Assessment of Aviation Maintenance Technical Manuals

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1. Background – Aviation Manuals

Aircraft maintenance technical manuals have been in use from the earliest days of flight. Aircraft are typically complex and technologically advanced machines, requiring detailed information to guide the many aspects of maintenance operations including airframe, engine, and component repair.

The format for technical manuals has been largely standardized over the years, primarily through the application of industry standards such as the Air Transport Association's Specification 100. Through this standardization, the "look and feel" of various types of manuals is readily apparent, from maintenance manuals to illustrated parts catalogs to fault isolation manuals. The standardization extends to the format of each type of page, the format for cautions and warnings, margins, weight of paper, type fonts, placement and size of holes, etc.

Technical manuals have grown in volume and weight as aircraft systems have become even more complex and sophisticated. The process for making page-by-page changes to these manuals has grown increasingly cumbersome and expensive. Development and distribution of paper-based changes to a worldwide set of aircraft operators is a major industry unto itself, as original equipment manufacturers have outsourced a significant amount of this activity to third-party providers.

During the 1980s and 1990s, significant progress was made to develop alternatives to the paper-based system of manuals. The first generation of *microfilm and microfiche products have been replaced by CD-ROM* versions that have vastly improved portability and ease of manufacture. Eventually, sufficient standards were in place to contemplate a complete shift away from the paper-based standards of the past to a fully digital set of technical information that could be accessed by key word or link. *Interactive Electronic Technical Manuals (IETMs)* are now being developed and fielded that are based on the manufacturer's original design data base, which feed performance history back to the same data base. The digital links also serve to minimize potential errors that can be built into the translation process from design to technical manual formats.

The transition to the digital vision has not occurred as rapidly as may have been originally hoped. For a variety of reasons, there is an apparent reluctance to abandon the page-based formats of the paper technical manuals, particularly for flight-critical applications where correct information is essential to safe operation of the aircraft. In addition, there are paper-based manuals, which will exist for the lifetime of aircraft, particularly for types that are out of production. Paper-based technical manuals will be a fundamental part of the industry for the foreseeable future.

Thus, the Federal Aviation Administration (FAA) is embarking on a study that will assess the maintenance manual process. This study will

- identify the processes employed to develop and update aviation maintenance technical manuals;
- assess the degree of error that is inherent in contemporary versions of these publications;
- identify principal causes for such errors, and suggest practical approaches to minimize error as appropriate; and
- Identify and summarize measurements and assessments of the effectiveness of the present system of technical manuals and evaluations of the mechanisms employed to make revisions.

2. FAA Guidance

2.1 FAA Aviation Regulatory Requirements[1]

This section contains a brief overview of critical Federal Aviation Regulations (FARs) that provide controls for the maintenance program.

FAR Part 121.363, Responsibility for Airworthiness, states that each certificate holder is primarily responsible for (1) the airworthiness of its aircraft, including airframes, aircraft engines, propellers, appliances, and parts thereof; and (2) the performance of the maintenance, preventive maintenance, and alteration of its aircraft, including airframes, aircraft engines, propellers, appliances, emergency equipment, and parts thereof, in accordance with its manual and the regulations of this chapter. This FAR Part also states that the certificate holder may make arrangements with another person, e.g., repair station, for the performance of any maintenance, preventive maintenance, or alterations. However, this does not relieve the certificate holder of the responsibility regarding the airworthiness of the aircraft.

Synopsis: The FAA holds an air carrier accountable for the airworthiness of its operating fleet of aircraft.

FAR Part 121.365, Maintenance, Preventive Maintenance, and Alteration Organization, states that each certificate holder that performs any of its maintenance (other than required inspections), preventive maintenance, or alterations, and each person with whom it arranges for the performance of that work, must have an organization adequate to perform the work.

Synopsis: The FAA holds the air carrier responsible for all outsourcing maintenance. The facility must have adequate personnel, equipment, and material to perform the work.

FAR Part 121.367, Maintenance, Preventive Maintenance, and Alterations Programs, states that each certificate holder shall have an inspection program and a program covering other

[1] Extracted from the Code of Federal Regulations, Title IV, Aeronautics and Space

maintenance, preventive maintenance, and alterations that ensures that maintenance, preventive maintenance, and alterations performed by it or by other persons (e.g., FAR-145-certificated repair stations) ***are performed in accordance with the certificate holder's manual***; competent personnel and adequate facilities and equipment are provided for the proper performance of maintenance, preventive maintenance, and alterations; and each aircraft released to service is airworthy and has been properly maintained for operation under this part.

Synopsis: Basically, the air carrier must conduct its inspection program in accordance with its approved program as stated in their operation specifications and maintenance in accordance with the air carrier maintenance manual that has been accepted by the FAA.

FAR Part 121.369, Manual Requirements, states that each certificate holder shall put in its manual a chart or description of the certificate holder's organization required by FAR Part 121.365, and a list of persons with whom it has arranged for the performance of any of its required inspections, other maintenance, preventive maintenance, or alterations, including a general description of that work. Specifically, this FAR Part requires that

a. The certificate holder's manual must contain the programs required by Sec. 121.367 that must be followed in performing maintenance, preventive maintenance, and alterations of that certificate holder's airplanes, including airframes, aircraft engines, propellers, appliances, emergency equipment, and parts thereof.

b. The certificate holder must set forth in its manual a suitable system (which may include a coded system) that provides for preservation and retrieval of information in a manner acceptable to the Administrator[2] and that provides

   - A description (or reference to data acceptable to the Administrator) of the work performed;

   - The name of the person performing the work if the work is performed by a person outside the organization of the certificate holder; and

   - The name or other positive identification of the individual approving the work.

Synopsis: An air carrier maintenance manual must meet the FAA requirements that are delineated in this FAR section.

FAR Part 121.373, Continuing Analysis and Surveillance, states that each certificate holder shall establish and maintain a system for the continuing analysis and surveillance (CAS) of the performance and effectiveness of its inspection program and the program covering other maintenance, preventive maintenance, and alterations and for the correction of any deficiency in those programs, regardless of whether those programs are carried out by the certificate holder or by another person.

[2] The term *Administrator*, used throughout this paper, refers to the FAA Administrator.

Synopsis: The FAA holds an air carrier accountable for a well maintained inspection program that is inclusive of its maintenance program.

FAR Part 121.379, Authority to Perform and Approve Maintenance, Preventive Maintenance, and Alterations, states that

a. A certificate holder may perform or may make arrangements with other persons to perform, maintenance, preventive maintenance, and alterations as provided in its continuous airworthiness maintenance program and its maintenance manual. In addition, a certificate holder may perform these functions for another certificate holder as provided in the continuous airworthiness maintenance program and maintenance manual of the other certificate holder.

b. A certificate holder may approve any aircraft, airframe, aircraft engine, propeller, or appliance for return to service after maintenance, preventive maintenance, or alterations that are performed under paragraph a. of this section. However, in the case of a major repair or major alteration, the work must have been done in accordance with technical data approved by the Administrator.

Synopsis: The FAA grants authority to the air carrier to perform aircraft maintenance in accordance with an *FAA-accepted* maintenance manual. The maintenance may be conducted in-house or outsourced to an FAA-approved facility. In addition, the air carrier may conduct maintenance of another air carrier's aircraft. However, that maintenance must be conducted in accordance with the other carrier's *FAA-accepted* maintenance manual. Finally, in the case of a major repair or major alteration, the work must have been accomplished in accordance with technical data approved by the FAA.

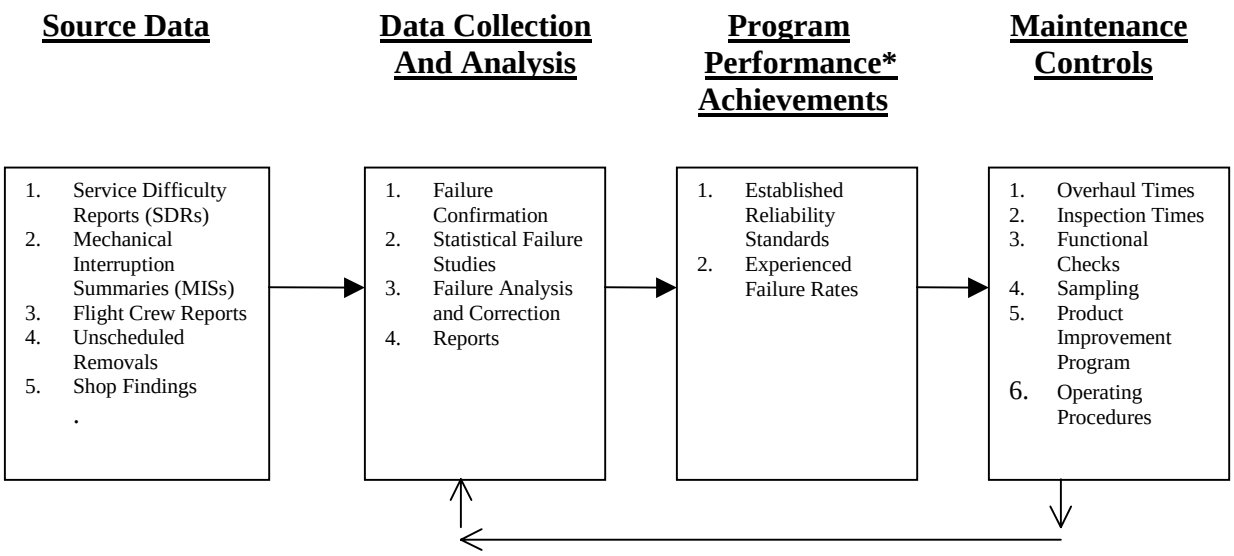
2.2 Advisory Circular on Maintenance Control by Reliability Methods

The FAA Advisory Circular 120-17, *Maintenance Control by Reliability Methods,* provides information and guidance material *which may be used*[3] to design or develop maintenance reliability programs. Also included is a standard for determining time limitations.

Figure 1 provides a model of a generic reliability program operation. In order to develop a quality reliability program, an air carrier needs to establish a data collection system related to aircraft system and/or component reliability. The air carrier must then be able to conduct data analysis and then to apply the analysis to maintenance program controls. Once the air carrier has been able to prove to the FAA that it has a quality reliability program, the carrier may petition the FAA to alter maintenance intervals.

Thus, it is conceivable for an air carrier to seek maintenance interval changes as described in the Airframe Maintenance Manual (described in more detail in section 4) based on a technically sound maintenance reliability program. By proving to the FAA that an interval change is not compromising safety, the air carrier could save millions of dollars in maintenance expenditures.

[3] Not an FAA requirement. However, the air carrier must seek FAA approval for a reliability program.



*Established reliability standards (based on operating history and the airworthiness significance of aircraft system or component under consideration) as compared to experienced failure rates realized in program operation

Figure 1: Reliability Program Operation

3. Problem

In order to carry out maintenance, there is still a need for technically sound and properly maintained maintenance manuals that contain accurate procedures and technical data. However, there is a growing body of evidence that the current system of technical manuals may be inadequate to prevent errors in task accomplishment. Technical manuals may contain an unacceptable level of built-in errors generated from within the publication process. For example, tasks that are inadequately or incorrectly generated from within the publication process or tasks that are inadequately or incorrectly defined are likely to generate process errors. Process errors, in turn, can lead to equipment failure and costly rework. Three illustrations of this type of evidence follow.

a. The National Transportation Safety Board Accident and Incident database contains instances where technical manuals were a primary or contributing cause. One example from the mid-1990s involved a jet engine which was incorrectly installed due to errors in maintenance documentation and which subsequently fell off at an overseas location.

b. The FAA has sponsored research under its Human Factors Program that has identified the substantial potential for error in task documents.

c. Companies working to develop Interactive Technical Manual Systems have documented the extent of error from paper-based systems which might be replaced or avoided using linked digital technical information.

In a study recently published by the Australian Transport Safety Bureau, the most commonly reported unsafe act in aircraft maintenance involved either failing to refer to a maintenance manual or being misled by confusing documentation (Hobbs & Williamson, 2000)[4]. This study was a culmination of responses to a set of questions that were "…designed to identify safety issues in maintenance, with a particular emphasis on human factors." Their results[5] indicated that

a. 67% of the respondents reported being misled by documentation

b. 73% of the respondents failed to refer to manual on a familiar job

c. 7% of the respondents failed to refer to manual on an unfamiliar job

d. 34% of the respondents didn't refer to parts catalog when ordering parts

e. 47% of the respondents have performed jobs in a way they think is better than that outlined by the manual

Thus, the processes employed to create and update technical manuals need to be reviewed to assure that the processes produce a minimal error rate.

4. Research Objective

An FAA research effort has been initiated that will identify the processes employed to develop and update aircraft maintenance technical manuals. It will further assess the degree of error that is inherent in contemporary versions of these publications, identify principal causes for such errors, and suggest practical approaches to minimize error in page-based manuals as appropriate. Finally, it will identify and summarize measurements and assessments of the effectiveness of the present system of technical manuals, including estimates of usage rates and evaluations of the mechanisms employed to make revisions. For our research effort, we will focus on airframe maintenance manuals.

5. Airframe Maintenance Manuals

The issue surrounding the development and subsequent use of airframe maintenance manuals are twofold. The first issue is the content of the manuals, their design (ease of use), and the clarity of the information contained. The second is the varying differences based on the aircraft's

[4] Hobbs, Alan (Australian Transport Safety Bureau) and Williamson, Ann (University of New South Wales), *Aircraft Maintenance Safety Survey – Results*, Department of Transport and Regional Services, Australian Transport Safety Bureau, 2000.
[5] Percentages include those technicians that report engaging in a behavior occasionally or often.

configuration and the changes or omissions in maintenance procedures used in the accomplishment of maintenance and inspection.

Manuals are developed during the aircraft design process often in isolation by the engineering departments of the Original Equipment Manufacturer (OEM). During the design and development stage the OEM produces a Maintenance Planning Document (MPD). The FAA also developed a Maintenance Review Board (MRB) process to supplement the MPD in developing initial maintenance and inspection programs. In the late 1960s, representatives of various airlines developed Handbook MSG-1, *Maintenance Evaluation and Program Development*. This document included decision logic and inter-airline/manufacturer procedures for developing a maintenance program for the then new Boeing 747 aircraft. The latest revision, MSG-3, was a combined effort of the FAA, United Kingdom Civil Aviation Authority, aircraft and engine manufacturers, and U.S. and foreign airlines.

The MSG-3 recognized the new damage tolerance rules and the supplemental inspection programs and provided a method by which their intent could be adopted to the MRB process, as shown in figure 2. The aircraft cannot be issued a Type Certificate unless the MRB process is complete. This was not the case in the past and allowed for numerous errors and omissions in the maintenance programs and manuals. Out of this process a generic set of maintenance task cards are also developed. These are actual work instructions, which are required to be an exact replica of the maintenance procedures located in the maintenance manual.

Thus, every airline purchasing aircraft from the OEM specifies or selects from a variety of choices how the aircraft will be configured. Then each manual is specifically tailored to meet the maintenance needs of the aircraft and its systems. If airline A buys a B757 and selects certain options and airline B purchases the very next aircraft off the production line, but selects different options, the two maintenance manuals, although very similar, are not exactly alike. In some cases, the information that is placed in these manuals are extracted from the basic document but erroneously placed into the wrong operator's manuals.

To further complicate matters, each airline can develop and modify its own maintenance program based on its operating experience and capabilities. Basic information contained within the original OEM manuals, i.e., inspection intervals, could be extended by the airline, based on its approved reliability records. The procedures for this are contained within the reliability program manual or an approved section of what is commonly referred to as the General Maintenance manual (GMM) and supported by the airline approved reliability program. Many airlines outsource their maintenance to certified Part 145 repair stations, which are required by regulation to maintain that aircraft under the airlines' maintenance program[6]. This in itself creates problems. It is feasible and very common place to have two model B757-200s in the repair station for maintenance at the same time and the work being accomplished by the same maintenance staff. However, should the two aircraft be from two different airlines they will probably have to be maintained under different procedures using the airline's specific task cards.

[6] Reference: FAR-145.2, *Performance of Maintenance, Preventive Maintenance, Alterations, and Required Inspections for an Air Carrier or Commercial Operator Under the Continuous Airworthiness Requirements of Parts 121 and 127, and for Airplanes Under the Inspection Program Required by FAR-125*.

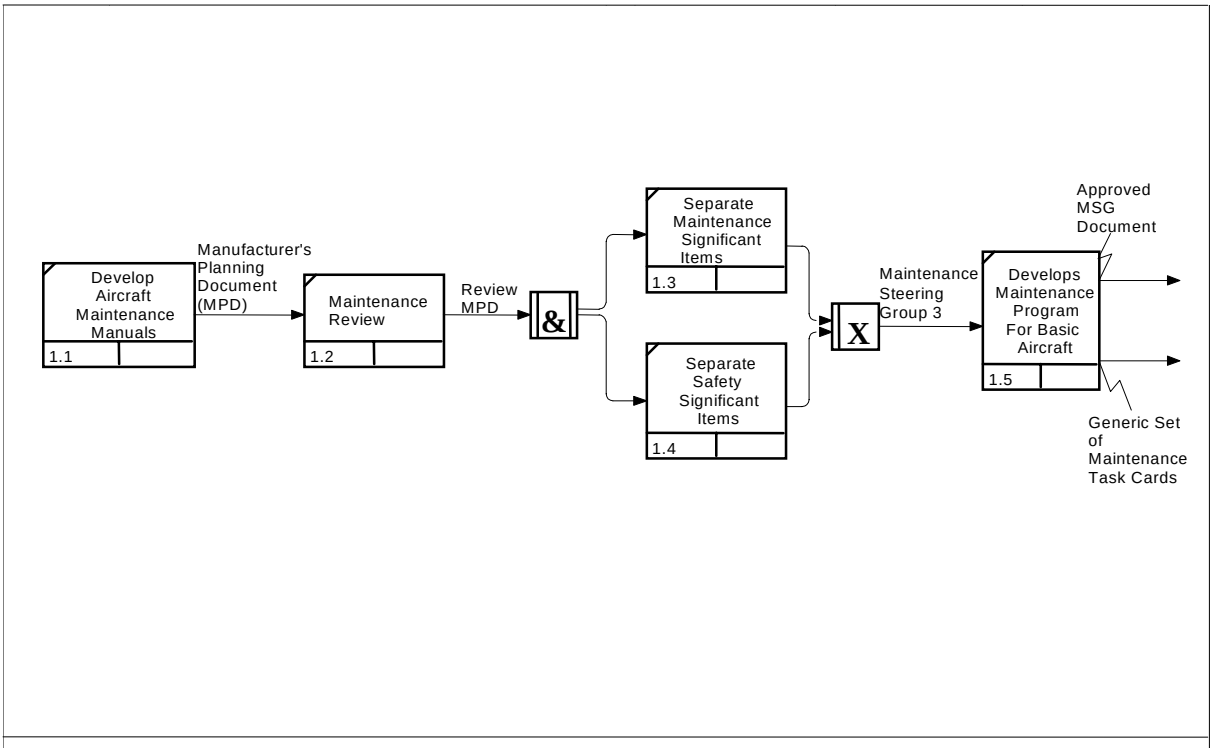


Figure 2: Airframe Maintenance Manual Development Process

A direct quote from an employee at a FAR 145-certificated repair station follows:

> "Each customer has their own maintenance manuals, illustrated parts catalogs, structures repair manual, general maintenance manual, quality control procedures manual, maintenance procedures, routine job cards and non-routine job cards. These documents are mixed with our general maintenance manual and our own job cards. Imagine, at one time we can have three or four customer aircraft in work, all of the same type and model, with a different set of paper work for each. Keeping all the documentation straight and correct is a real challenge. It is an area where it is easy to make errors if not very alert and careful. Mechanics with experience should be used to write job cards; there would be fewer errors, more productivity."[7]

Further complicating the issue is the application of Supplemental Type Certificates (STC) which are usually applied after the aircraft is in service. It has been found that in many cases the STC contains significant amounts of instructions for the installation of the modification but are completely void in the area of maintenance procedure addressing the continuing airworthiness of the aircraft. This is often the case when the FAA issues a Field Approval[8], which subsequently becomes an STC.

The varying degrees and frequencies of changes made to maintenance manuals and their procedures often leave the mechanic unaware of the latest maintenance requirements. Coupled

[7] Goldsby, Raymond P. (Senior Aviation Specialist) *Improving Operations and Oversight of Contract Maintenance,* Galaxy Scientific Corporation, Information Technology Division, 1999.
[8] FAA Form 337, Request for Automation of Major Alteration and Repair Data

with a manual that is hard to research and retrieve information from, the mechanic, in many cases, defaults to memory in the accomplishment of his/her assigned tasks. Additionally, manuals with varying changed procedures often allow for errors in the task cards, such as omissions and out dated information. Although it is the carrier's responsibility to ensure that the documents and manuals are correct and current with the vast numbers of changes occurring on a fairly frequent basis, this sometimes slips through the cracks and work is preformed without current instructions.

6. Approach

The FAA, with support from Wichita State University (WSU), is undertaking the review of how aviation airframe maintenance technical manuals are developed and revised, to assess the potential for erroneous material and to seek interim solutions to reduce erroneous material, short of full digitization of the information.

Conduct Surveys. Sample surveys will be conducted of fielded technical manuals to identify published errors from an airline's perspective. The feedback information regarding the usability and accuracy of technical manuals from the users' perspectives will be obtained. In addition, our desire is to obtain systemwide information regarding publication errors from other existing sources, including published research and industry surveys. The objectives are to:

- Identify the degree and types of error present in current fielded technical manuals

- Survey maintenance technicians to assess user perceptions of accuracy, flexibility, clarity, and efficiency, as well as user satisfaction with current technical manuals.

Interviews. We will compliment the survey results with interviews of maintenance technicians at a variety of facilities regarding their use and perception of technical manuals. The goal is to meet with engineers, technical writers, customer service personnel, and related managers. To the extent available, we will compile information from company databases about the types and frequency of documentation errors, as well as the types and frequency of customer responses. Eventually, we will compare user feedback with data related to the development and revision of manuals in an attempt to quantify the strengths and weakness inherent in a given development/revision process style.

Examples of Questions. Although the list has not been completed; we still need input from industry. The final set of questions will be based on our analysis of manufacturer databases, preliminary studies, and existing literature. The questionnaire will be tested on a sample population and revised before widespread use. Consideration will be given to scope, thoroughness, term usage, and time requirement.

Typical questions to be posed include:

- Manual Usage

    1. What is the usage patterns?

2. How does user perception of technical manuals affect their usage?
3. What is the possibility of standardizing all air carrier manuals?

- Users

1. What training is required or provided for use of technical manuals?
2. How do users confirm suspected errors?
3. How do users report errors?
4. What feedback do they receive?
5. How are other workers notified of errors?

- Errors

1. Is there a lack of detail explanation in the manuals?

2. Has the user experienced any situation of incorrect information? Omission? Typographic?

- Usability

1. Is the technical material/data in the manual clear?
2. Are the manuals easy to use?
3. Is the organization of the manual sensible?
4. What is the overall level of satisfaction?

Human Factor Analysis. As part of our usability analysis, human factors experts will examine the potential for aircraft maintenance technicians or other users to identify problems in technical manuals. This review will also explore suggested approaches to identify and correct errors in technical manuals.

Some of the usability issues to be explored include:

- Inherent process error
- Error sensitivity
- Ease of error identification
- Reading level
- User preference

Some of the human factor questions being proposed in support of this area are:

- Are users able to identify errors when they exist?

- What process variables have the greatest impact on errors and perceived usability?

- What practical improvements can be made to the existing system of manual development and revision?

As a final step, human factors experts will review current processes for the development and revision of manuals. Information about the development and revision processes will be tracked to errors and user perceptions of usability to identify inherent strengths and weaknesses of a given process.

Reporting the Results. Based on the information gathered through the efforts described above, potential problems in the development, updating, and usage of technical manuals will be identified. A report describing the problems with recommendations for addressing them will be prepared. The final report is scheduled for release in February 2002.

7. Initial Findings

The effort was initiated this past July 2000. To date, we have uncovered several critical findings warranting both FAA and industry attention.

Consistency. The process used by a particular manufacturer today may very likely change a year from now. The manual development and revision processes for new models may often differ from legacy manuals. Quality assessments of manuals are often based on either customer complaints or industrywide evaluations.

Use of Simplified English. In many cases, maintenance manuals are very complex and prepared by well-educated engineers. The users may not possess the same reading grade level. Thus, the material in these documents may be subject to misinterpretation. Most, if not all, maintenance facility personnel would agree that *Simplified English* reduces comprehension errors by at least half. The technology to convert all maintenance documents exists, *why isn't its use a requirement*?

Users' Input. Manufacturers generally lack detailed knowledge of user problems and manual usage rates. User problems are primarily identified through customer helpline calls. Rarely are users consulted in the design of manual procedures. Manuals are often customized to suit a particular operator.

Errors in Manuals. Typical errors that have been identified to date include:

- Referenced chart or table may not agree with the text
- Spelling/grammatical errors
- Tasks are inadequately or incorrectly described

Update Notification. There is no standard method for a maintenance facility to be informed that it has the most current version of a maintenance manual. Some manufacturers do maintain this type of information on their websites. Others might provide this information on compact discs, hardcopy mailings, etc. It is an FAA requirement that maintenance be conducted in accordance with the most current maintenance manual.

Technical Writers. There is a shortage of well-trained technical writers. In fact, most manufacturers do not have a training program for technical writers. There is such a demand for technical writers that the positions are being filled by individuals who have none or limited technical writing expertise. Since there are no standards for the preparation of maintenance manuals, format and style inconsistencies are found in many manuals.

Shortage of Aircraft Maintenance Technicians. A Pilots and Aircraft Maintenance Technicians (AMTs) for the 21st Century: An Assessment of Availability and Quality (1993), Blue Ribbon Panel Study indicated that that there were no numerical shortage of AMTs. However, as shown in figure 3, the demand for AMTs will drastically increase. Ultimately, the major air carriers will feel the shortage as they conduct maintenance of their aircraft. Exacerbating the problem is the dwindling number of (ex-military personnel with aviation maintenance experience.

Figure 4 shows that there was over a 50% decrease in the number of first-year active duty a military personnel in aviation maintenance from 1986 through 1995. Thus, the pool for available talent has dramatically decreased. This will necessitate doing more with less, i.e., working overtime, increasing productivity, etc. Having easy to use and understandable maintenance manuals would be a welcome relief.

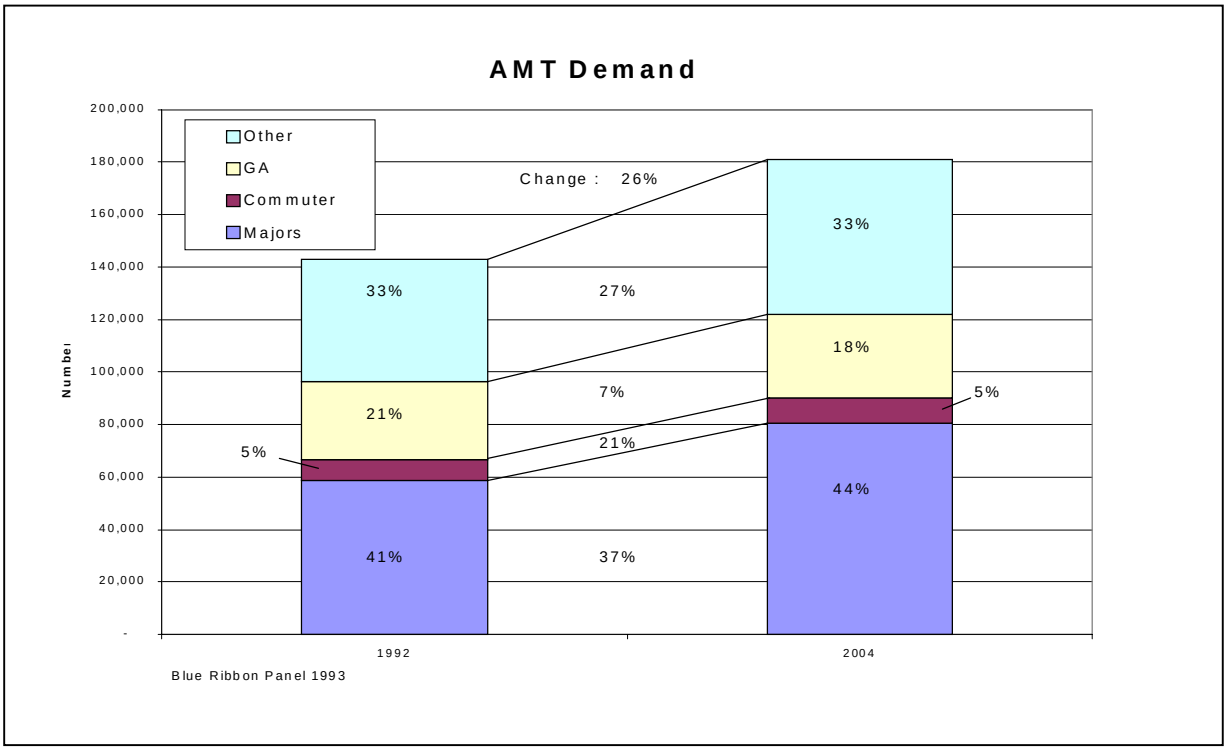


Figure 3: Aircraft Maintenance Technician Demand

Figure 4: Aviation Maintenance, First Year of Duty

8. Conclusion

Today's aircraft are complex marvels of engineering success. Their maintainability requires continuing analysis and surveillance that should be enhanced with a technically sound mechanical reliability program. In the center is the human, the aircraft maintenance technician that has the assignment to inspect and make the appropriate repairs. These AMTs rely on accurate maintenance manuals in order to accomplish the assigned tasks. With the possibility that there might be a shortfall in AMTs, there is an ever-increasing need to ensure that maintenance manuals are current, high quality, and error free.