports customer satisfaction as the primary measure of document quality. Measures of customer satisfaction are based on feedback gathered through customer support. In some cases, user surveys conducted by industry journals are used as a benchmark for comparison with other manufacturers. Within the individual companies, quality is also judged on more subjective criteria including the degree to which the writing adheres to an established look, feel, or style. Decisions regarding the details of wording and writing style are left to the judgment of the writer, and through the feedback of lead writers, an appreciation for these subjective criteria is conveyed to less experienced writers. Whether it is performed by a peer or a formal evaluation procedure, all the manufacturers audit revised data for technical accuracy in terms of procedural logic, efficiency, source data accuracy, and completeness. However, it should be emphasized that there is currently no independent measure of manual quality derived using psychometric principles. Instead, quality standards derive from company history and what users have accepted in the past.

TABLE 6. MEASURES OF DOCUMENT QUALITY

Company V	• New procedures are reviewed by a peer, approved by a lead writer, and proofread for grammar and typographic accuracy. • Vocabulary is limited to include only words found in the United States Air

	Force dictionary. • The writing process is ISO 9000 certified.
Company W	• New procedures are reviewed by a peer, approved by a lead writer, and proofread for grammar and typographic accuracy. • Attempts are being made to become ISO 9000 compliant.
Company X	• New procedures are reviewed by a peer, approved by a lead writer, and proofread for grammar and typographic accuracy. • Procedures are checked for adherence to the simplified English standard. • The writing process is ISO 9000 compliant and certification is expected.
Company Y	• New procedures are reviewed by a peer, approved by a lead writer, and proofread for grammar and typographic accuracy. • Procedures are checked for adherence to the simplified English standard. • The writing process is ISO 9000 certified.
Company Z	• New procedures are reviewed by a peer, approved by a lead writer, and proofread for grammar and typographic accuracy.

3.3 SIGNIFICANT ISSUES.

Although no recommendations will be made until the completion of this project, the following issues were identified during Phase 1.

3.3.1 Inconsistent Guidelines for Control of the Development Process.

In many cases, the development of manuals is driven by "tribal knowledge" and company history rather than clearly defined standards. As a result, it is hard to implement and enforce improved procedures. At the time that this report was written, only companies V, X, and Y have sought ISO 9000 certification of their technical writing process. ISO 9000 is only one of the options for verifying compliance to company procedures and certainly not without its own costs. However, some effort is required to verify that all published technical information adheres to the same standard and is generated in a manner consistent with established company procedures. Measures of quality should be based on adherence to established procedures rather than a lack of customer complaints. Customer response should drive the guidelines used to develop the manual, rather than serve as measure of document quality. If detailed guidelines are maintained and enforced, the source of any resulting error could be easily tracked and corrected.

3.3.2 Use of Feedback.

The use of user feedback is generally limited to a reactive response to problems as they are identified. Users function as the final stage of proofreading for the manual, with the downside that they can only perform that function once the offending procedure has been attempted and a difficulty is encountered. The primary shortcomings of using user feedback are that (1) users are allowed to encounter a procedure that has the potential to result in an unchecked maintenance error, (2) errors in procedures that are not frequently used may go unidentified for a long period of time, and (3) the user must identify the error and take the time to report it. This could be eliminated by testing or validating the quality of procedures before their release.

Except for isolated cases, the validation of maintenance procedures is not a part of the standard development process. When validation is performed, testing usually involves company employees rather than representative users. The testing of procedures is intended to identify problems before the manual is distributed to users. A critical part of usability testing is the evaluation of procedures under real-world working conditions, using mechanics that are representative of the user population. Company-employed mechanics fail to represent field users to the extent that they are part of company culture. Likewise, if a consistent pool of field mechanics is maintained to act as participants in validation studies, they will cease to represent the broader user population as they become more acquainted with the culture of the manufacturer.

When designing any product, the ultimate success of that design is dependent on how valuable the intended user finds it. In the technology sector, usability testing has become a crucial part of new product development. At the heart of designing a usable product is the adage, "Know thy user." Whether the product is a portable electronic device, a software product, or a maintenance manual, it should be designed with the user's experience, preferences, and abilities in mind. If designers fail to gather this type of information about their users, the only choice they are left with is to design with their own experiences and preferences in mind. In almost every case, this results in a drastically misdirected effort. Technical writers spend their days submersed in engineering drawings and the writing process. Aircraft mechanics spend their days submersed in the task of maintaining aircraft; to them a maintenance manual is merely an addition to the collection of tools necessary to complete a task. They are not privy to, nor do they have the time to research, all of the information available to writers. What is dismissed as elementary to the writer may pose a serious obstacle to the mechanic.

3.3.3 Tracking Manual Quality.

One of the primary goals of this research phase was to develop an estimate of the degree of error present in fielded technical manuals. To date, this has not been accomplished, primarily because such data is not tracked by manufacturers to a level sufficient for making such an estimate. The majority of error tracking done by manufacturers is limited to those errors identified before release. Monthly reports of illustration, grammar, and configuration errors are used to measure the work output of various departments. This type of tracking is useful for maintaining internal control of procedures but provides no information about the quality of fielded manuals. As they relate to fielded manuals, errors identified before release are a measure of success rather than failure.

Preliminary interviews of mechanics at project partner airlines indicate that fielded manuals contain very little erroneous data. In the case of one large and active maintenance facility, mechanics report finding an average of only two-three errors per year in the entire collection of manuals. Analyses of manufacturer customer feedback and error databases maintained by third-party maintenance facilities reveal similar levels of technical accuracy. While there were cases of incorrect part numbers and torque settings, the majority of technical errors appeared to have resulted from attempts to speedup the writing process using computers. For example, configuration errors, resulting from copying text from the manual of a similar aircraft or formatting errors, were caused by failing to update image links.

Mechanics that were asked about the technical accuracy of maintenance procedures, reported that they were generally very good. However, when asked about problems encountered while using manuals, mechanics reported having encountered awkward procedures and confusing diagrams. In some cases, suggestions were made to add additional labels warning against potential mishaps; all of which relate to larger usability issues, rather than simply verifying the accuracy of included data. As mentioned previously, Phase 2 of this project will explore these issues in greater depth through user interviews. In addition to the tracking of internally identified errors, writers should seek to track usability problems encountered by users. Responding to trends in user problems will lead to constant improvement in the manuals, resulting in the best possible product rather than one that is merely acceptable.

3.4 FINAL COMMENTS.

Of the identified issues, none are meant to be direct criticisms of the personnel responsible for developing technical manuals. In nearly all cases, these issues were offered, in one form or another, by the technical writers themselves as ways of improving the technical manual process. To simply suggest that such changes be added to the existing task of manual development would serve to overload a system that is already operating at capacity. The time and budget constraints that manufacturers place on their technical writing departments has forced them to do the best they can with what they have. Writers are aware of the potential benefits of detailed error tracking and procedure validation; they simply lack the resources needed to enact these programs. An underlying concern is the degree of influence that maintenance technical writing departments are given within their respective companies. It has been suggested, that during times of financial difficulties, technical writing departments are often the first to suffer reduced funding. Although it is outside of the scope of the current study, it should be noted that many of the surveyed companies cited difficulties in hiring and retaining sufficient numbers of qualified writers. Typically, technical writers do not command salaries as high as other areas of design, and as result, it is harder to find qualified applicants to fill writing positions. On occasion, writers are even lured to other, higher paying jobs within their own company. As a result, time and effort is required to train and supervise writers that could otherwise be dedicated to improving manuals.

Finally, although the application of computers has transformed the manual writing process, it has created an unforeseen problem for technical writers in the expectation that technical documents can now be generated much more quickly. Word processing software has made some areas of manual development, such as spell checking and the handling of illustrations, much faster and easier, but the time required to generate manual content has changed very little. Technical writers must now battle the perception that they should be able to instantly update manuals as new engineering is released. This perception further aggravates the problems created by the limited budget and scheduling resources allotted to technical publications departments.

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