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Final Report

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16. Abstract

This report details the development and demonstration of an Aging Mechanical Systems Methodology, a methodology for the proactive study of commercial aging aircraft in an effort to ensure on-going safety. The report includes a description of the methodology and documentation of an inaugural case study. The Embraer 120 pitch control system was the subject of the case study. Findings and recommendations resulting from both the development of the methodology and the execution of the case study were included.

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LIST OF ACRONYMS

AC	Advisory Circular
AD	Airworthiness Directive
AMSM	Aging Mechanical Systems Methodology
ASRS	(FAA/NASA) Aviation Safety Reporting System
ATA	Air Transport Association
CAA	Civil Aviation Authority
CFR	Code of Federal Regulations
CTA	Centro Técnico Aeroespacial
CV	Control volume
DAC	Civil Aviation Department
EMB	Embraer
FAA	Federal Aviation Administration
FHA	Functional hazard assessment
FMEA	Failure mode and effects analysis
FMECA	Failure mode and effects criticality analysis
FOD	Foreign object debris
FTA	Fault tree analysis
JAR	Joint Aviation Requirements
MECSIP	Mechanical Equipment and Subsystems Integrity Program
MH	Man hours
MIL-HDBK	Military Handbook
MMEL	Master Minimum Equipment List
MPD	Maintenance Planning Document
MRB	Maintenance Review Board
MSI	Maintenance Significant Item
MTBF	Meantime between failure
MTBM	Meantime between maintenance
NASA	National Aeronautics and Space Administration
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
OEM	Original equipment manufacturer
OSS&E	Operational safety, suitability, and effectiveness
PIWG	Product Improvement Working Group
PSSA	Preliminary system safety assessment
RCM	Reliability-Centered Maintenance
SAE	Society of Automotive Engineers
SDR	Service Difficulty Report
SSA	System safety assessment
TSO	Technical Standard Order
UDRI	University of Dayton Research Institute
VRCM	Versatile reliability centered maintenance
WSIG	Weapon System Integrity Guide
U.S.	United States

EXECUTIVE SUMMARY

The United States continues to enjoy a very impressive record of airline safety. At the same time, the age of the United States commercial aircraft fleet continues to rise. Currently, aging programs exist for items such as structures and engines, but not for mechanical systems and components.

This report describes a recently developed Aging Mechanical Systems Methodology (AMSM) for use in commercial aviation. The methodology that is a proactive tool focuses on the identification and disposition of potential risks that affect safety. It is consistent with the Federal Aviation Administration (FAA) Aging Transport Non-Structural Systems Plan. It compliments current FAA safety programs including the Air Transportation Oversight System and the Safer Skies Initiative. The development approach was a research effort based on the compilation of data from a wide variety of government, commercial, and military sources.

In this report, the methodology was presented and described in detail. The methodology required the collection and evaluation of data from numerous sources including the original equipment manufacturer, public databases, and airline operators. The methodology was applied via an inaugural case study, which served as a tool to validate and improve the methodology. The Embraer (EMB) 120 pitch control system was the subject of the case study.

In developing and applying the methodology, several findings were made. These findings included the inherent value of reliability and sustainment programs, the surprising absence of foreign object damage (FOD) prevention programs in commercial aviation, the significant effort required to support data collection for the effort, and the lack of focus on nonmechanical failures (maintenance-induced failures, human errors, and design flaws) in the design and certification analysis of aging commercial mechanical systems. Several aircraft-specific findings were also made during the case study. In total, 32 items were documented on a Potential Studies List. For example, one item revealed that for the case study system, much of the Safety Analysis is dependent on the proper operation of one mechanical component. If this component suffers a latent failure, the aircraft could be at risk for a 1+1 catastrophic event.

It is recommended that the AMSM continue to be applied to additional aging aircraft systems for the dual purposes of refining the methodology and increasing the current understanding of aging mechanical systems in commercial aviation. In addition, there are several recommendations specific to the EMB 120 pitch control system. The complete list of findings and recommendations from the methodology development and the case study are included in this report.

1. INTRODUCTION.

1.1 PURPOSE.

This program was established to investigate the potential safety issues of aging mechanical systems in the United States (U.S.) commercial aviation system and to develop a methodology to help alleviate risks in this area. This work is consistent with recommendations in the Federal Aviation Administration (FAA) report titled "FAA Aging Transport Non-Structural Systems Plan" dated July 1998. It is also consistent with the stated goal of the Safer Skies Initiative to reduce the number of fatal accidents by 80 percent by 2007 (although the study of aging aircraft systems is not among the 16 safety problems specifically identified by this initiative). A unique aspect of this research is its proactive approach to the alleviation of commercial aviation risks.

1.2 OBJECTIVES.

The specific objectives of this work were to develop a generic methodology and to execute the methodology on a case study. The purpose of the case study was to test and improve the methodology.

1.3 BACKGROUND.

As indicated in table 1, the average age of the U.S. commercial fleet is over 10 years old for many of the major airlines with high values of 20.19 years and 26.83 years for Northwest Airlines and Midwest Airlines, respectively. This data was based on a study by AirSafe.com conducted in June 2002. Although this study includes only aggregate data, the implications are clear: the U.S. commercial aviation fleet includes many aging aircraft.

Table 1. Average Fleet Age for Selected U.S. Carriers

Airline	Average Age	Fleet Size
AirTran	15.21	63
Alaska	9.37	103
Aloha	13.76	23
America West	10.29	141
American	10.46	836
ATA	8.16	61
Continental	7.35	379
Delta	11.22	594
Jet Blue	1.73	26
Midwest	26.83	36

Table 1. Average Fleet Age for Selected U.S. Carriers (Continued)

Airline	Average Age	Fleet Size
Northwest	20.19	431
Southwest	9.23	370
United	8.76	561
USAirways	11.42	241

A search of the FAA website using the keywords "aging aircraft" provided a detailed history of the development of aging aircraft programs. In general, this development was in response to safety incidents or accidents. Initially, in response to an aircraft incident involving a structural failure, Congress passed the Aviation Safety Research Act of 1988. This act increased the scope of the FAA mission to include research into aging aircraft structures. In the years that followed, the FAA added other aircraft elements, including engines, to the program. Based on a 1997 White House Commission on Aviation Safety and Security Report, the FAA developed the nonstructural aging plan, which launched research into the effects of aging on electrical and mechanical systems.

In electrical systems, wire is a universal component. In aging electrical systems, wire insulation degraded with time, though the wire continued to perform its intended function. The brittle insulation, however, caused other problems not necessarily related to electrical system function. The mechanical systems program identified no such universal components. Mechanical systems consist of such varied components as mechanical cables, bearing, cranks, actuators, pumps, pressure vessels, fans, valves (automatic or manual, powered or passive), springs, hoses, tubes, control rods, cams, brakes, mechanical fuses, heat exchangers, ratio changers, heaters, power screws, transmissions, mechanical summing devices, tires, and even mechanical computation devices. The wide variety of components and the flexibility with which these components are used makes a simple, overarching aging program difficult for mechanical systems. Many of these components have associated specific design standards such as Technical Standard Order (TSO) or Society of Automotive Engineers (SAE) standards. Other components do not have associated specific design standards. Many of these components are one-of-a-kind designs made for a specific purpose. Therefore, general conclusions that extend beyond a particular component are difficult to formulate.

A major tool to ensure commercial airplane safety for mechanical systems was the design standard that any system that can affect continued safe flight and landing was typically duplicated to ensure that single failures did not put an aircraft in jeopardy. This use of redundant systems assumed that appropriate maintenance was performed at intervals that ensured safety until a failure was detected, often the next maintenance interval. It is accepted that some dualized devices were uninspectable; therefore, their capability was unknown. The presence of a dualized device was typically an indication that a component was critical to flight safety. Additionally, current procedures allow escalations in maintenance intervals, which may not include adequate support data. The FAA also learned that wear was treated as a phenomenon that was considered in design, but it was not treated as a failure mode. In aging mechanical systems, wear needs to be considered in the system safety assessment to ensure that activities, including lubrication and on-condition monitoring, are specified to proactively minimize risk,

especially for known consumables. These varied aspects must be integrated into a simple aging mechanical systems program that can be used as a methodology to study these systems without overburdening the operator or manufacturer and without restricting the evaluation to the degree that it cannot produce useful information.

2. AGING MECHANICAL SYSTEMS METHODOLOGY.

The Aging Mechanical Systems Methodology (AMSM) was developed in support of an FAA effort to study the aging of aircraft mechanical systems. Completion of this methodology was a primary goal of the current program. The intent of the AMSM is to study commercial aging aircraft in a proactive manner in an effort to improve the safety of these aircraft.

Although the methodology focuses on the subset of commercial aircraft identified as aging aircraft, it is important to note that all categories of failure events were considered, not just those designated as aging or wear-out failures. This methodology put a priority on safety over other commercial considerations with a special emphasis on supporting the no single failure goal as well as assessing 1+1 catastrophic failures. These 1+1 failures were dual failures that, after the occurrence of the initial failure, left the aircraft one failure away from catastrophe. This situation was especially critical if one of the dual failures was latent.

The AMSM is a proactive risk reduction exercise for aging aircraft that have seen significant service time since their initial evaluation during design and certification. It was inherently assumed that this evaluation included a valid certification process and all regulations are currently enforced. The purpose of the AMSM is to take an inclusive look at old systems using the benefit of current knowledge.

Section 2.1 provides an overview flowchart of the AMSM and detailed descriptions of the primary activities included in the methodology. Also included is a summary with findings from this effort and recommendations for further development and application of the AMSM.

2.1 AGING MECHANICAL SYSTEM METHODOLOGY DESCRIPTION.

The AMSM is a process that is used to study aging aircraft to seek a better understanding of current risks that may exist in mechanical systems. The AMSM may serve as a standardized, proactive approach to the management of aging mechanical systems in commercial aviation. A simplified flowchart of the AMSM is shown in figure 1. This flowchart is a top-level description of the methodology without detail for the individual activities and evaluation criteria. The activities required to complete the process include multiple steps in data gathering, analysis, risk assessment, and documentation. These activities are described in the sections that follow.

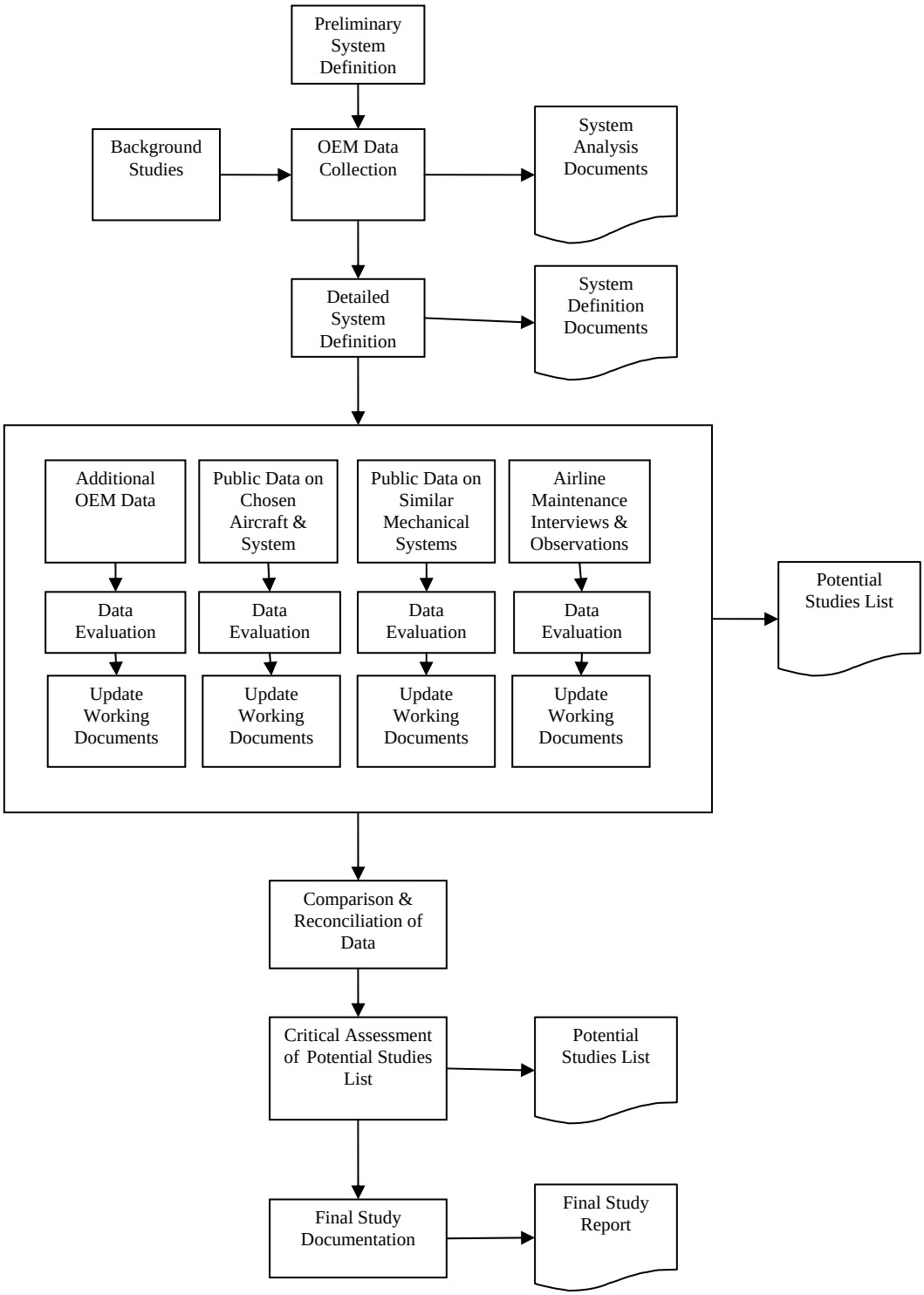

Figure 1. The Aging Mechanical Systems Methodology Overview

The AMSM was developed based on research from a variety of sources. These sources included military maintenance and integrity documents, governmental regulatory standards, industry resources, internal military and FAA reports, and safety and reliability textbooks. A complete list of references for this effort is given in section 4. In addition, appendix A contains a list of the primary references, standards, and their summaries that are used directly in the development of the AMSM.

A large part of the initial effort in performing the AMSM is data collection. Data is collected from a wide variety of public and commercial sources. Once the data has been collected, the key to an effective result is the evaluation of the data. All gaps, conflicts, potential risks, and potential inaccuracies discovered during the all phases of the AMSM must be documented. This process of data collection, evaluation, and documentation is iterative. Depending on the quality and quantity of data gathered from the sources, this cycle may repeat several times. A generalized flowchart for data collection and evaluation was provided. In addition, specialized flowcharts were provided for the data collections activities from both the original equipment manufacturer (OEM) and the airline operators. The primary documentation for these activities will be through the Potential Studies List. This list will be created at the outset of an AMSM study and updated throughout the process. The final form of the Potential Studies List will become part of the study documentation.

The following sections describe each primary AMSM activity in detail. These sections contain description information regarding the purpose of and steps to perform each activity. In addition, several of the sections include activity-specific flowcharts. These flowcharts are an expansion of the activity blocks found in figure 1.

2.1.1 System Definition.

The first activity of the AMSM is to select an aging aircraft and specific mechanical system to be studied. The methodology can be applied to any aging mechanical system; therefore, the optimal selection is dependant on the objectives of the study. Appendix B describes three approaches to choosing an aircraft and system for an AMSM study. Regardless of which approach is used, because the AMSM is a safety-based process, it is important to limit the system selection to those systems that are critical to aircraft safety.

Once a study system is selected, a detailed system definition process begins. Figure 2 is a flowchart of the system definition process. The system definition process uses two common scientific concepts; control volume and symbiotic systems. For an AMSM study, the control volume is drawn around the system being studied. A detailed list is then made of the specific hardware items that are included within the control volume. For the AMSM, the symbiotic systems are aircraft systems that are not part of the control volume, but that have a significant relationship to the study system. Each of these systems needs to be identified and a decision made as to how their relationship will be addressed in the study. An example might be the relationship between the aircraft's hydraulic system and a study system with hydraulic components.

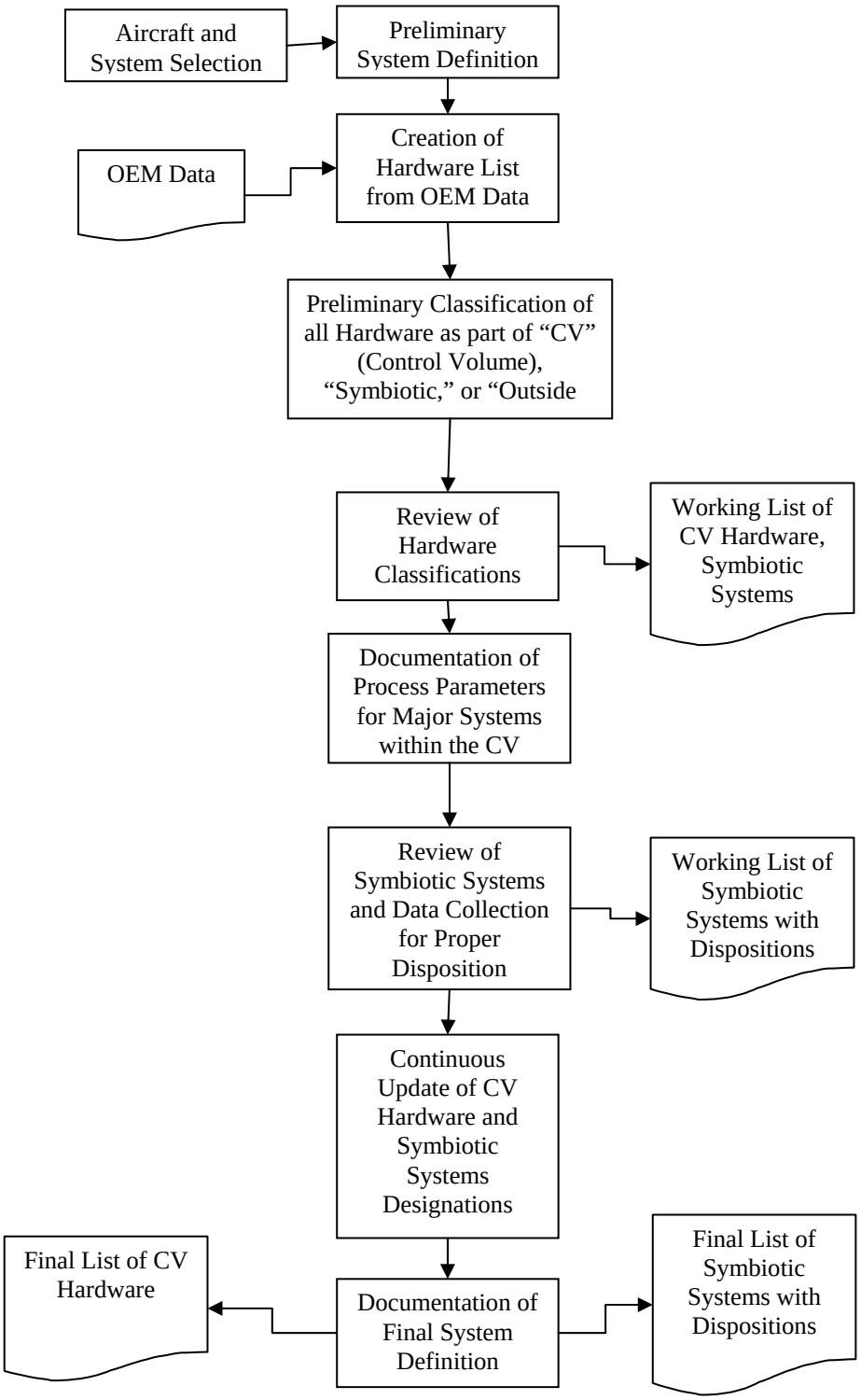

Figure 2. System Definition Flowchart

The preliminary system definition is a brief, written statement of the mechanical system to be studied, which includes the identification of the boundaries of the control volume. An example of a preliminary system definition is:

> "The study system is the ailerons and their associated controls. The system includes the specific hydraulic components that activate the ailerons, but not the overall hydraulic system of the aircraft. All electrical components are considered outside of the control volume. The control volume ends where the ailerons attach to the wings. The aileron attachment is within the control volume; however, the wing is outside of the control volume."

The intent of the preliminary system definition is to provide enough definition so that the major data gathering can begin. Next, a detailed system definition is created using data from the OEM if possible, and supplements from other sources as necessary. Then, a running list of all hardware items found in the OEM data is created. This list is written at the detailed component level. It includes all hardware items found in OEM reports and system drawings. The list is checked for duplications and then divided into three classifications: items in the control volume (CV), symbiotic items, and items outside the CV. If the system is large or contains natural subsystem groupings, it may be helpful to designate subsystems within the study system. Once the list is complete, items confirmed to be outside the study CV are dropped. The remaining items are kept as two working lists: CV Hardware and Symbiotic Systems.

The items on the working list of CV hardware are further documented with the addition of process parameters where available. These parameters are defined at the subsystem or major equipment (not component) level. Some important parameters include the intended function, the modes of operation, performance parameters (with allowable limits), and the full range of expected environmental conditions. It is also important to note the various mission profiles expected for the aircraft, since differences in mission profile can affect maintenance and aging. Data gaps are common when dealing with aging aircraft systems; therefore, not all data may be available. The hardware list and process parameters are updated as new data are accumulated.

Items on the working list of symbiotic systems need to be further evaluated to determine both the extent of their relationship with the study system and how this relationship will be handled for the AMSM study. As each system is evaluated, it is possible that another system will be added into the CV of the study. It is also possible for additional studies to be recommended to ensure that potential risks inherent in the symbiotic systems do not overlap the current study. Once these studies are complete, the disposition of these items with respect to the study CV should be documented. Table 2 is an example of a Symbiotic System List used during the AMSM System Definition activity. Some parts of the table have been coded to protect proprietary data.

Table 2. Symbiotic Systems List Example

Item	Disposition
Stall warning system	Not part of study
Gust locking system	Keep on symbiotic list (due to XXX)
Stick pusher servos (affected by XXX)	Can drive the elevator, therefore, it should be included in the study CV
Flaps/Slats/Spoilers (i.e., systems that affect lift)	Not part of study
Pressure bulkhead cabin seals	Keep on the symbiotic list
Horizontal stabilizer junction fairing	Not part of study – it is a structural component, falls under other work
Bonding jumpers	Keep on the symbiotic list – check to see if it is included in aging electrical studies
Flight data recorder system	Not part of study – does not impact pitch control

Note that all items on the original list of symbiotic systems are retained as part of the permanent record of the study. If the disposition shows that an item was added to the study CV, the item is not removed from the Symbiotic Systems list; it is simply noted that it is now part of the CV. The CV Hardware and Symbiotic Systems lists are both updated throughout the project and are part of the final study documentation.

2.1.2 BACKGROUND STUDIES.

Another important activity early in the AMSM is the performance of background studies. These early studies are performed on the OEM, the aircraft, and the system under study. The purpose of these brief studies is to facilitate the establishment of a productive relationship with the OEM. Having this background allows the researcher to ask intelligent questions and to be sensitive to any relevant OEM circumstances. Later in the process, once an airline operator has been identified for interview, a brief company profile of the airline operator should be completed. If the AMSM study is being performed by the OEM or airline operator, portions of this activity can be skipped.

Company profile data can come from a wide variety of sources. A good source of company data is a reference library. Most reference libraries include references with company profiles in hardcopy and electronic form. A variety of online sources may also be available, such as the company's own website. The OEM's and airline operator's websites provide the data that they want the public to know; therefore, they are basic required reading before approaching an OEM or operator for data. Other online sources include general websites and general search engines.

The following basic data should be gathered on the aircraft manufacturer at the start of an AMSM study:

- Company type (public or private)
- History
- Country of origin
- Major products
- Major customers
- Major suppliers
- Locations
- Recent news events and trends

The background studies for an airline operator generally follow those of the OEM. One additional relevant topic for the airline operator is the general workplace structure, including the presence or absence of union labor and the use of third-party vendors for maintenance.

Preliminary background regarding a particular aircraft and system can also come from a variety of sources. Two helpful sources for aircraft-specific data include the reference book "Jane's All the World's Aircraft," and the OEM's website. General aircraft system information can be derived from a variety of text and online sources.

One online source that is particularly helpful for basic aircraft system understanding is the website of the National Aeronautics and Space Administration (NASA) Glenn Research Center (http://www.nasa.gov/centers/glenn/home/index.html). This site contains a Beginner's Guide to Aeronautics section under the Education heading.

The typical aircraft data needed at this point in the study is simply the basic function and typical hardware of the chosen system. It includes the following basic aircraft specifications:

- Design history
- Certification date
- Capacity
- Range
- Dimensions
- Powerplant
- Flying controls

Detailed information will be gathered from the OEM as part of the next activity. The purpose of the background studies is to provide enough basic information to make the initial contact with the OEM (or airline operator) efficient and productive.

2.1.3 Overview of Data Collection and Evaluation.

At this point in the AMSM, data collection and evaluation become the primary focus. Figure 1 shows that data for an AMSM study comes from a variety of sources. The generalized data

collection and evaluation for the AMSM is shown in figure 3. This generalized flowchart applies to all primary data used in an AMSM study: OEM-supplied data, public data, and airline-supplied data. The general approach begins with the initiation of data collection. Whether this data collection will be accomplished via an online search, reference library search, database search, data request to an OEM, or data request to an airline, it is important to have a clear inventory of what data is desired. Sections 2.1.4 through 2.1.6 include detailed inventories of data that can be collected from each source. They also document aspects of the data collection and evaluation process that are unique to each source.

It is important not to underestimate the effort that may be involved in data collection because much of the data collection effort is dependant on the voluntary support of OEM and airline operator personnel. The generalized flowchart includes a check for both incomplete and unclear data. In reality, it may require significant effort and numerous iterations before all required data is in hand and ready for evaluation. Fortunately, individual data sources and items can be evaluated in parallel. Near the end of the AMSM, the Comparison & Reconciliation of Data activity serves to ensure that a broad look is taken at the individual data streams.

As data is evaluated, items are placed on a Potential Studies List. This list is a key source of documentation throughout an AMSM study. The Potential Studies List has six columns:

- Item number
- Aircraft component(s)
- Description of potential study topic
- Original data source
- Study leads
- Final disposition/recommendation

Figure 4 shows a template for a typical Potential Studies List. The item number is used for tracking purposes during the AMSM study. All items added to the list are given a sequential number. The next column lists the specific piece of aircraft hardware affected by the proposed study. If the study topic covers a broad area of the study system, the system name or the word “general” may be used.

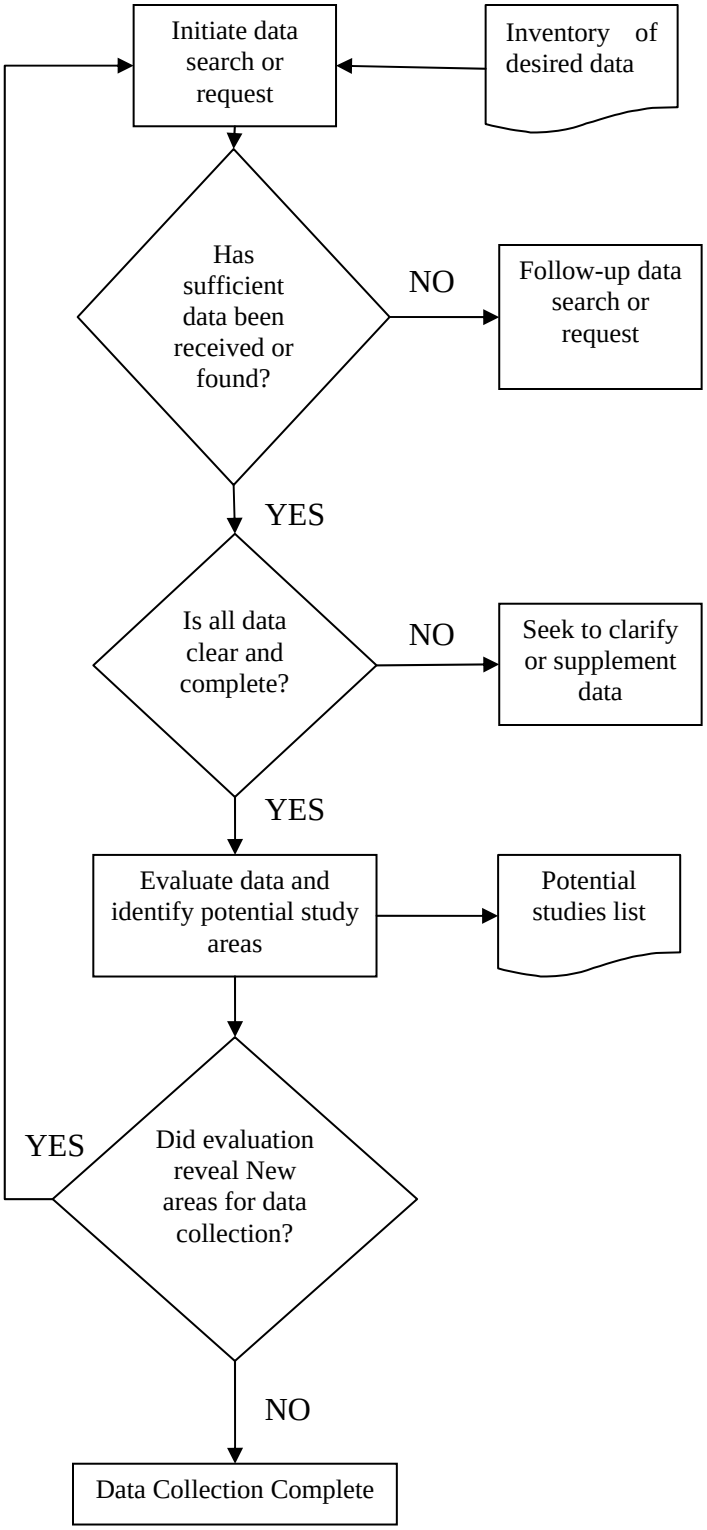

Figure 3. Generalized Data Collection and Evaluation Flowchart

AMSM Potential Studies List
Project: _____

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
1					
2					
3					
4					
5					
6					

Maintained by: _____
Last Updated: _____

Figure 4. Potential Studies List Template

The description of the potential study topic is a quick topic summary. Note that only topics with potential safety consequences should be recorded. The following are examples of topic descriptions:

- Water leaking at the door may lead to a short-circuit of electric displays and subsequent fire.
- Latent failure of disconnect device may eliminate planned corrective action of pitch control system.
- Maintenance on tail section may result in metal shavings intermixed with control cables.
- Secondary control system is not checked for latent failures.

The original data source and potential study topics are also included in the Potential Studies List. The last column shows the final disposition of the item. Any findings or recommended actions are documented in this final column. If a decision was made not to study the item, the reason for the decision is listed in this last column. No items will be removed from the Potential Studies List during the AMSM process.

In addition to generating items for the Potential Studies List, the evaluation of data will sometimes indicate a new area of data collection not originally considered. In these cases, this determination does not lead to a potential study item, but rather, the initiation of more data collection. The data collection process is then recommenced.

This generalized overview of the data collection and evaluation process was intended to provide some overall structure and strategy to these important AMSM activities. Although the general flow is the same, there are unique features to the data collection and evaluation that are source-dependant. The following sections describe the detailed data collection and evaluation activities for each of the three primary sources of data: OEMs, public data, and airlines.

2.1.4 Original Equipment Manufacturer Data Collection and Evaluation.

The most critical source of aircraft system data for completion of an AMSM study is the OEM. The OEM is the owner of all original design and certification data as well the initiator of all on-going Service Bulletins for the aircraft. As an on-going interested party in the life of its aircraft system, the OEM also receives and collects data from many of the public and airline sources. There is great benefit to the AMSM researcher in a successful OEM data collection effort. The data from the OEM forms the foundation for the rest of the analysis. Gaps in data from the OEM will remain gaps when carried over into the rest of the AMSM study. Figure 5 is a flowchart detailing the data collection and evaluation activity used for an OEM. This flowchart is a more detailed look at the activities outlined in figure 3, with OEM-specific details. It is consistent with the information in figure 3.

A productive relationship with the OEM must be established before data collection begins. As part of this effort, the following information should be provided to the OEM:

- Purpose of an AMSM study
- Aircraft and system of interest
- Types of data needed
- OEM staff support needed
- Offer of nondisclosure agreement

Experience from the initial case study proved that an on-site visit was important in establishing the desired relationship with the OEM. It was important for the OEM to understand the research nature of the study. The securing of a nondisclosure agreement proved to be a required, yet quite cumbersome and time-consuming, process.

It is also important to have a detailed list of the specific pieces of data requested and an estimate of the staffing required by the OEM to support the request. Appendix C shows a generalized OEM Data Request List, which should be customized for a given AMSM study.

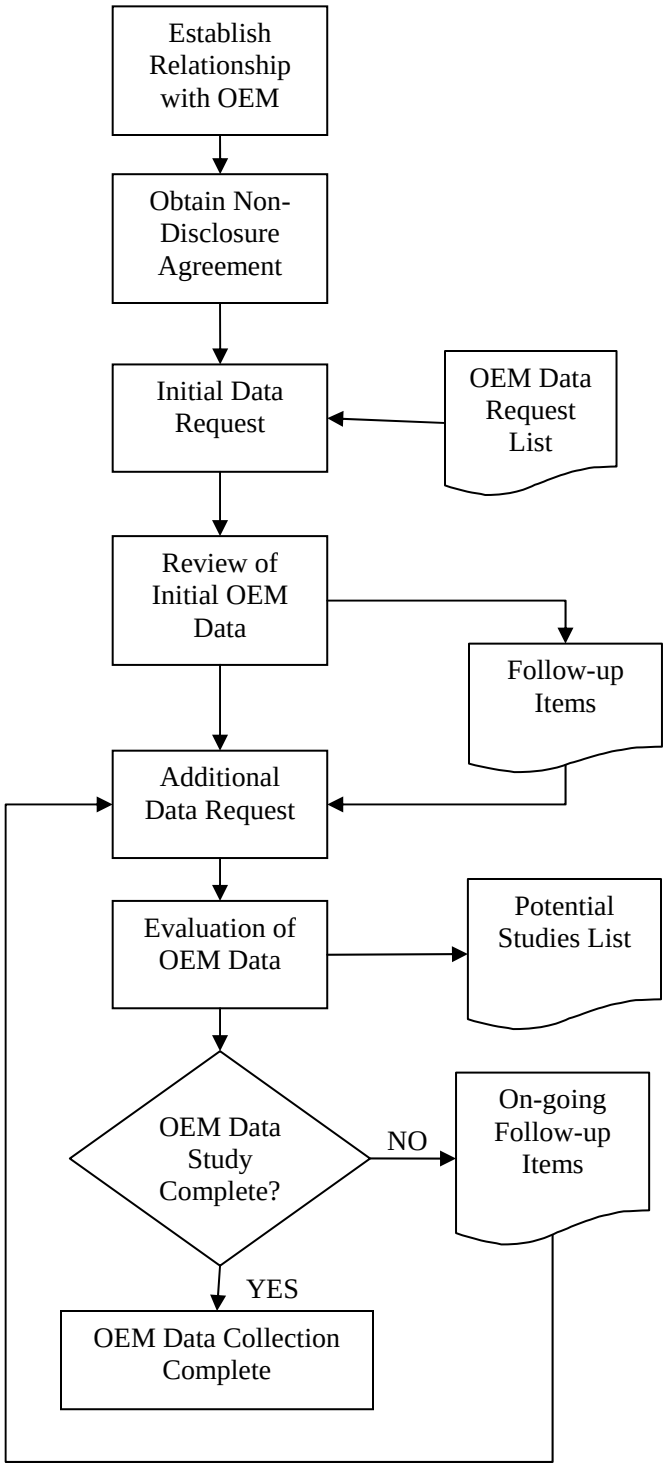

Figure 5. The OEM Data Collection and Evaluation Flowchart

Data is evaluated from the OEM as it is received. Appendix D provides a guide to OEM data evaluation. The detailed evaluation results in identification of potential risk areas (add to Potential Studies List), documentation of gaps in the data (document for additional data requests), and initial reconciliation of data. Although the final comparison and reconciliation of data occurs at a later point in the AMSM process, the foundation of that analysis is built when the initial data from the OEM is evaluated. For example, risks identified as part of System Safety Assessment documents should have a corresponding maintenance activity listed on the Maintenance Planning Document (MPD).

It is important to realize that, by nature, the study of aging aircraft systems will include some difficulty in data collection. Despite these difficulties, each step in the process needs to be pursued to the fullest extent possible.

2.1.5 Public Data Collection and Evaluation.

There are many sources of public data concerning aircraft systems. Once some of the initial OEM data is evaluated, it is time to make an aggressive attempt to find as much data as possible from public sources. Although it is efficient to gather and evaluate public data in parallel with the pursuit of OEM data, there is benefit to delaying the public data collection just a bit and allowing the OEM data collection and evaluation to stay just slightly ahead of the other data collection efforts. Sources for actual usage data include public databases that are specific to the aircraft and system under study as well as public databases for similar mechanical systems. The primary on-line sources needed to complete an AMSM study can be found in appendix E. This appendix gives a brief description of the type of data found on each site and some hints for easily using some of the sites. Appendix G is a list of international regulatory websites. These sites may also be useful in collecting data for a particular study, especially if the aircraft design originated outside the U.S.

There are an overwhelming number of public sources of aircraft maintenance and safety data that contain similar data. The key to a successful and efficient data-gathering process is to conduct a focused search based on knowledge of the types of data available and their sources. Whenever possible, government sites should be used rather than trade sites, and trade sites should be used rather than private sites. Table 3 lists several recommended public sources of aircraft data. The exact website addresses are found in appendix E.

Table 3. Recommended Public Sources of Aircraft Data

Data Available	Data Source
General Aviation Safety Information	National Aviation Safety Data Analysis Center Website
Aviation Accidents and Incident Reports	National Transportation Safety Board Website
Voluntary Aviation Incident Reports	FAA/NASA Aviation Safety Reporting System
Advisory Circulars	FAA Website
FAA Airworthiness Directive	FAA Website
Non-FAA Airworthiness Directive	Various International Regulatory Websites
Notice of Proposed Rulemaking	FAA Website
Service Difficulty Reports	FAA Website
Military Failure Rate Standards	Military Handbook-217
Military Failure Rate Standards	Military Handbook-338
Industry Failure Rate Standards	Rome Lab. "Reliability Engineer's Toolkit"
Industry Failure Rate Standards	Reliability Analysis Center Nonelectronic Parts Reliability Data
Industry Failure Rate Standards	Government Industry Data Exchange Program
Industry Failure Rate Standards	Reliability Analysis Center Failure Mode/Mechanism Distribution

A unique issue with the data collection activity focused on public data sources is that searches often result in too many records. In particular, searches for Advisory Circulars (AC) and Service Difficulty Reports (SDR) often result in an unmanageable number of records. The challenge is to find the proper balance between efficiency and completeness. If, on the other hand, data is scarce for a particular aircraft, then study system data from other aircraft using a similar system may be required to supplement the data collection. If the analysis is being done at a component level, it may be possible to reapply data from a same or similar component being used outside the aviation industry.

The evaluation of data from public sources begins by screening the multiple records for the most relevant events. Most records address a specific event or group of events. If possible, each event should be studied to understand its root cause. This information will be heavily used in the comparison and reconciliation activity and will contribute to the Potential Studies List.

2.1.6 Airline Operator Data Collection and Evaluation.

Although the initial design and certification of an aircraft is the responsibility of the OEM, the certificate holder (the airline) is primarily responsible for the airworthiness of its aircraft and the maintenance of its aircraft on an on-going basis. The airline operator, therefore, is another valuable source of information on an aging aircraft system. Figure 6 illustrates the airline operator data collection and evaluation activity steps. This flowchart is a detailed description of the generalized data collection and evaluation flowchart shown in figure 3.

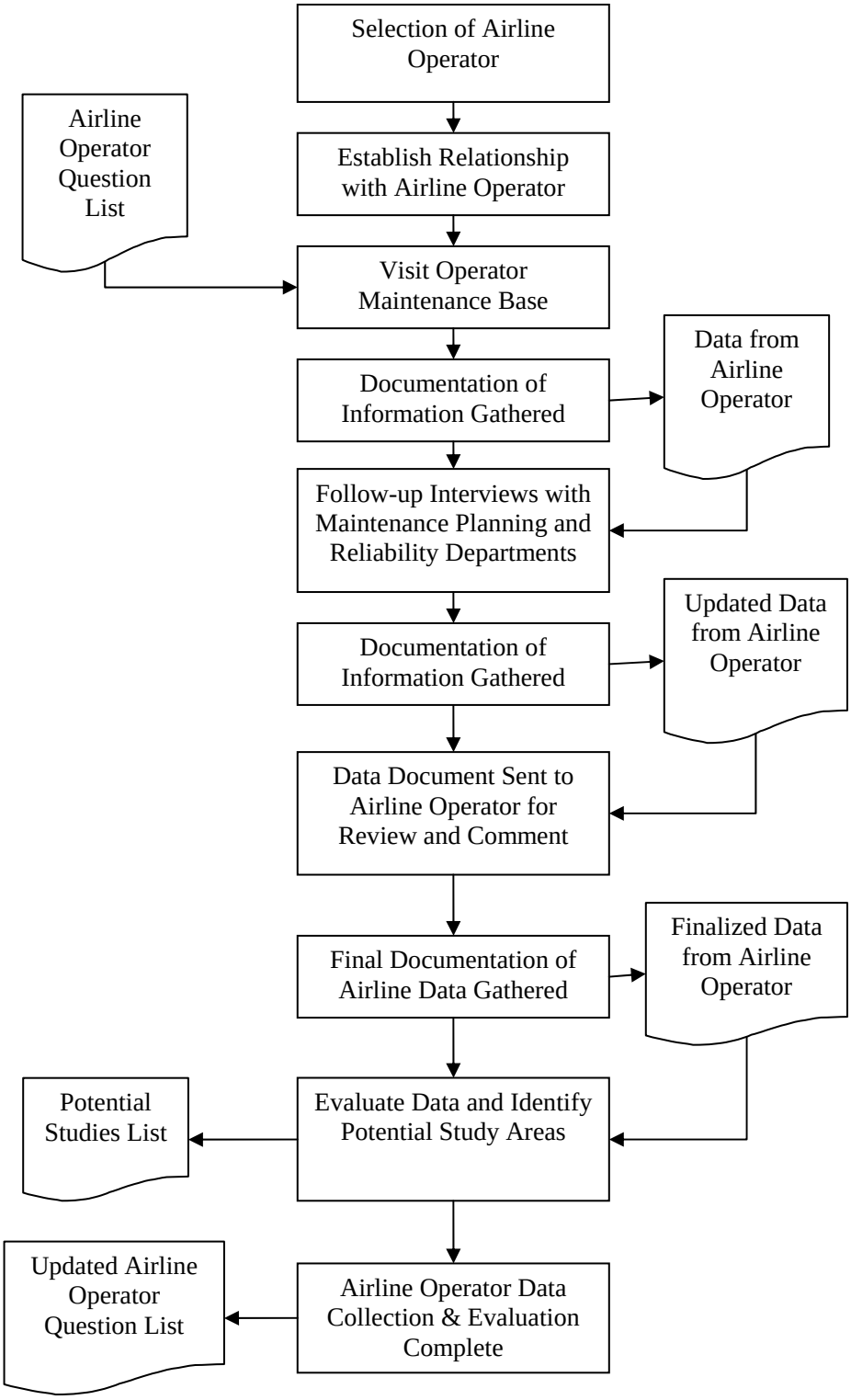

Figure 6. Airline Operator Data Collection and Evaluation Flowchart

An airline operator is selected at the beginning of the study. The preferred selection process is the recommendation of the OEM. The OEM can also be beneficial in establishing a working relationship with the airline operator.

Once an airline operator has been chosen and a relationship has been established, the data collection can begin. Appendix F is a detailed Airline Operator Question List that can be used to support the data collection process. This Question List is the result of notes taken from the research phase of the AMSM development in which wide military and commercial references and standards were studied. The original list of over 100 items was consolidated and cataloged into 11 major groups:

- Maintenance plan
- Task planning and priorities
- Personnel training and staffing
- Tools and instruments
- Spares and supplies
- Documentation
- Inspections and quality control
- Proactive efforts
- Maintenance metrics
- Analysis of aircraft and system specific tasks
- Miscellaneous

The best place to start collecting data is at a maintenance base that services the identified aircraft. Ideally, the maintenance base can be visited at a time when a planned maintenance activity, such as a C-check, will be performed on the aircraft of interest. If maintenance planners, quality control engineers, and reliability analysts are not located at the maintenance base, a separate effort will be required to gather information from these resources. Because the Airline Operator Question List is extensive and based on many varied reference sources, it is likely that some of the questions will not be relevant for a particular study.

Data gathered from relevant questions should be documented for the study. An easy way to document and validate the airline operator responses is to capture the responses to each question in a written document, which can be sent to airline personnel for review. This technique also facilitates the gathering of necessary follow-up data. Similar to data collected from other sources, the data collected from airline operators is then evaluated and items are added to the Potential Studies List as appropriate.

Finally, the Airline Operator Question List is revisited and modified as necessary based on the experience.

2.1.7 Comparison and Reconciliation of Data.

In understanding the affect of aircraft maintenance on commercial airline safety, there are two primary questions, Are we doing the right jobs? and Are we doing the jobs right? At this point

in the AMSM, data has been collected from a variety of sources and a list of potential study areas has been produced. Before the Potential Studies List undergoes its critical assessment, a review of the data gathered to date needs to occur. The purpose of this activity is to ensure that the total maintenance system contains smooth transitions at each stage of its life and to identify any potential study areas that arise due to incongruent data or practices. The approach is to review the totality of data from several sources and ensure that a continuous path can be traced from a potential or known risk through maintenance activity.

The data from the OEM provides insight into the initial aircraft design, the potential risks identified during design, and the recommended maintenance activities to mitigate those risks. The data from the airline operator provides insight into planned and unplanned interventions to mitigate risks and react to failures. The data from the public data sources provides insight into actual events that have occurred to an aircraft in use. What ties these pieces of data together are the failures that occur in commercial aircraft. Each maintenance task performed (other than those done for purely economic reasons) should have its roots in the prevention of an identified failure mode. Likewise, each failure mode identified should inspire a specific design feature or maintenance item to combat it. Finally, if a failure event or failure precursor is found in a public database, its root cause should be determined and tracked through the maintenance program. The comparison and reconciliation of data from the three primary sources (OEM, public databases, and airline operator) should be viewed from each of the three perspectives.

When beginning with the OEM data, the System Safety Assessment is the foundation. For each risk identified, there should be a design impact or maintenance task in place to ensure the risk is held to an acceptable level. The first check that must be made is whether the maintenance planning document is a solid reflection of those risks. If gaps exist, the items should be documented. The next two questions are whether the maintenance plan is still valid and whether the airline operators follow it. A maintenance plan for an aging aircraft system can become partially obsolete for many reasons. These include change in operating environment, change in mission profile, loss of spare parts vendor, and operation of the aircraft beyond the design life. It is also possible that the airline operators are not adequately following the maintenance plan. Factors contributing to operator noncompliance include difficulty of performing outlined tasks, lack of training, lack of proper tools, and unjustified escalation of maintenance tasks. Discrepancies and concerns arising from this evaluation will be added to the Potential Studies List.

Viewed from the perspective of the public database, any incidents or events that have occurred are a potential risk. For each failure event or failure precursor that is identified, a root cause is determined. Armed with this information, the maintenance plan will be reviewed to determine if the item is addressed. If the root cause is not addressed, then a possible gap exists. If the root cause is addressed, yet the event still occurred, then a breakdown in the maintenance chain has occurred. Another factor to consider is any planned response from a regulatory agency. Finally, data from actual usage events can be used to verify or dispute the likelihood and severity assumptions used in the System Safety Assessment. Discrepancies and concerns arising from this evaluation will be added to the Potential Studies List.

From the airline operator's point of view, any safety-based maintenance task should be able to be tracked back to the mitigation of a specific failure mode. The performance of an unnecessary maintenance task not only wastes valuable resources, but also can be the root cause of excessive wear on aircraft components or the root cause of maintenance-induced errors. The growing application of Reliability-Centered Maintenance techniques has brought to light the surprising abundance of superfluous maintenance tasks in many industries. Discrepancies and concerns arising from this evaluation will be added to the Potential Studies List.

Although the comparison and reconciliation of data is presented as an activity toward the end of the AMSM, it is helpful to integrate these concepts throughout the data evaluation whenever possible. The purpose of a structured activity for this evaluation is to ensure that the most complete Potential Studies List is carried into the next phase of the AMSM.

2.1.8 Critical Assessment of Potential Studies List.

Throughout the AMSM study, items have been added to the Potential Studies List. To this point, the items were not thoroughly evaluated; any item deemed to be a potential safety issue was considered a valid addition to the list. The previous activities deployed a wide net to identify potential risks and were divergent in nature. In contrast, this activity is convergent and seeks to critically assess each item.

Figure 7 illustrates an assessment process for items that were added to the Potential Studies List during the AMSM. There are three possible terminating actions to the process: No Action Required, Action Required-Make Recommendation, and Further Evaluation. Once a determination of the proper action is made, this information will be recorded under the Final Disposition & Recommendation column of the Potential Studies List.

Although the flowchart is fairly simple and straightforward, the determination of the correct answer for several of the decision blocks may require significant effort. In particular, the "Covered by Adequate MPD?" decision can be very complex. It includes not only an evaluation of whether a maintenance activity is planned, but also whether the frequency, instructions, training, tools, and subsequent inspection provide adequate protection.

If the assessment indicates that action is required, a recommendation should be formulated. The recommendations will be dependent on the conclusions drawn during the entire AMSM analysis. Recommendations may include changes in the maintenance program, indications for design changes, or a need for further data collection and analysis. There are several important factors to consider when designing a corrective action for an existing system including the use of inspection tasks and the reliability of the maintenance task. It is often reported that inspection is 80 percent accurate. To ensure detectability, inspection frequency is often selected to ensure two valid inspections before a failure mode is reached. The reliability of a maintenance task is dependent on the task itself, and the entire maintenance system of the airline operator. If the reliability of a maintenance task cannot be determined and the item is safety critical, redesign is required to ensure that the risk is acceptable.

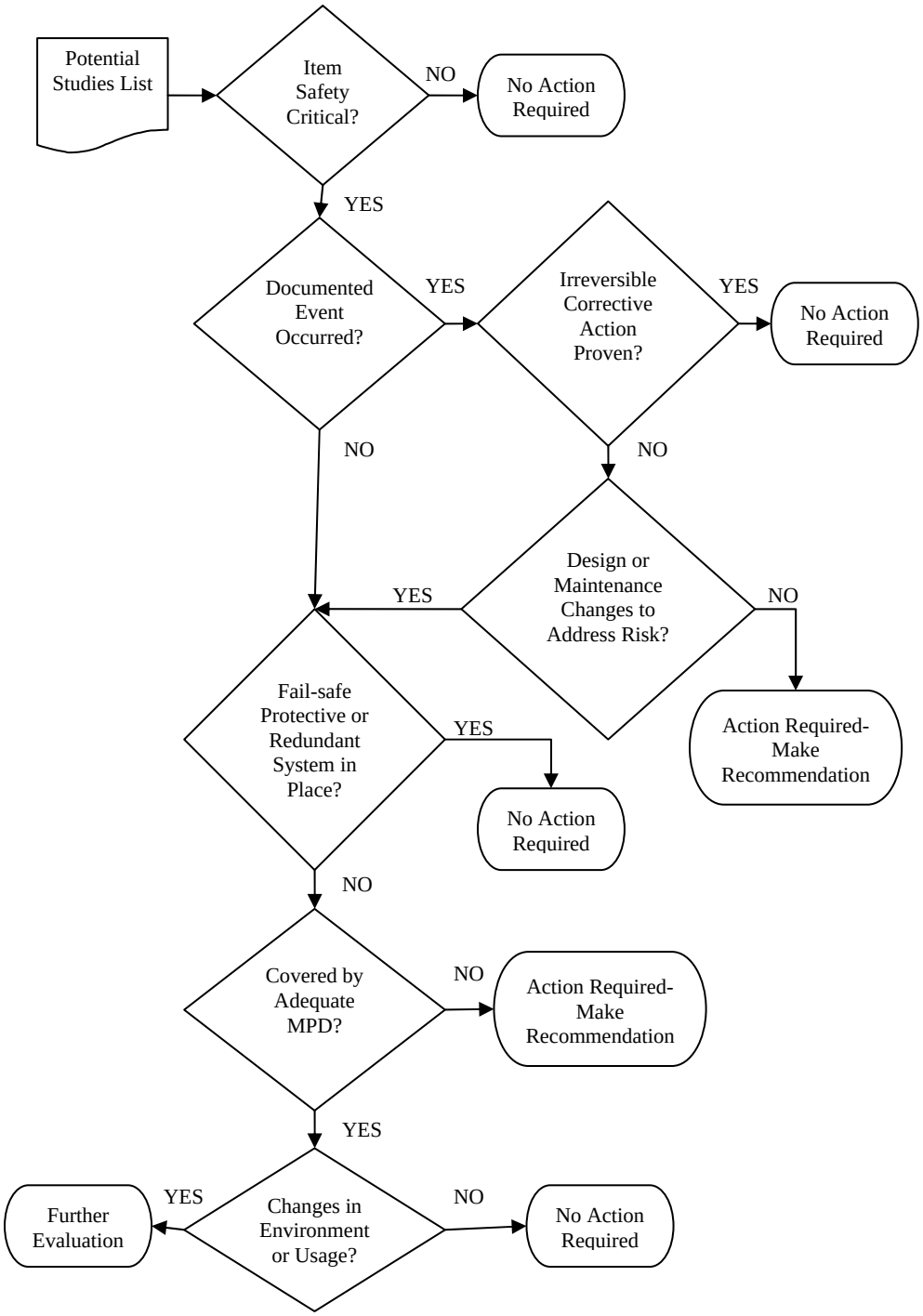

Figure 7. Critical Assessment of Potential Studies Flowchart

2.1.9 Final Study Documentation.

The final activity in the AMSM process is the completion of the final study documentation. Assuming good documentation practices have been followed throughout the study, this step is simply a matter of writing a study summary and collating the final version of several documents that have been continuously updated throughout the study.

The study summary includes two sections: findings and recommendations. The findings are the significant results of the study investigation. Each finding should be presented as a simple statement. The recommendations section should include only the most significant recommendations that will produce the biggest impact on system safety. While both the findings and recommendations should focus primarily on the study aircraft and system, it is also acceptable to include comments relevant to future applications of the AMSM or the methodology itself.

In addition to the study summary, the most up-to-date version of the following AMSM documents should be included in the final report:

- Potential Studies List
- System definition documents
- OEM data evaluation documents
- Finalized data from airline operator
- Copies of all relevant data from public sources

Special care should be taken to protect all proprietary data in the final documentation. Distribution of the final report must follow all nondisclosure agreements.

2.2 AGING MECHANICAL SYSTEMS METHODOLOGY SUMMARY.

This program was established to investigate the potential safety issues of aging mechanical systems in the U.S. commercial aviation system and to determine if a methodology can be established that would help alleviate risks in this area. The result is an AMSM, which is documented in this report and has been tested via an inaugural case study. The finding and recommendations listed here include general knowledge from the case study, but no aircraft or system-specific items. It has been assumed that the knowledge from this inaugural case study is representative of all aging mechanical systems in the current commercial fleet. Section 3 of the report outlines the case study and includes the aircraft and system-specific findings and recommendations.

2.2.1 Aging Mechanical Systems Methodology Findings.

The AMSM presented is based on theory and general engineering experience, as well as an inaugural case study. Although presented as a complete methodology, the AMSM is still in its infancy. The findings listed below are a result of the research effort into numerous reliability, integrity, and maintenance programs as well as the case study application.

- Reliability and sustainment programs are important for the continued safe operation of commercial aviation.

- Previous aging aircraft programs have provided valuable knowledge to the aviation community.

- All references stressed the importance of failure-mode-based analysis.

- In commercial aviation, no one entity is responsible for “cradle-to-grave” safety.

- Contemporary standards for design and reliability understanding have improved over what was state of the art at the time when many aging aircraft systems were designed and certified.

- The current operating environment and mission profile of aging aircraft currently in use may be different from the assumptions made during design and certification.

- Data collection for aging aircraft systems requires significant effort.

- Although the AMSM is presented as a structured and often sequential methodology, for the sake of clarity, application of the methodology is often iterative and concurrent.

- Although military programs contain robust foreign object debris (FOD) avoidance steps, similar regulations are not documented in commercial programs.

- Maintenance-induced failures, human errors, and design flaws were not considered as part of the design and certification analysis of aging mechanical systems.

- The system examined during the case study was a simple design with no risk of single, catastrophic mechanical failure.

- The case study OEM has integrated many safety features into the design of the aircraft. These safety features were documented in a Design Analysis report that was provided by the OEM.

- The case study resulted in the cataloging of 32 items for the Potential Studies List. These items originated from a multitude of sources including OEM data, public databases, and aircraft operator interviews.

- For the case study system, much of the Safety Analysis was dependent on the proper operation of one mechanical component. If this component suffers a latent failure, the aircraft could be at risk for a 1+1 catastrophic event.

- A significant portion of the case study effort was directed at data gathering. Although much data was gathered and received, significant gaps in data remained.

2.2.2 Aging Mechanical Systems Methodology Recommendations.

Based on the development of the AMSM and the inaugural case study, the following recommendations are given.

- The methodology needs to be further developed by its application to additional aging commercial aircraft systems. Specific questions that can be answered with further applications include, Who should conduct future AMSM studies? What is the typical time and cost required to perform an AMSM study? What is the optimal long-term use of the AMSM?

- Additional applications of the AMSM need to be conducted to learn more about the aging commercial aircraft fleet. These applications will provide contemporary safety insight into the systems studied. The current findings were derived from one case study and research. It is uncertain if the findings from this case study are representative of the larger aging commercial aircraft fleet.

- The effect of the current trend towards maintenance outsourcing on the current maintenance community needs to be determined. The AMSM will be updated to reflect any impacts.

- An effort to integrate FOD avoidance techniques in aging aircraft maintenance programs needs to be initiated. This area is the starkest difference between what was learned during the research phase and what was seen during the inaugural case study of the AMSM. FOD avoidance systems will need to consider all sources of foreign objects including metal shavings from maintenance tasks, discarded tools, discarded rags, and water ingress. Military standards address this topic in tremendous detail.

- An effort to integrate maintenance-induced errors, human errors, and design flaws in aging aircraft maintenance programs needs to be initiated. In conjunction, a study to research the hypothesis that mechanical failures are not the dominant source of commercial aviation risk is recommended.

- Although in-depth analysis of the items case study Potential Studies List was not completed, eight recommendations were made based on the information gathered during the case study. It is recommended that these case study-specific items be pursued.

3. CASE STUDY: EMBRAER EMB 120 PITCH CONTROL.

3.1 CASE STUDY OVERVIEW.

As part of the development of the AMSM, a case study was identified for a test application of the methodology. The purpose of the case study was to ensure that the AMSM was practical and to determine the effort required to complete the tasks. In addition, by carrying out a case study, gaps in the methodology became more apparent. The Embraer EMB 120 pitch control system was the subject of the inaugural AMSM case study.

The following sections detail the step-by-step application of the AMSM to the EMB 120 pitch control system. Section 2 of this report, and specifically figure 1, should be consulted as needed to follow the process flow. The section numbers for the case study activities correspond to the section numbers used to describe the AMSM.

As expected in all case studies during data gathering, some sources proved more fruitful than others. The effort required to obtain data in some areas was significant and time-consuming while relatively simple in others. Despite the sequential treatment of the activities in this report, in reality, the application of the methodology was often cyclical and many activities were performed in parallel based on data available at the time. It is expected that each application of the AMSM will have a unique pattern of data gathering and other activities. As more applications are completed, the AMSM can be updated to reflect a broader range of actual experiences.

Also note that, although specific findings and recommendations are given for the EMB 120 pitch control system, the purpose of this study was to improve and validate the AMSM, not to study the safety of the EMB 120. For this reason, some of the analysis is less rigorous than would be expected in future applications of the AMSM. In a more typical application of the AMSM, more effort would be placed on the comparison and reconciliation activity as well as the critical assessment of the Potential Studies List.

3.1.1 System Definition.

As shown in figure 2 and described in section 2.1.1, system definition is largely an exercise of defining a CV and subsequently documenting each hardware item that resides within that control volume. The first step in system definition is the selection of an aircraft and system for study. For this first application of the AMSM, the aircraft and system were simply assigned by the FAA program manager to be the EMB 120 pitch control system.

For the EMB 120 pitch control study, no preliminary system definition statement was written. In hindsight, it is clear that it would have been helpful for the study team members, as well as Embraer and SkyWest personnel, to have access to a written system definition in the early stages of the study. For this reason, writing a preliminary system definition statement was added as an AMSM task.

The detailed system definition began during the review of data received from Embraer. The pitch control system is illustrated in several figures extracted from the EMB 120 Maintenance Manual. Figure 8 is a schematic diagram of the elevator control system. Figure 9 is a schematic diagram of the elevator trim system. Figure 10 is a drawing that illustrates the location of several key components of the pitch control system.

During the review of the maintenance data, any piece of hardware that appeared on a drawing or in the text was listed as part of the pitch control system. Once the initial list was complete, duplicate entries were eliminated. The Embraer data identified four primary subsystems of the pitch control system. These four subsystems are control surfaces, elevator control system, elevator trim system, and elevator control disconnect system. The individual hardware items were listed by subsystem. These items comprise the CV for the study. Appendix H lists the hardware items included in the CV for the EMB 120 pitch control system.

In addition, eight items were placed on the list of symbiotic systems. These items may not be part of the actual system under study, but have a significant interface which needs to be considered at some level.

The preliminary system definition was reviewed by the AMSM study team, and it was determined that each item included in the CV belonged on that list. The eight items included in the symbiotic systems list were discussed in detail, and a working list of symbiotic systems and their dispositions was developed. This list was updated during the study as new information became available. Appendix I documents the final disposition of all items identified as symbiotic systems. Of the eight items originally identified, one was added to the study CV, four were eliminated from the study, and three were retained as symbiotic systems that should be given some consideration during the study.

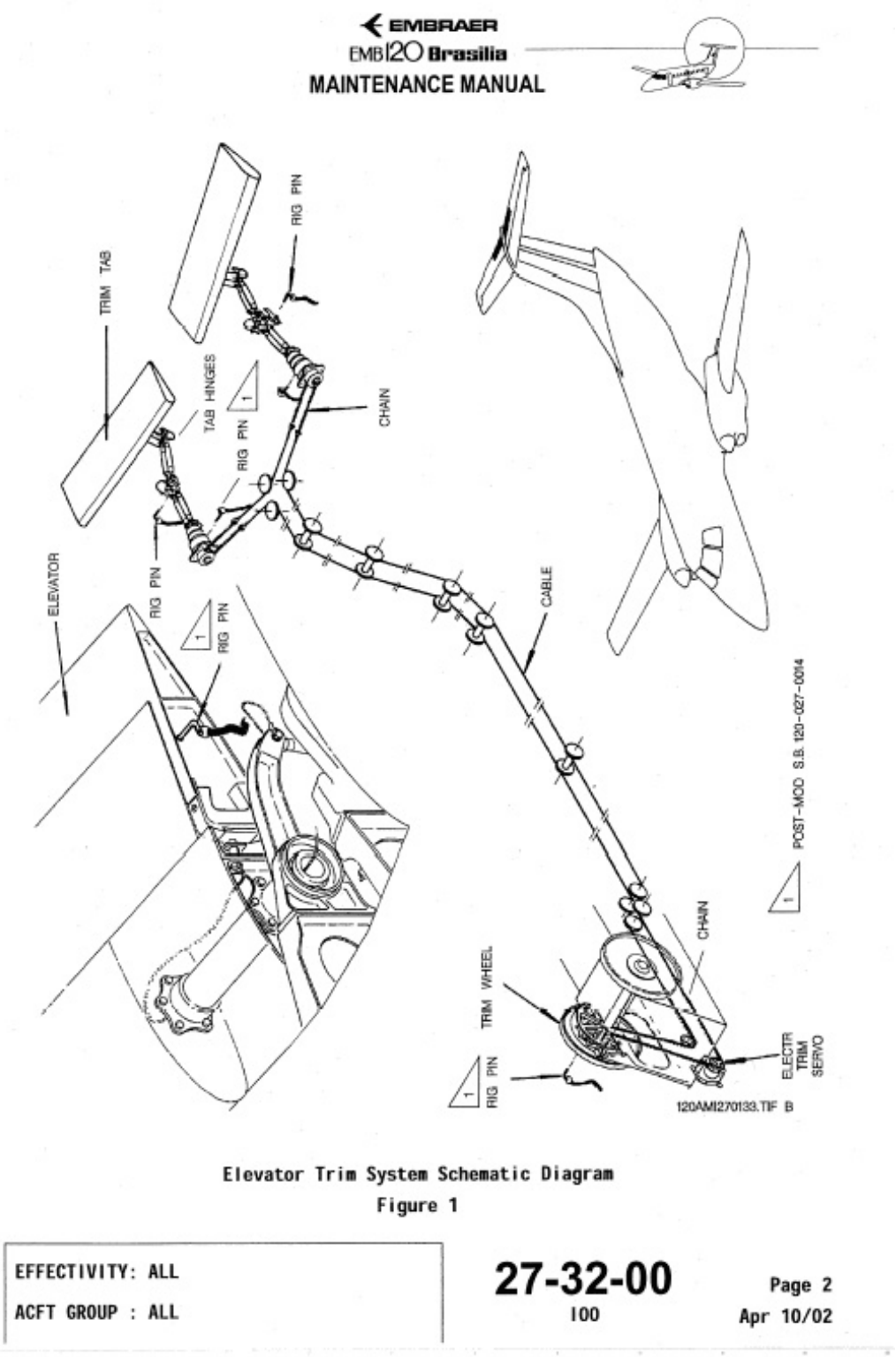

Figure 8. EMB 120 Elevator Control System Schematic Diagram

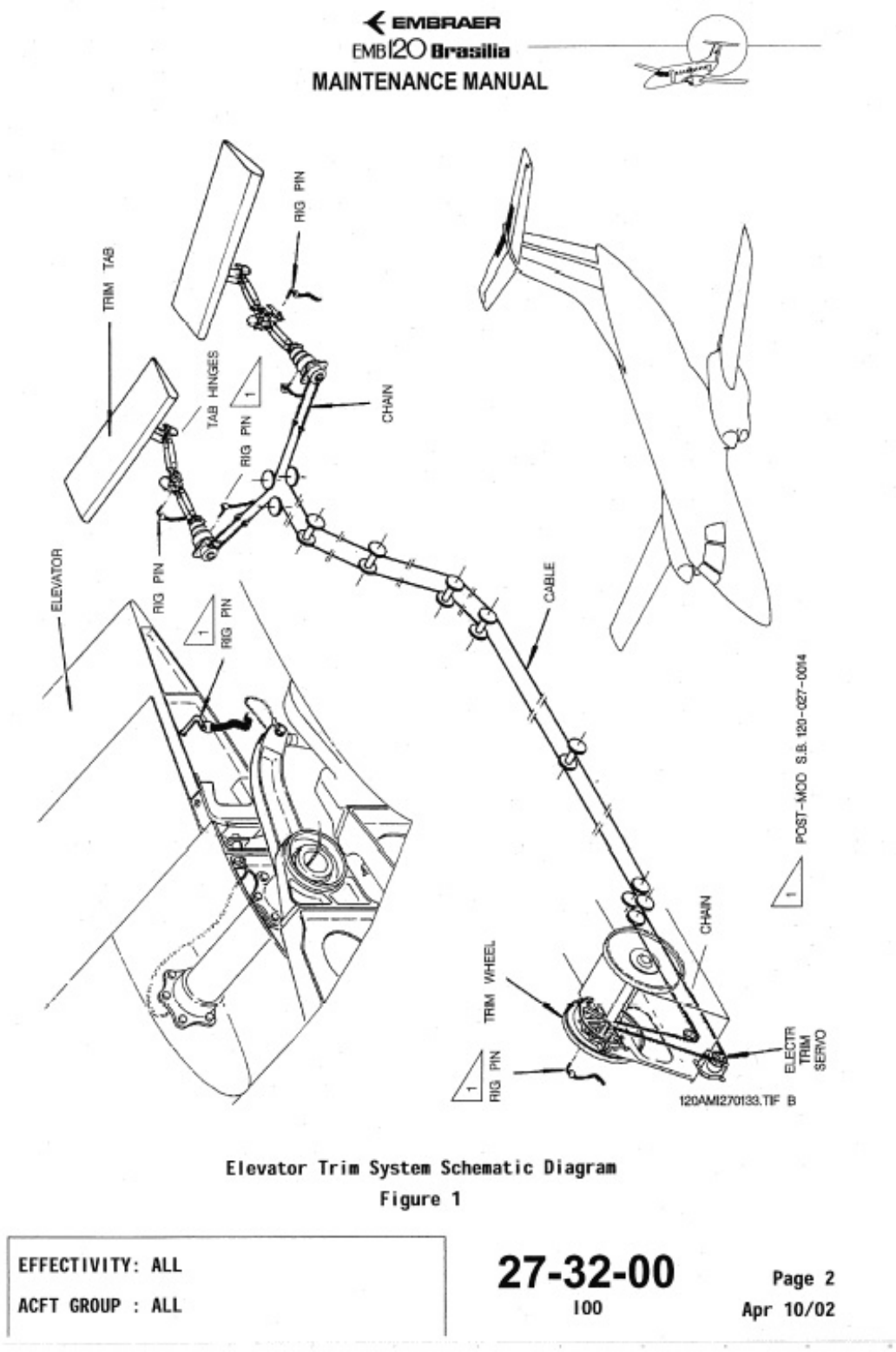

Figure 9. EMB 120 Elevator Trim System Schematic Diagram

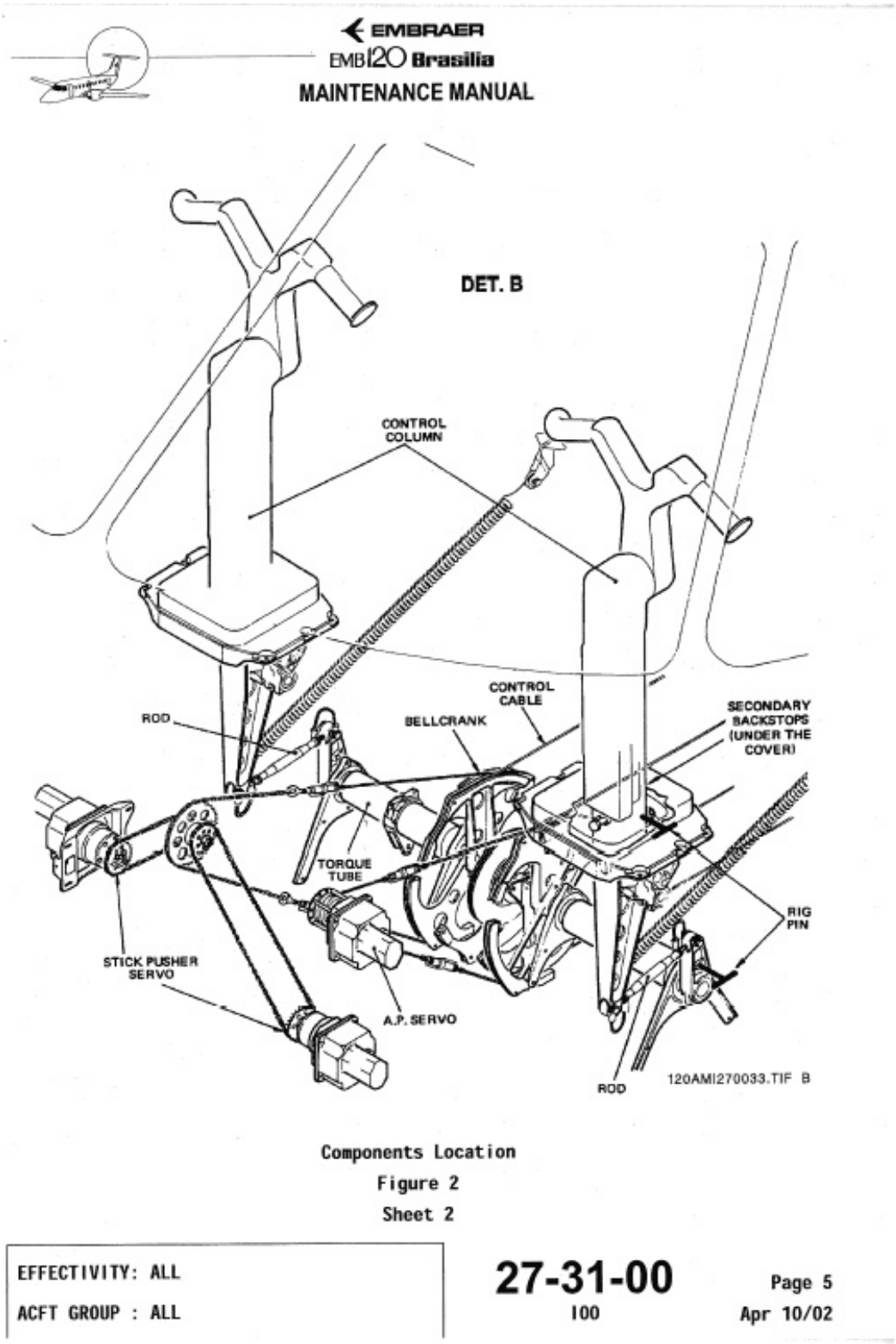

Figure 10. EMB 120 Pitch Control Components Illustration

3.1.2 Background Studies.

The chosen study system for the AMSM case study was the EMB 120 pitch control system. The EMB 120 pitch control system uses a simple, well-established design, which is viewed as a benefit when performing an initial case study application. The airline operator chosen to assist in the study was SkyWest Airlines. SkyWest is one of the largest domestic operators of the EMB 120 aircraft. As part of the AMSM study, brief background studies were conducted on Embraer, the EMB 120 aircraft, and SkyWest.

3.1.2.1 Embraer Company Profile.

Embraer-Empresa Brasileira de Aeronáutica S. A. (commonly referred to as Embraer) is a leading aviation manufacturer. Embraer produces regional commercial, military, and corporate aircraft, including jets and turboprops. Founded in 1969, its company headquarters are in São José dos Campos, São Paulo, Brazil. Originally a government initiative, Embraer was privatized in 1994.

Embraer was Brazil's largest exporter from 1999 to 2001 and the second largest from 2002-2004. Embraer employs more than 16,000 people, over 85% of which are based in Brazil.

3.1.2.2 EMB 120 Aircraft Profile.

The EMB 120 is a twin-turboprop commuter airliner. Its design began in September 1979. Brazilian Centro Técnico Aeroespacial (CTA) certification was received on May 10, 1985, with FAA-type approval following on July 9, 1985. Deliveries began in June 1985 and commercial service began in October 1985. Since 1994, manufacturing has focused exclusively on the EMB 120ER, which has extended range.

Some basic EMB 120 aircraft specifications are provided in table 4.

Table 4. Basic EMB 120 Specifications

Passenger capacity	Up to 30 passengers
Range	1482 km (ER= 1575 km)
Length	20 m
Height	6.35 m
Wingspan	19.71 m
Powerplant	Two PWII8B turboprop engines w/1800 SHP each
Flying controls	Conventional and assisted. Mechanically activated elevators

3.1.2.3 SkyWest Airlines Company Profile.

SkyWest Airlines is a wholly owned subsidiary of SkyWest, Inc. based in St. George, Utah. As a partner carrier with both United Airlines and Delta Air Lines, SkyWest operates as United

Express and Delta Connection. As of April 2006, SkyWest was the world's largest independently owned regional airline.

As of April 2006, SkyWest is a major operator of EMB 120 aircraft with over 60 in service.

3.1.3 Overview of EMB 120 Data Collection and Evaluation.

For the EMB 120 pitch control case study, data collection proved to be the most difficult and time-consuming activity in the AMSM. Each AMSM study requires data from each of three primary sources: the OEM, public databases, and at least one airline operator. The OEM used for the case study was Embraer, and the airline operator was SkyWest. Both Embraer and SkyWest provided data for the EMB 120 pitch control study. To obtain data, it was often necessary to detail the data needed and the specific reason for the request. A nondisclosure agreement was required to get OEM support.

In data gathering from public sources, there was often a large amount of information. The ability to effectively query and efficiently sort was crucial. Appendix E provides recommendations regarding optimal websites for some public data gathering.

The resulting data from each of the three primary sources of data for the EMB 120 pitch control system are detailed in the following sections. The EMB 120 pitch control Potential Studies List includes items derived from all three sources of data. This list was updated throughout the AMSM study. The final EMB 120 Potential Studies List can be found in appendix J.

3.1.4 Embraer Data Collection and Evaluation.

Once the EMB 120 pitch control system was selected for the case study, efforts began to collect relevant data from Embraer. The University of Dayton Research Institute (UDRI) and the FAA requested specific data during an on-site visit. Appendix K is a list of the data and resources requested from Embraer as part of this visit. This list was an attempt to gather most of the required case study data from Embraer. Although not all items from the original request were received, several key pieces of data were collected from Embraer, which formed the foundation of the original case study analysis. The original packet of information from Embraer included relevant pages from the EMB 120 Operations Manual, the Maintenance Review Board (MRB) Report, and the Aircraft Maintenance Manual. After the review of this initial data, another formal request for clarification and additional data was made. Additional mailings were received from Embraer during the study period. In the end, relevant sections of the following five documents were received:

- EMB 120 Operations Manual (see appendix L)
- MRB Report (see appendix M)
- EMB 120 Maintenance Manual (see appendix N)
- Safety Analysis (see appendix O)
- Control Systems Design Analysis (see appendix P)

Detailed summaries and analysis are included in the appendices indicated.

The analysis of Embraer-supplied data resulted in several outcomes. The most obvious is the contribution of numerous items included on the Potential Studies List (see appendix J). OEM data was also used to support the system definition documents discussed in section 3.1.1 and detailed in appendices H and I. Two additional outcomes included a list of fixtures, kits, and equipment required for EMB 120 pitch control maintenance and a qualitative correlation between identified risks and maintenance recommendations. Appendix Q is a list of fixtures, kits, and equipment required for EMB 120 pitch control maintenance. This list can be used during the interview of the airline operator to evaluate maintenance compliance. Appendix R documents the correlation of the five operational recommendations given in the Safety Analysis Report (appendix O) and the tasks listed in the MRB report (appendix M) designed to mitigate those risks. This analysis is important because each identified risk should be addressed with a maintenance task. The converse is also true; each maintenance task should have its root in addressing a potential risk area. If there is not a clear link to a failure, then the purpose of the task needs to be identified to ensure that it is necessary. Because each maintenance task performed results in exposure to potential maintenance-induced errors, unnecessary maintenance items are both an economic drain and a safety risk.

Comparing the initial list of data requested (appendix K) to the list of five data items received reveals that gaps still exist. It is believed, however, that the items that are most relevant to the pitch control study were obtained.

3.1.5 Public Data Collection and Evaluation.

The primary purpose of the EMB 120 pitch control case study was to validate the AMSM process. As part of this process, several public databases were searched for relevant information on the EMB 120 pitch control system. For the EMB 120 case study, the following five primary sources of public data were queried.

- http://www.ntsb.gov/ntsb/query.asp - Accident and Incident Data
- http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAD.nsf/MainFrame?OpenFrameSet - FAA Airworthiness Directives (ADs)
- http://webfdh.ifi.cta.br/ - Centro Técnico Aeroespacial (CTA) ADs
- http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/MainFrame?OpenFrameSet – FAA ACs
- http://av-info.faa.gov/isdr/SDRQueryControl.ASP?vB=IE&cD=32 - Service Difficulty Reports

In some cases, the same or similar data items can be obtained from several different sources. Appendix E provides more information on each online source that may be helpful in an AMSM

study. Appendix S details the results of the search for accident and incident data. Appendix T lists the results of the search for FAA ADs. Appendix U gives the results of the search for CTA ADs. Appendix V gives the results of the search for ACs. Appendix W outlines an SDR study that was completed.

The data gathered was briefly reviewed and relevant items were added to the Potential Studies List. As a matter of principle, all relevant records from the Accident and Incident database resulted in an addition to the Potential Studies List because they indicate a documented occurrence of an actual event. A number of items from other public sources were also added to the Potential Studies List.

A more thorough review and evaluation of public data sources would likely result in additional items for the Potential Studies List. Data from public sources can also be valuable during the comparison and reconciliation of data activities as well as the critical assessment of items on the Potential Studies List activities.

3.1.6 SkyWest Airline Interviews.

On October 20, 2005, the development team for the AMSM visited the SkyWest maintenance facility in Fresno, California. Appendix X is an internal team document that was used before the trip to clarify the trip purpose, talking points for an initial contact with SkyWest, and a rough agenda. Although observing an actual maintenance activity had been part of the plans for the trip, the facility's schedule had changed and no aircraft were undergoing active maintenance during the visit. Despite this disappointment, productive conversations were held with the chief inspector and a maintenance technician. The Airline Operator Question List found in appendix F was studied by the AMSM team before the trip.

As a follow-up to the Fresno visit, a conference call was held on December 19, 2005, with SkyWest personnel located at the company headquarters in St. George, Utah. Appendix Y is a list of follow-up questions that formed the basis of the call. SkyWest personnel participating in the call included the EMB 120 fleet coordinator, the reliability manager, and the director of quality.

A review and analysis of the data obtained from SkyWest Airlines resulted in several items posted to the Potential Studies List.

3.1.7 Comparison and Reconciliation of Data.

The purpose of this step in the AMSM is to identify additional risks or study areas by reviewing the data from several sources and to ensure that a continuous path can be traced from potential or known risk through a scheduled maintenance task. For the EMB 120 pitch control study, some comparison and reconciliation steps were accomplished; however, the absence of critical data elements hindered the effort.

Appendix R documents the reconciliation of OEM-identified safety risks and their corresponding recommended maintenance tasks. This analysis demonstrates that the first step in the continuous

path is intact. For each OEM-identified safety risk, there is a corresponding maintenance task recommended in the MRB report. The next step to ensure that the path is continuous is to verify the inclusion and frequency of these maintenance tasks in the current maintenance program of the airline operator. Unfortunately, although the airline operator provided an abundance of data for this study, specific maintenance planning documents and maintenance task cards for the EMB 120 were not received.

The absence of this current maintenance plan precluded the evaluation of current compliance to the initial MRB report recommendations documented in appendix M. If the current maintenance plan were evaluated, deviations from the original MRB plan would be noted. Deviations that were not supported by documentation justifying the change would be added to the Potential Issues List. Another task that was not completed in this case study was the comparison of the fixtures, kits, and specialized equipment (see appendix Q) from the OEM data against the items found at the airline operator. Again, deviations that were not supported by documentation justifying the change were added to the Potential Issues List.

For this study, the potential risk items identified from the Accident and Incident databases (see appendix S) were all added to the Potential Studies List. Several items from the SDR database (see appendix W) were also added to the Potential Studies List. A positive outcome of the cross-comparison of data was that several items originally added to the Potential Studies List based on SkyWest interviews were also indicated by the SDR study. The final reconciliation and disposition of these items with data from other sources occurred as part of the assessment activity outlined in the next section.

3.1.8 Critical Assessment of Risk Items.

Throughout the study of the EMB 120, any item that might pose a risk to aircraft safety was documented on the Potential Studies List. At the conclusion of this data gathering and initial analysis, 32 items were captured on the EMB 120 pitch control Potential Studies List, which can be found in appendix J. The next step was to evaluate each item using the assessment process outlined in figure 7 and discussed in section 2.1.8. Following this flowchart would result in one of the following terminating actions for each item: No Action Required, Action Required — Make Recommendation, or Further Evaluation.

Because the focus of the EMB 120 case study was to test the AMSM, the critical assessment of the risk items was not carried to completion. The Potential Studies List was updated to reflect the data gathered, but no additional studies were completed. Consequently, the assessment flowchart shown in figure 7 was not completed for the individual items. Therefore, the majority of risk items do not include a final disposition or recommendation.

Given the nature of the process used to add items, this list is very conservative and undoubtedly contains items that would not present any safety risk to the EMB 120 if the studies were completed. Although some information on corrective action was obtained through the AD search (see appendices T and U), a thorough analysis of corrective actions was not completed. It is also likely that several of the items overlap. As part of the study documentation, items are not

removed from the list if proven redundant or not actionable. The disposition is simply indicated in the final column.

3.1.9 Recommendations and Documentation.

The bulk of the documentation of the EMB 120 pitch control AMSM study can be found in the appendices to this report. In addition, several key findings and recommendations are given in the following sections.

3.1.9.1 Case Study Findings.

The inaugural case study of the AMSM proved valuable in the refinement of the AMSM. In addition, several key findings resulted from the case study of the EMB 120 pitch control system.

- The EMB 120 pitch control system is a simple design with no risk of a single, catastrophic mechanical failure.

- Embraer integrated many safety features into the design of the EMB 120. See appendix P for a detailed description of the Embraer Design Analysis document.

- The safety analysis performed by Embraer during certification took a very limited view of potential failures and identified only eight failures modes in the system-level elevator failure mode and effects analysis (FMEA) (see appendix O). The FMEAs used groupings of elements and assumed identical failure effects for all elements within the grouping. The failure model considered fracture/separation and jammed as the primary failure modes. Follow-up with Embraer indicated a belief that more in-depth analysis was not warranted at the time.

- The EMB 120 documents received from Embraer did not include an analysis of safety risks due to nonmechanical items, such as maintenance-induced failures, weather-related issues, FOD, manufacturing errors, and operational-induced issues.

- The EMB 120 case study resulted in the cataloging of 32 items for the Potential Studies List.

- Much of the EMB 120 pitch control safety analysis is dependent on the proper operation of the mechanical disconnect system. If the mechanical disconnect suffers a latent failure, the aircraft could be at risk for a 1+1 catastrophic event.

- Although military maintenance programs include strong FOD prevention processes, no formal FOD prevention was in place at Embraer or SkyWest. No evidence of FOD prevention was found in documentation or processes. For this study, a foreign object was defined as any unintentional mass left in or near the aircraft. Examples include metal shavings resulting from drilling repairs, unremoved rig pins, and forgotten tools.

- Automatic retaining plates and split-pinned, self-locking nuts are used at each end of any bolt that serves as a dual-load path for primary control systems (those that are required for safe flight and landing) on the EMB 120 (see appendix K).

- Consistent with previous FAA research on aging aircraft, SkyWest personnel identified corrosion on the EMB 120. Specifically, corrosion was documented on EMB 120 flight control actuators, elevator torque tubes, and mass balance weights.

- Water ingress issues were documented for the EMB 120 pitch control system (see appendices W and S).

3.1.9.2 Case Study Recommendations.

Although in-depth analysis of the items listed on the EMB 120 pitch control Potential Studies List was not completed, several recommendations were made based on the limited information gathered during the case study. The supporting data for several of these recommendations are found in the appendices. The following eight recommendations are believed to be the most important actions in support of ongoing safety.

- All items listed on the Potential Studies List should be evaluated per the critical assessment flowchart. The Potential Studies List should be updated with the Final Disposition and Recommendation.

- Additional effort should be made to obtain the EMB 120 maintenance plan from SkyWest or another airline. Once obtained, it should be compared and reconciled with the Maintenance Planning Document received from Embraer and data derived from public databases.

- The mechanical disconnect is the key to many of the documented failure responses for the EMB 120 pitch control system. A more in-depth failure analysis of this key component should be carried out with particular emphasis on the detection of latent failures. A component-level Failure Mode and Effects Criticality Analysis (FMECA) that includes mechanical failures, maintenance-induced failures, weather-related issues, FOD, manufacturing errors, and operational-induced issues is recommended.

- It has been reported that when the disconnect is tested during planned maintenance, it is often extremely hard to reconnect. In addition, it is common for the sensor to malfunction because of this maintenance task, resulting in sensor replacement. A difficult maintenance task is more prone to maintenance-induced errors than a simple maintenance task. This task needs to be further evaluated.

- Numerous incidents of trim aural warning incidents on the EMB 120 resulting in aborted takeoffs were documented by means of SDRs. It is recommended that this failure mode(s) be studied to determine if an irreversible corrective action is warranted.

- An active study of EMB 120 maintenance-induced failures should be initiated. As an aircraft ages, its number of maintenance events continues to increase, resulting in increased exposure to maintenance-induced errors.

- Sources of water ingress in the EMB 120 pitch control system should be identified. Once identified, each source should be eliminated or counteracted by a water drainage plan.

4. RELATED DOCUMENTATION.

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- The Engineering Society for Advancing Mobility Land Sea Air and Space, *Aerospace Recommended Practice*, "ARP4761: Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment," December 1996.

- The Engineering Society for Advancing Mobility Land Sea Air and Space, *Joint Ground Vehicle/ Aerospace Standard*, "JA 1011: Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes," August 1999.

- F-15 Systems Program Office, *F-15 Reliability Centered Maintenance Program Plan*, Warner Robbins AFB, GA, November 2003.

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APPENDIX A—PRIMARY REFERENCES AND STANDARDS FOR AMSM DEVELOPMENT

1. Air Force Material Command, *Air Force Material Command Instruction*, "AFMCI 21-103: Reliability-Centered Maintenance Programs," 8 August 1994.

   This instruction implements AFPD 21-1. It provides guidance and procedures for establishing and monitoring preventive maintenance programs for aerospace equipment using Reliability-Centered Maintenance (RCM) methodology. It includes a recommendation that an assessment of existing inspection and maintenance requirements be performed at least every 2 years. It also emphasizes the importance of documenting the initial RCM analysis and updating the documentation as needed. The document gives a brief outline of the RCM Program Procedures that follows a fairly typical set of RCM tasks (7 pages).

2. Air Transport Association of America Inc., (ATA). *ATA MSG-3*, "MSG-3-2002.1: Operator/Manufacturer Scheduled Maintenance Development," 2002.

   Published by the Air Transport Association (the trade organization of the principal U.S. airlines), MSG-3 is the guideline document for the development of Maintenance Review Board (MRB) documents. The MRB documents form the initial scheduled maintenance for an aircraft. The MSG-3 document begins with a brief overview on the objectives of scheduled maintenance, the typical content of scheduled maintenance, and a method for scheduled maintenance development. The bulk of the document is divided into four major sections: Systems/Powerplant, Aircraft Structures, Zonal Inspections, and Lightning/High-Intensity Radiated Field. Each section contains a series of logic diagrams and explanatory material as appropriate and can be used independent of the other sections. The Systems/Powerplant section was reviewed more thoroughly than the others for this effort. As with most of the working sections, the Systems/Powerplant section begins with a detailed logic diagram. Important early steps in the procedure include identifying Maintenance Significant Items (MSI), determining the function of each MSI, identifying the functional failures of each MSI, identifying failure effects, and identifying failure causes. Once this initial information is determined, the logic diagram is used. There are two basic levels of decision logic: Level 1 (determining the failure effect category for each functional failure, i.e., safety, operational, economic, hidden safety, or hidden nonsafety) and Level 2 (taking the failure cause(s) for each functional failure into account for selecting the specific type of maintenance task). Once the Level 1 determination is made, additional logic diagrams are used to guide the maintenance task development. Descriptive material is provided for each maintenance task. A discussion regarding task interval selection and a review of task interval parameters is given. At the end of the document, there is an extensive 92-page glossary of terms.

3. Department of the Air Force, *Air Force Instruction*, "AFI 21-101: Aerospace Equipment Maintenance Management," 1 June 2004.

   This instruction implements AFPD 21-1 (*Managing Aerospace Equipment Maintenance*) and is the basic Air Force directive for aircraft and equipment maintenance management. The maintenance mission is defined as aircraft and equipment readiness. The maintenance function ensures assigned aircraft and equipment are safe, serviceable, and properly configured to meet mission needs. Maintenance actions include, but are not limited to, inspection, repair, overhaul, modification, preservation, refurbishment, testing, and analyzing condition and performance. The instruction deals with many aspects of maintenance, including preventive versus corrective, on-equipment and off-equipment maintenance. Five levels of maintenance capability are discussed: organizational, intermediate, depot, and two- and three-level maintenance. Several maintenance management metrics are defined. The Maintenance Standardization and Evaluation Program is defined. This program is implemented by the quality assurance staff. Overall, this Air Force instruction provides guidance on a wide range of maintenance-related topics, including a large chapter devoted to special programs. It details the specific tasks and responsibilities of the numerous squadrons and their specific personnel in a well-functioning Air Force maintenance organization. The instruction ends with ten attachments that provide a wide range of additional materials (574 pages).

4. Department of the Air Force, *Air Force Instruction*, "AFI 21-118: Improving Air and Space Equipment Reliability and Maintainability," 2 October 2003.

   This instruction implements AFPD 21-1, AFI 63-107 (*Integrated Product Support Planning and Assessment*), AFI 21-101, and AFI 21-103 (*Equipment Inventory, Status, and Utilization Reporting*). The document is divided into five chapters: Responsibilities, Reliability & Maintainability Program, Product Improvement Working Groups (PIWG), On Site Technical Support, and Correcting Deficiencies. The Reliability & Maintainability chapter outlines a method using numerous sources of documentation to ensure reliability and maintainability. The document also includes a five-page glossary of references, acronyms, and terms, as well as two PIWG attachments (27 pages).

5. Department of the Air Force, *Air Force Instruction*, "AFI 63-1201: Assurance of Operational Safety, Suitability, & Effectiveness," 1 February 2000.

   This document implements AFPD 63-12. It defines the process for establishing and preserving the operational safety, suitability, and effectiveness (OSS&E) of Air Force systems and end-items over their entire operational life. The document is divided into two chapters. The first chapter outlines the mandatory process elements of OSS&E. These elements include disciplined engineering process, inspections and maintenance, sources of maintenance and repair, sources of supply, training, certifications, operations & maintenance, and technology demonstrations. The second chapter provides a detailed outline of responsibilities and authorities for the implementation of OSS&E. The last five pages are a glossary of references, acronyms, and terms (12 pages).

6. Department of the Air Force, *Air Force Policy Directive*, "AFPD21-1: Air and Space Maintenance," 25 February 2003.

This directive provides overarching guidance for the maintenance of air and space equipment. Compliance with this publication is mandatory for all Air Force and Department of Defense contractor activities. It briefly outlines the AF policy and objectives with respect to maintenance. It also outlines the roles and responsibilities that the various AF units have for maintenance activities. Over half of the document is devoted to an expanded list of publications, acronyms, terms, and metrics (9 pages).

7. Department of the Air Force, *Air Force Policy Directive*, "AFPD 63-12: Assurance of Operational Safety, Suitability, and Effectiveness," 1 February 2000.

This document establishes the Air Force requirement for assurance of operational safety, suitability, and effectiveness (OSS&E) for all Air Force product lines. The policy refers to AFI 63-1201 as the resource for OSS&E. The basic policy states that all systems and end-items must be delivered with a baseline consistent with OSS&E, the baseline must be preserved throughout the operational life, and the baseline must be updated when changes or modifications are made to the systems or end-items. Responsibilities and Authorities are outlined in detail. Three of the six pages are devoted to a glossary of references and terms (6 pages).

8. Department of Defense, *Military Handbook*, "MIL-HDBK 514: Operational Safety, Suitability, and Effectiveness for the Aeronautical Enterprise," 28 March 2003.

This handbook describes the OSS&E process, providing great detail regarding the specific requirements of the process and the responsibilities of individuals who perform the process. It reviews all the mandatory process elements of the OSS&E approach and is the guidebook used to meet the requirements set forth in AFPD 63-12 and AFI 63-1201 for all Air Force systems. The purpose of OSS&E is to preserve the critical characteristics established during system/end-item acquisition. The preservation process begins when the system/end-item is turned over to the operational user. Hence, OSS&E is substantially a sustainment function, with its roots established during acquisition. The OSS&E process consists of two parts: (1) establishing the OSS&E baseline and (2) preserving the OSS&E baseline throughout the life of the system or end-item. There are six levels of OSS&E implementation, each with its own primary activity. The activities are chief engineer assigned, configuration control process established, plan to assure and preserve OSS&E documented, OSS&E baseline developed and coordinated with user, OSS&E assessment of fielded systems/end-items, and full OSS&E policy compliance. The OSS&E mandatory process elements include disciplined engineering process, total ownership costs, inspections and maintenance, sources of maintenance and repair, sources of supply, training, certifications, operations and maintenance, and technology demonstrations. The handbook also includes a section on other systems engineering processes. Overall, the focus of this handbook is largely regulatory versus technical/instructional (110 pages).

9. Department of Defense, *Military Handbook*, "MIL-HDBK 515: Weapon System Integrity Guide (WSIG)," 11 October 2002.

This handbook provides guidance on how to integrate the existing Air Force integrity processes within systems engineering. The following integrity systems are addressed: the Aircraft Structural Integrity Program, the Engine Structural Integrity Program, the Mechanical Equipment and Subsystems Integrity Program (MECSIP), and the Avionics/Electronics Integrity Process. It also illustrates the link from WSIG to several OSS&E processes. A WSIG process flowchart is included. The process addresses new equipment, COTS, and modifications. An interesting aspect is the identification of eight design solutions: allow failure, detect before break, redundancy, scheduled replacement, inspection, fault tolerance, high design margin, and flight restrictions (25 pages).

10. Department of Defense, *Military Handbook*, "MIL-HDBK 1798A: Mechanical Equipment and Subsystems Integrity Program," 24 December 2001.

This handbook describes the general design and analysis process to achieve and maintain the physical and functional integrity of the mechanical elements of airborne, support, and training systems, also known as MECSIP. The process is intended to be in direct support of AFPD 63-12 and AFI 63-1201. The process is intended to be applied from the design phase up through and including the sustainment phase. This process applies to both development and non-development items, including commercial off-the-shelf items. The document presents a Table of Mechanical System Integrity Program life-cycle tasks and provides a brief description of each task. The items used as design criteria and the tasks described may be useful as a benchmark design process during the data-gathering and interview processes performed during an application of the Aging Mechanical Systems Methodology. Specifically, the initial design should be assessed relative to the tests outlined as part of Task III and Task IV. The Task V (Force Management) life-cycle tasks (pages 16-20) are directly applicable to the work at hand (22 pages).

11. The Engineering Society for Advancing Mobility Land Sea Air and Space, *Aerospace Recommended Practice*, "ARP4754: Certification Considerations for Highly-Integrated or Complex Aircraft Systems," November 1996.

Published by the Society of Automotive Engineers (SAE), this standard was created to provide guidance during the system development of highly integrated or complex aircraft systems. The standard focuses on the development process for electronic/software-based systems from an aircraft-level function standpoint. The standard contains nine major sections and four appendices. The system development section introduces the concept of development assurance. There are six development assurance activities: certification coordination, safety assessment, requirements validation, implementation verification, configuration management, and process assurance. Development assurance establishes confidence that system development has been accomplished in a sufficiently disciplined manner to limit the likelihood of development errors that could impact aircraft safety. The section on certification planning includes a detailed list of the range of possible

certification data that may be used. The section on requirements determination and the assignment of development assurance level identifies three types of requirements: safety requirements, functional requirement, and derived requirements. It establishes five development assurance levels, which departs slightly from those specified in Advisory Circular (AC) 25.1309-1A in that an "E" level is defined as "no safety effect." Five architectures are also identified: partitioned design, dissimilar independent design, dissimilar design, active/monitor parallel design, and backup parallel design. A table shows the effects these architectures may have on the item development assurance level. A discussion of the safety assessment processes, which may be used to provide analytical evidence showing compliance with airworthiness requirements, is included. The standard identifies four primary safety assessment processes: functional hazard assessment (FHA), preliminary system safety assessment (PSSA), system safety assessment (SSA) and common cause analysis. The requirement validation section includes a validation process model that is comprised of the following activities: development of a validation plan, determination of the necessary level of validation, performance of completeness and correctness checks, validation of assumptions, preparation of a validation matrix, and creation of a validation summary. The assumption categories are thoroughly discussed and can be used to assist in the evaluation of identified assumptions or the identification of implicit assumptions that have not been specifically identified. A table provides the appropriate requirements validation methods based on the development assurance level of the function under evaluation. The document ends with four appendices, one of which describes a generic approach to systems development from a conceptual definition of the desired functionality to certification (88 pages).

12. The Engineering Society for Advancing Mobility Land Sea Air and Space, *Aerospace Recommended Practice*, "ARP4761: Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment," December 1996.

    Published by the SAE, this document provides guidelines and methods for performing the safety assessment required for the certification of civil aircraft. Its intent is to support the demonstration of compliance with Code of Federal Regulations/Joint Aviation Requirements (CFR/JAR) 25.1309. The first 30 pages of the document review the safety assessment process. The remainder of the document consists of 12 appendices that provide more information about the safety assessment process steps and safety analysis methods. The first three appendices outline the major process steps for a safety assessment process: FHA, PSSA, and SSA. The fourth through eleventh appendices provide information on the following safety analysis methods that are often used in the completion of a safety assessment: fault tree analysis (FTA), dependence diagram, Markov analysis, failure modes and effects analysis (FMEA), failure modes and effects summary, zonal safety analysis, particular risks analysis, and common mode analysis. The final appendix is a contiguous safety assessment process example, which is over 150 pages in length (331 pages).

13. The Engineering Society for Advancing Mobility Land Sea Air and Space, *Joint Ground Vehicle/Aerospace Standard*, "JA 1011: Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes," August 1999.

Published by the SAE, this document is the standard that defines the criteria that any process must comply with to be called an RCM. It lists numerous references and publications related to RCM. It documents the seven questions that must be answered "satisfactorily" and in the correct sequence to have an RCM process. It also provides some clarifying descriptions and guidance relative to each of the seven required questions (12 pages).

14. F-15 Systems Program Office, *F-15 Reliability Centered Maintenance Program Plan*, Warner Robbins AFB, GA, November 2003.

This paper documents a plan for implementing the Versatile Reliability-Centered Maintenance (VRCM) program processes to the F-15 Eagle aircraft and related systems. VRCM is described as a logical process used to identify preventative maintenance requirements to achieve the inherent reliability of systems and equipment at minimum expenditure of resources. The approach uses Age Exploration as the major contributor in the refinement of principle maintenance tasks and task intervals. The process includes the use of specialized VRCM software. The seven RCM questions are listed, where questions 1-4 are for the FMEA, while questions 5-7 are for the function preservation strategies. The stated goal of the VRCM analysis is to identify the appropriate function preservation strategy to eliminate, avoid, mitigate, or live with the consequences of the failure. VRCM is identified as having 6 steps. These steps are based on the seven questions of RCM. Step 5 of VRCM is said to meet the requirements of SAE JA1011. Included in the F-15 specific analysis is a description of the method used for analysis only. A description for determining the boundaries of analysis is also given. This report lists several equations and sources for calculating mean time between failures (MTBF) values and preliminary task intervals. (Note: Distribution Limited to U.S. Government Agencies Only, 35 pages).

15. Lloyd, E. and Tye, W., *Systematic Safety: Safety Assessment of Aircraft Systems*, 3rd ed, London: Civil Aviation Authority, March 2002.

First published in 1982, this book was written by two engineers who retired from the British Civil Aviation Authority and was published by the Safety Regulation Group of the Civil Aviation Authority. Primarily, the book is concerned with the principles of safety assessment during the design and certification of an aircraft. The early chapters discuss the development of acceptable accident rates and provide information on the establishment of requirements. A thorough discussion of the meaning of "per hour" is also given. An extensive probability chapter is included. Topics include series versus parallel design, common-part versus common-cause/common-mode versus cascade failures, unwanted operation of systems, the exponential curve, dormant faults, and sequencing of failures. The authors use the mathematics of probability to illustrate the

advantages and disadvantages of various reliability strategies based on the characteristics of the failure mode. A detailed chapter on cascade and common-mode failures is included. Specific common failure modes are discussed for electrical systems, hydraulic systems, mechanical linkages, fuel systems, and cooling systems. A discussion of external events that can cause failures is presented. Four suggested methods are given for the defense against cascade and common-mode failures: segregation of services, zonal analysis, noncontainment of fragments of turbine engines, and use of dissimilar redundancy. The book ends with a call for well written documentation and reporting processes (159 pages).

16. Moubray, J., *Reliability-centered Maintenance*, 2nd ed, New York, NY, Industrial Press Inc., 1992.

    This book describes a formal process for RCM with instructive detail. The process is developed through the following seven basic questions: (1) What are the functions and associated performance standards of the asset in its present operating context? (2) In what ways does it fail to fulfill its functions? (3) What causes each functional failure? (4) What happens when each failure occurs? (5) In what way does each failure matter? (6) What can be done to predict or prevent each failure? (7) What should be done if a suitable proactive task cannot be found? The RCM Decision Worksheet is the primary documentation tool for the RCM process. This worksheet is a specialized FMEA worksheet. The RCM II Decision Diagram serves as a roadmap to complete the RCM Decision Worksheet. The book also provides direction on how to implement the RCM process as well as a discussion on the potential benefits and metrics for a successful implementation. The appendices include valuable information on sources of human error, understanding risk tolerance, and a catalog of condition-monitoring techniques (414 pages).

17. NAVAIR, Management Manual, NA-00-25-403, "Guidelines for the Naval Aviation Reliability-Centered Maintenance Process," 01 March 2003.

    This document serves as the Naval Aviation Guideline for RCM processes for aircraft, engines, aircrew escape systems, weapon systems, aircraft launch and recovery equipment, and support equipment. In the document, RCM is defined as an analytical process used to determine preventive maintenance requirements and identify the need to take other actions that are warranted to ensure safe and cost-effective operations of a system. The document is comprised of four major sections: RCM Program Management, RCM Analysis Process, Implementation of Analysis Results, and RCM Program Sustainment. A sample RCM Program Plan is included as an appendix. As part of the Failure Mode and Effects Criticality Analysis (FMECA) description, the document provides some valuable discussion on the importance of having a well-defined operational context, and consideration of the multiple (and secondary) functions of a piece of hardware. An interesting discussion of the effects of preventive maintenance on MTBF values is presented. The method discussed uses Integrated Reliability-Centered

Maintenance System software to assist in the analysis. The sustainment section is particularly applicable to the task at hand (122 pages).

18. Office of the Federal Register National Archives and Records Administration, Code of Federal Regulations, "Title 14: Aeronautics and Space," Washington: U.S. Government Printing Office, 01 January 2004.

    Title 14 Code of Federal Regulations is published as three books. The following parts and relevant subparts of Title 14 were reviewed: Part 25 (Airworthiness standards: Transport category airplanes), Part 43 (Maintenance, preventive maintenance, rebuilding, and alteration), Part 65 (Certification: Airmen other than flight crewmembers), Part 121 (Operating requirements: Domestic, flag, and supplemental operations), Part 135 (Operating requirements: Commuter and on demand operations and rules governing persons on board such aircraft), Part 145 (Repair stations), and Part 147 (Aviation maintenance technician schools). These regulations form the basis of "the law" for commercial aviation.

19. U.S. Department of Transportation: Federal Aviation Administration, Advisory Circular 25.1309-1A, "System Design and Analysis," 21 June 1988.

    While Title 14 CFR Part 25.1309 is "the law," this Advisory Circular (AC) serves as a set of "helpful hints" that can be used to meet the intent of that law. Published in 1988, its intent is to describe various acceptable methods for showing compliance with the requirements of § 25.1309. The AC addresses the Part 14 requirement of a fail-safe design and offer the following design principles or techniques: designed integrity and quality, redundancy, isolation of systems components and elements, proven reliability, failure warning or indication, flightcrew procedures, checkability, designed failure effect limits, designed failure path, margins or factors of safety, and error-tolerance. A major concept presented is the Probability versus Consequence Graph. This graph provides the simple guidance that as the consequences of a failure become more severe, the probability of that failure occurring must become more improbable. Specifically, a "minor" failure condition would be acceptable at the "probable" level (greater than 1×10^{-5} probability per flight hour), while a "major" failure condition must be shown to be "improbable" (between 1×10^{-5} and 1×10^{-9}) and a "catastrophic" failure condition must be shown to be "extremely improbable" (less than 1×10^{-9}). The development of a Master Minimum Equipment List (MMEL) is indicated to identify the equipment and functions that are not specifically required to be operative for safe flight and landing (19 pages).

20. U.S. Department of Transportation: Federal Aviation Administration, Advisory Circular *Advisory Material Joint*, 25.1309 (Arsenal version), "System Design and Analysis," 10 June 2002.

    This unpublished work-in-progress represents the next update of AC 25.1309. The draft reviewed is dated 6/10/2002. Its intent is identical to AC 25.1309, to describe various acceptable methods for showing compliance with the requirements of § 25.1309. This

revised version includes much of the same information with a few important modifications and additions. The number of Failure Condition Classifications has increased from 3 to 5. The new classifications include No Safety Effect, Minor, Major, Hazardous, and Catastrophic. The number of probability terms has increased from 3 to 4. The new qualitative probability terms are Probable Failure (greater than 1×10^{-5} probability per flight hour), Remote Failure (between 1×10^{-5} and 1×10^{-7}), Extremely Remote (between 1×10^{-7} and 1×10^{-9}), and Extremely Improbable (less than 1×10^{-9}). The Probability versus Consequence Graph is again used, with a few important differences. The X and Y variables have been interchanged and the probability axis now indicates an increasing value (versus decreasing). As a result of these changes, the relationship is now shown as a linearly-decreasing function. As the severity of a failure condition increases, the acceptable probability of the failure condition decreases. A descriptive table has been added which is very helpful in fully understanding the classification of failure conditions. The AC also contains 4 appendices: Assessment Methods, Safety Assessment Process Overview, Calculation of the Average Probability per Flight Hour, and Allowable Probabilities (40 pages).

APPENDIX B—AIRCRAFT AND SYSTEM SELECTION APPROACHES

The first activity of the Aging Mechanical Systems Methodology (AMSM) is to select an aging aircraft and specific mechanical system to be studied. The methodology can be applied to any aging mechanical system; therefore, the optimal selection is dependant on the objectives of the study. This appendix describes three approaches to choosing an aircraft and system for an AMSM study. These approaches include selection based on data-driven risk evaluation, current maintenance burden, and engineering insight. Regardless of the method used, because the AMSM is a safety-based process, it is important to limit the system selection to those systems that are critical to aircraft safety.

B.1 DATA-DRIVEN RISK EVALUATION.

If the selection will be based on a data-driven risk evaluation, potential study systems will be evaluated based on available incident and accident data. According to the 1988 Federal Aviation Administration (FAA) Aging Transport Non-Structural Systems Plan, the four databases that are most relevant to the study of aging nonstructural aircraft systems include the National Transportation Safety Board (NTSB) Accident and Incident Database, the FAA Accident and Incident Data System, the FAA Service Difficulty Report (SDR) Database, and the FAA/National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS). Appendix E is a list of several on-line sources and databases. Data from one or more of these databases can be evaluated using a Pareto chart or other analytical method to support the system selection activity. As this data is evaluated, it is important to separate anecdotal information from actual findings. For example, both the SDR and ASRS databases are anecdotal and conclusions inferred from the data they contain need to be vetted by additional means. If this system selection approach is used, the resulting system selection will be one that addresses potential risk areas based on historical data.

B.2 CURRENT MAINTENANCE BURDEN.

Another approach to system selection is based on identifying systems that carry a high maintenance burden. To use this approach, a current maintenance database must be available. Using this database, individual systems are listed. For each system, the approximate maintenance man hours (MH) and mean time between maintenance (MTBM) are documented. A relative weight is determined for each of the two measures resulting in a value for total maintenance burden.

MAINTENANCE BURDEN = [(MH) * MH weight factor] + [(MTBM) * MTBM weight factor]

The systems were then listed in order by total weight, which is the order of priority for analysis.

Choosing a study system based on maintenance level is consistent with the safety focus of the AMSM. A system that requires maintenance intervention at a high frequency may be a system that is subjected to higher levels of wear or damage than other systems. In addition, because

maintenance-induced errors are a concern in aging aircraft systems, the increased exposure of some systems to maintenance activities increases their risk of this class of failures.

B.3 ENGINEERING INSIGHT.

An alternative method of system selection is the use of engineering insight. An argument can be made that mechanical systems that experience many incidents or accidents as well as mechanical systems that require a large amount of maintenance are already the focus areas of any continuous improvement work. It is, therefore, possible that other mechanical systems tend to be overlooked. The use of engineering intuition to select the best study system supports the theory that some of the biggest untapped opportunities to mitigate safety risks in any engineering discipline are those things that often go unnoticed.

The selection of a specific aircraft system for the application of the AMSM is an important first step in the methodology. The AMSM can be applied to any aging mechanical system and is not dependant on the system selection approach taken.

APPENDIX C—ORIGINAL EQUIPMENT MANUFACTURER DATA REQUEST

The original equipment manufacturer (OEM) is an important source of data during an Aging Mechanical Systems Methodology (AMSM) study. The following list of items is a generalized request for OEM data. This list should be reviewed and customized for each AMSM study.

- Maintenance planning documents/maintenance review board reports from MSG-3
- System safety assessment documents including:

    - System description
    - Failure modes and effects criticality analysis
    - Fault tree analysis/dependence diagrams/Markov analysis
    - Functional hazard assessment

- Maintenance manual
- Aircraft specifications and drawings for study system
- Written description/training materials for study system
- Airplane flight manual
- Maintenance and material management data
- Service Difficulty Report
- FAA Airworthiness Directive (AD)
- Local regulatory agency AD (if aircraft not of U.S. origin)
- OEM service bulletins
- Maintenance depot data
- Extended maintenance task requests
- Typical flight operations statistics (hours/flight, flights/year, etc.)
- Certification Maintenance Requirements
- Age exploration studies
- Advisory Circular reports
- Pilot squawks
- Lead-the-fleet data
- Contact names for parts suppliers
- Engineering change reports for hardware or software
- Minimum equipment required for continued operation
- System schematics
- OEM all operator letters

APPENDIX D—ORIGINAL EQUIPMENT MANUFACTURER DATA EVALUATION

Original equipment manufacturer (OEM) data must be critically evaluated as it is received. The first step in the evaluation is to document the critical characterization of the aircraft system. This characterization can be achieved through the creation of the following lists. These lists should be started once the initial packet of OEM data is received and updated throughout the process. They form the basis for characterizing the study system and are an important part of the study documentation.

- Primary and secondary functions for all major system and components
- Redundant systems and components
- Isolated systems and components
- All known operating environments and mission profiles
- All protected systems and protective functions
- Uninspectable load paths and undetectable latent failures
- All tools, fixtures, and specialized equipment required for system maintenance

The second step in the evaluation of OEM data is the in-depth analysis of the data. The following questions are designed to facilitate this analysis. While not all questions will apply to every system being studied, there is risk in dismissing a question too easily. There is also a risk in applying the questions in a cursory fashion. The intent is to use these questions as a path to penetrate beyond the surface and identify potential study areas. The existing design and certification data from the OEM will, by its very nature, be dated when studying aging aircraft systems. The goal of the evaluation activity is to identify relevant gaps or risks based on contemporary standards without raising undue alarm or criticism of a certification process that is several decades old. The following questions are presented to support the evaluation of the OEM data.

- Is the System Safety Assessment analysis thorough? Are all system and hardware items in the study control volume covered? How many failure modes are identified?

- When inspection tasks are required, does the maintenance documentation include specific inspection criteria with a description of unacceptable conditions for all inspection tasks?

- Which maintenance tasks allow for the creation of dust or metal shavings? Are maintenance procedures in place to prevent these shavings from being deposited on system components? Are inspections made for this source of FOD?

- Does the System Safety Assessment address failures of both the primary and secondary functions of each major system or component?

- Does the System Safety Assessment consider failures caused by human error, design flaws, and maintenance-induced errors?

- Are failure rates composite numbers reflecting an overall value for a number of operations? Although this technique was common in the past, current reliability analysis emphasizes the importance of evaluating each failure mode independently and characterizing each failure rate at the lowest reasonable level.

- Have redundant systems been identified? For redundant systems, special attention should be paid to common-mode failures which can impact both systems with a single failure.

- Is isolation (or independence) used as a design principle? What is the purpose of the isolation? Is it complete?

- Have multiple operating environments been identified? Do end users operate under different mission profiles? Does the System Safety Assessment include failure modes that may arise under each of the operating environments and mission profiles identified?

- Have protected systems and protective functions been identified? Has a failure mode analysis been performed to understand the potential failure of the protective function? A multiple failure occurs if a protected function fails while a protective device is in a failed state. How does the maintenance plan address the potential failure of a protective function?

- Have uninspectable load paths and potential latent failures been identified? What is the maintenance plan for uninspectable load paths? Does the maintenance plan include tasks intended to address specific latent failures? Have these failure modes been identified in the System Safety Assessment?

- Have specific tool, fixtures, and specialized equipment required to perform the system maintenance tasks been identified? Are these items readily available to the maintenance provider? Will the use of substitute items contribute to maintenance-induced errors?

As these and other questions are answered, some will identify areas where further data collection would be helpful. The data may be available from the OEM or other sources. Another outcome of this evaluation is the addition of items to the Potential Studies List.

APPENDIX E—ON-LINE SOURCES AND DATABASES

http://www.ntsb.gov/ntsb/query.asp Database that can be queried for accident and incident data from 1/1/1962 to present.

http://www.nasdac.faa.gov/ Website of the National Aviation Safety Data Analysis Center. The site has three major tabs: Database, Subjects, and Studies. The Database tab provides links to eight aviation safety-related databases. These include both domestic and international databases. The Subjects tab sorts the same eight databases by subject (and includes one or two additional databases under some of the subject headings). The Studies tab provides electronic copies of formal reports from recent Federal Aviation Administration (FAA) studies. There is no search or query feature on this site. When searching for accident/incident data, this site is not the preferred option; instead use the http://www.ntsb.gov/ntsb/query.asp site. Although both sites should provide the same database information, the National Transportation Safety Board (NTSB) site has a more user-friendly query, which results in an increased probability for a successful search. In addition, the NTSB site usually provides several report options for each event in .pdf format, while the site provides a brief for each event.

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/MainFrame?OpenFrameSet On-line location for all FAA Advisory Circulars (AC). Both current and historical ACs can be accessed. Searches can be based on AC number, part, or keywords. All ACs are available electronically in .pdf format.

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAD.nsf/MainFrame?OpenFrameSet On-line location for all FAA Airworthiness Directives (AD). Site includes Emergency ADs (last 30 days), New ADs (last 60 days), Current ADs, and Historical ADs. Searches can be performed by number, make, product, or keywords. The text of the AD is available directly from the site (sometimes as a .pdf).

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgADNPRM.nsf/MainFrame?OpenFrameSet On-line location for all FAA Notices of Proposed Rulemaking.

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgTSO.nsf/MainFrame?OpenFrameSet On-line location for all FAA Technical Standard Orders.

http://av-info.faa.gov/isdr/SDRQueryControl.ASP?vB=IE&cD=32 FAA website for Service Difficulty Reports. Query options are somewhat difficult. The best search results are obtained when several fields are left blank.

http://www.gpoaccess.gov/fr/index.html The website of the Federal Register. This site provides on-line access to the Code of Federal Regulations (CFR). Viewing a specific electronic page from the CFR resulted in mixed success. It also is a source of Proposed Rules that are part of the Federal Register, such as Docket No. 2003-NM-33-AD, which addresses an EMB-120 pitch control issue. The site has both simple and advanced search capabilities.

http://webfdh.ifi.cta.br/ Website of the Brazilian Centro Tecnico Aeroespacial (CTA). The CTA is the certifying agency for Brazilian-designed aircraft. Contains an on-line database of Brazilian ADs and Notice of Proposed Regulation (NPR). It also contains the Type Certificate Data Sheets (TCDS) and Master Minimum Equipment List for many commercial aircraft. An SDR database and query tool is also available. Most items are available in pdf format in English, Portuguese, or both. A comprehensive link library which includes most of the world's aviation authority sites is also located on the site.

http://www.dac.gov.br/principalIng/index.asp Website of the Civil Aviation Department (DAC). The DAC is the airworthiness authority in Brazil. The DAC is an organization subordinated to the Aeronautical Command—Ministry of Defense, whose mission is to study, guide, plan, control, stimulate, and support the activities of public and private Civil Aviation, as well as to keep a good relationship with other agencies in dealing with matters of its competence. The website contains data concerning airports, registered aircraft, pilot and crew requirements, registered maintenance facilities, etc.

http://www.e-publishing.af.mil/ The website of Air Force Publishing. It is the source site for all Air Force administrative publications and information management tools. This site provides electronic copies of Air Force Instruction (AFI), Air Force Material Command Instruction (AFMCI), Air Force Policy Directive (AFPD), and many other Air Force documents. Documents can be found by title, if known, or by using a search engine.

http://dodssp.daps.dla.mil/ A database for military specifications and standards. Access is available only after going through a free registration process. A good source for Military Standards and Military Handbooks (MIL-HDBKs).

http://logistics.navair.navy.mil/ The website of the Naval Air Systems Command. This website is the source of NA-00-25-403 (a comprehensive guide to the Naval Aviation Reliability-Centered Maintenance Process) as well as Office of the Chief of Naval Operations INSTRUCTION 4790.2H, which details the Naval Aviation Maintenance Program.

www.grc.nasa.gov Website of the National Aeronautics and Space Administration Glenn Research Center. This site contains a Beginners Guide to Aeronautics, which includes both written material and interactive activities. The site also documents research into future aeronautical technologies.

http://www.airlines.org/home/default.aspx Website of the Air Transport Association (ATA). The ATA is the trade group of America's leading airlines.

http://hfskyway.faa.gov/document.htm Human Factors Issues in Aircraft Maintenance and Inspection website. This site provides access to all reports from the Human Factors Issues in Aircraft Maintenance and Inspection Research Program.

APPENDIX F—AIRLINE OPERATOR QUESTION LIST

F.1 THE MAINTENANCE PLAN.

What is the process by which a Maintenance Review Board report is translated into a maintenance plan? Does the airline operator have task cards for all items listed in the MPD?

Are there failure modes that were not identified in the original FMECA but are protected by scheduled maintenance? Do these tasks tend to address economic and operational concerns only?

How does the maintenance plan change over time? Do you receive annual input from the Maintenance Review Board? What other information is received from the FAA and OEM? Is there a list of items that have been extended?

How does the plan change in response to changes in usage? Are these changes tracked? Do they result in increased or decreased stress on the aircraft?

Are there many internally generated changes? What process do you follow to get approval for changes to the maintenance plan? What is the system for maintenance technician feedback on instructions, fixtures, etc?

How are changes in the maintenance plan communicated to the maintenance planning group and mechanics performing the work? What type of documentation is kept when changes are made?

Some researchers indicate that OEM-produced maintenance plans tend to include a high level of "over-maintenance." Is this characterization true based on your experience?

Do you follow a Reliability-Centered Maintenance program? What is your typical split of the following maintenance categories: scheduled restoration tasks, scheduled discard tasks, scheduled on-condition tasks, failure-finding tasks, and unscheduled repairs.

F.2 TASK PLANNING AND PRIORITIES.

When all is going according to plan, how are maintenance tasks assigned? Who does the maintenance task planning? What are the overriding priorities relative to maintenance task planning? How flexible is the schedule to upsets?

How are the assigned tasks communicated to the personnel responsible for performing the work? Are locally published procedures clear and current? What additional resources are available for mechanics?

What is the relationship between the maintenance group and the operations group? Which is the "dominant force," operations or maintenance? How are conflicts in schedules typically resolved?

Are the same resources typically used for both scheduled and unscheduled maintenance? Are all resources typically capable of completing all tasks? If not, which how are specialized resources allocated?

How do you schedule AD-required activities? Are they usually coordinated with regular scheduled maintenance?

What is the process if a task needs to be carried over to the next shift or handed-off to a different maintenance technician?

Are there aircraft being maintained that are of a different status (e.g. transient aircraft, non-company aircraft)? If so, how are these aircraft integrated in the planning process? Do different aircraft require different practices for records, parts disposition, etc.?

Are the maintenance tasks evaluated for safety (of personnel, equipment, and environment)? Have any tasks been modified to accommodate company safety policies? What type of PPE (personal protective equipment) is required to perform the maintenance tasks outlined on the aircraft system?

What happens if an aircraft requires maintenance while at a non-company location?

Is any part of this process computerized? If so, what software is used? Is this process integrated with other computer-assisted maintenance processes?

F.3 PERSONNEL TRAINING AND STAFFING.

What is the structure of the maintenance organization? Who has ultimate responsibility to ensure tasks are done correctly and on time?

What is the typical training for maintenance personnel? Is it company-based or industry taught? Do most personnel come in with experience or licensing?

Are there various designated technician levels based on training/experience?

Are there specialty classifications (ala Special Experience Identifier) used for certain tasks? Are there different “flights” with different responsibilities for portions of the aircraft, types of systems, or specialized tasks? Are there any specific tasks that require specialty skills beyond those of regular maintenance personnel? If so, how are the skills/staffing managed?

What are the typical guidelines for duty time of maintenance personnel? What are the extreme limits allowed in special circumstances? How are peaks and valleys of demand handled?

Does the maintenance planning include a provision for “Red Ball” maintenance, whereby qualified personnel are standing by to eliminate and repair last minute issues in order to prevent delays in takeoff?

Do you have any permanently-grounded surplus aircraft used for training? Do personnel have any opportunities to learn on actual aircraft that are not active flight aircraft?

Do you use computers-based training or staffing programs?

F.4 TOOLS AND INSTRUMENTS.

How are requirements for task-specific tools determined for an individual maintenance plan? Do OEM materials typically indicate all standard and custom tools required? What is the process for the approval of locally designed tools or equipment?

Have any additional tools been added to assist in the maintenance tasks?

Are provisions in place to protect delicate or sensitive tools protected during handling and storage? What happens when a task-specific fixture or tool is broken or lost? Are spares on-hand? What is the ETA for replacements?

Are there instruments or indicators that are easily mis-read or mis-interpreted and can lead to faulty operation of the system under study?

Is there a tool and equipment management program (to prevent FOD and unnecessary costs)? Is a record kept of all tools used during the maintenance task? Is an inventory taken upon task completion to ensure that none are left behind? Are chits/dog tags/ID tags/dust caps placed on any tools? Do any of the tools have pocket clips attached? Can they be removed? Are they secured in a way that will prevent FOD?

Are tools and equipment adequate and serviceable to support the unit mission? Do tool availability issues result in any maintenance delays?

What types of tools are company-owned and what types/amounts are the personal property of mechanics? If personal tools are used, how are inventories managed and controlled? What criteria are used to replace old tools?

F.5 SPARES AND SUPPLIES.

Do you have an IPL (Initial Provisioning List) from the OEM? Do you follow it? What type of spares, parts, and supplies do you usually keep on hand?

Are there are repairable parts on the study aircraft system? If a part is reconditioned, does its time go to zero? What if the part is older than the aircraft upon which it is added? Will the part's time go beyond a limit because the aircraft itself is still below the limit?

What is the policy on cannibalization? Who can override normal policy? Are cannibalization procedures being complied with as outlined by company policy?

Are replacement parts inspected upon receipt? Where are replacement parts stored? What steps are taken to ensure no damage occurs during storage? Are there special procedures for particularly fragile or sensitive parts?

Are any parts "matched sets" which need to stay together during rebuild?

How are bad/used/worn-out parts labeled? What is the disposal process to ensure no mixing with good parts? How are the pieces sorted to ensure that old/bad pieces are not mistakenly re-assembled?

How are local documents updated when parts become obsolete or are replaced by the vendor/OEM for any reason? Are any after market parts that are independently manufactured used on this system?

Is a record kept of all parts used during the maintenance task? Is an inventory taken upon task completion to ensure that none are left behind?

Are bench stock bins properly filled, flagged, labeled, and shelf life items properly binned and kits being controlled? What about rag inventory? FOD?

F.6 DOCUMENTATION.

What data systems are used to document maintenance activities?

Where are the maintenance records kept for an individual aircraft? Are there multiple copies? If so, how are they kept consistent? Where are records kept when repair is in-progress? Is there a logbook that stays at the station, or goes with the aircraft (or part)? Do maintenance records include the identification of the individual who performed the work? What is the process for temporary modifications?

What is the reporting process if a problem is noticed while completing a maintenance task which is not part of the task itself (e.g. corrosion of a nearby component)? What is the process if a task needs to be carried over to the next shift or handed-off to a different maintenance technician?

How is information regarding maintenance activities performed disseminated to the pilot who will fly the aircraft immediately after maintenance?

Is an aerospace vehicle status reported after each flight? What status levels result in what maintenance activities?

Is there a system for the inventory and management of tools, equipment, and spares in place to prevent foreign object damage and unnecessary costs? How tightly are these items managed? Is an inventory taken upon task completion to ensure that none are left behind?

What systems are in place to ensure the accuracy of the maintenance documentation? Is maintenance data being accurately completed and reviewed by supervisors prior to processing or filing? Is there a formal process for correcting or updating maintenance records once they have been submitted?

Assuming you have an electronic records-keeping system, what is the back-up/manual procedure if the electronic system is down or unavailable?

If electronic documentation is used, are hardcopies printed out periodically to serve as back-up in case of system failure?

F.7 INSPECTIONS AND QUALITY CONTROL.

What is the base plan for inspections and quality control during and after maintenance? Is there an independent QA function which evaluates the quality of maintenance accomplished by the maintenance staff?

Is most inspection done by internal resources? Do any outside organizations inspect the maintenance activities (FAA, private auditors)? Which of these inspection types are performed: "over-the-shoulder" personnel inspection, management evaluation, document audit, parts/supplies audit?

Is there a grading process for QA inspections? Are shifts/teams given a designation (e.g. OUSTANDING, EXCELLENT, SATISFACTORY, MARGINAL, and UNSATISFACTORY) or is it just PASS/FAIL?

Are operational or functional flight checks performed after all maintenance activity? If no, what types or extent of maintenance activities result in a flight check requirement?

What is the typical pilot's inspection before flight?

Is there a documentation system for tools, spare parts, and supplies to ensure that all are accounted for at the end of the maintenance task? What about rig pins?

Research has indicated that the following five types of maintenance errors are typically responsible for accidents and incidents: (1) incorrect assembly (2) the carrying forward of defects or the incorrect diagnosis of defects (3) the leaving of loose objects (4) putting wrong fluid into vital systems (5) the lack of good housekeeping when making modifications and repairs. These failures are not typically included in OEM-provided materials. Has any analysis been done regarding potential maintenance-induced failures?

How do employees document recommendations or observations that they feel need to be escalated?

F.8 PROACTIVE EFFORTS.

Is there an analysis function which proactively looks at maintenance data and records to spot trends? Do you calculate failure data based on maintenance records or maintenance materials usage?

How are seasonal or other cyclic variations and trends recorded?

If an individual aircraft has suffered damage in an accident or incident, how will its maintenance program be modified to protect against residual fatigue, secondary damages, or other risks?

What is the reporting process if a problem is noticed while completing a maintenance task which is not part of the task itself (e.g. corrosion of a nearby component)? Is there a chafing program to watch for chafing while performing other tasks?

Is there a "lead-the-fleet" program in place?

Is "outside" data evaluated to proactively look for trends or anticipate potential problems? Are internal SDRs evaluated?

Are unplanned repairs causing safety or economic issues? Is there a metric for systems, tasks, or components which contribute to a high NMC (not mission capable) rate? Would the addition of scheduled tasks alleviate any economic burdens? Who initiates the economic life analysis?

Is there a "bad actor" type designation for parts or components that are always the source of trouble?

Is the corrective action taken on problems from previous inspection reports adequate and still valid? Who is responsible for the follow-up?

What computer software and analysis techniques are used to proactively evaluate maintenance data?

F.9 MAINTENANCE METRICS.

What metrics are used to evaluate the maintenance system? What drives a positive score?

What % of scheduled maintenance tasks are completed? What happens to those tasks that are not completed?

What is your "schedule reliability"? What is your "% rollback" within 15 minutes of scheduled departure time?

Do you use computers to analyze or calculate trends?

F.10 ANALYSIS OF AIRCRAFT AND SYSTEM-SPECIFIC TASKS.

General fleet questions: How many study aircraft do you operate? What is their average age? Oldest? What is the average FH? Highest FH? How does this information compare to design life data from the OEM?

What general comments do you have regarding the identified study system maintenance program? How many items are regularly scheduled? What is the most common unplanned maintenance task?

In what ways have you customized this plan and modified it over the years?

Has the aircraft system been subjected to any after market design changes incorporated by supplemental type certificate? If so, what changes were made to the maintenance plan?

What tasks are burdensome, unclear, or overly difficult to perform? What tasks require special safety precautions? Are there any tasks in the Maintenance Planning Document that are not possible to do as directed?

Some research indicates that OEM-produced maintenance plans tend to include a high level of "over-maintenance." Does this characterization fit the identified study system maintenance program provided by the OEM?

Are there any failure-finding/functional checks on this system (e.g., on the disconnect system)?

What is the process for mechanics to provide feedback on instructions, fixtures, or other aspects of the maintenance program?

Are there unusual tools or fixtures that are hard (or expensive) to replace if lost or damaged?

Are the rig pins attached or free? What is the "button-up" plan for rig pins?

F.11 MISCELLANEOUS.

What is unique about your airline? (company, operations, philosophy)

Is your airline ATOS or not? What ramifications does the ATOS or non-ATOS status have?

Impact of maintenance outsourcing

Use of software

What do you see as the future of aircraft maintenance?

APPENDIX G—INTERNATIONAL REGULATORY WEBSITES

Note: Only websites that are written in English or that have an English option are included in this listing.

Website	Agency
http://www.ilmailulaitos.fi/caafinland	Civil Aviation Authority Finland
http://www.caa.govt.nz/	Civil Aviation Authority New Zealand
http://www.caa.co.za/	South African Civil Aviation Authority
http://www.caa.co.uk/index.asp	Civil Aviation Authority United Kingdom
http://www.casa.gov.au/	Civil Aviation Safety Authority Australia
http://www.easa.eu.int/home/index.html	European Aviation Safety Agency
http://www.faa.gov/	Federal Aviation Administration USA
http://www.aviation.admin.ch/index.html?lang=en	Federal Office for Civil Aviation Switzerland
http://www.lba.de/englisch/englisch.htm	Luftfahrt-Bundesamt Germany
http://www.tc.gc.ca/	Transport Canada
http://www.dac.gov.br/principalIng/index.asp	Civil Aviation Department Brazil

APPENDIX H—EMB 120 PITCH CONTROL STUDY CONTROL VOLUME

For the EMB 120 Pitch Control Study, four systems were defined within the control volume. The individual hardware items that are included in each system are listed below.

- Control surfaces

  - Right elevator
  - Left elevator
  - Horizontal stabilizer
  - Connecting joint
  - Right elevator trim tab
  - Left elevator trim tab

- Elevator control system

  - Pilot's control column
  - Copilot's control column
  - Interconnection shaft
  - Cable tension regulator/limiter (right)
  - Cable tension regulator/limiter (left)
  - Elevator control alarm system
  - Elevator control cables
  - Elevator control rods
  - Control rods (at control columns)
  - Rear quadrant bellcranks
  - Elevator control bellcranks
  - Elevator torque tubes (right and left)
  - Elevator rear torque tubes
  - Primary elevator backstop
  - Secondary elevator backstop
  - Primary control column backstop
  - Secondary control column backstop
  - Torque tube attachment fairings
  - Locking points
  - Rig pins
  - Pulleys
  - Quadrants
  - Fairleads
  - Turnbuckles

- Elevator trim system

  - Elevator tabs (right and left)
  - Trim tab control wheels (right and left)

- Trim tab switches (pilot’s and copilot’s)
- Autopilot servo
- Trim tab position displays (right and left)
- Mechanical backstop (located in the control wheel)
- Movable backstop
- Interconnecting shaft
- Control wheel chains
- Trim tab control cables
- Trim tab control cable turnbuckles
- Elevator trim actuator chain
- Elevator tab actuators
- Trim tab control rods
- Rockers
- Elevator trim proximity switches
- Pulleys
- Sprockets
- Bellcranks

• Elevator control disconnect system

  - Disconnection device
  - Safety lock button
  - Elevator disconnection handle

APPENDIX I—DISPOSITION OF ITEMS DESIGNATED AS SYMBIOTIC SYSTEMS

For the EMB 120 Pitch Control Study, the following items, shown in table I-1, were initially identified as potential symbiotic systems. Of the eight items originally identified, one was added to the study control volume, four were eliminated from the study, and three were retained as symbiotic systems that should be given some consideration during the study.

Table I-1. Symbionic Systems

Item	Disposition
Stall warning system	Not part of study
Gust locking system	Keep on symbiotic list
Stick pusher servos (affected by disconnection device)	Can drive the elevator, therefore, it should be included in the study control volume
Flaps/Slats/Spoilers (i.e., systems which affect lift)	Not part of study
Pressure bulkhead cabin seals	Keep on the symbiotic list
Horizontal stabilizer junction fairing	Not part of study – it is a structural component, falls under other work
Bonding jumpers	Keep on the symbiotic list – check to see if it is included in aging electrical studies
Flight Data Recorder System	Not part of study – does not impact pitch control

APPENDIX J—EMB 120 POTENTIAL STUDIES LIST

Table J-1 is the potential studies list generated during the Aging Mechanical Systems Methodology case study of the Embraer EMB 120 pitch control.

Table J-1. Potential Studies List

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
1	DISCONNECT	Latent failure of disconnect	Analysis of OEM data (safety analysis)		
2	TAIL	Bird nests found in tail	SkyWest mechanic interviews		
3	DISCONNECT	Hard to reconnect the disconnect after C-check	SkyWest mechanic interviews		
4	DISCONNECT	Switch for disconnect won't turn off after disconnect pulled for C-check, so it gets replaced	SkyWest mechanic interviews		

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
5	BONDING JUMPERS	Bonding jumpers are often broken - found during mx checks.	SkyWest mechanic interviews	- Many are difficult / impossible to see during walk-around checks	
6	GENERAL	Foreign Object Damage (FOD) due to items left during maintenance	Analysis of OEM data, SkyWest interviews	-SkyWest stresses FOD-prevent principles, but no specified process	
7	GENERAL	Water egress in control systems	Analysis of Public data, FAA Aging Transport Non-Structural Systems Plan		
8	TRIM TAB AURAL WARNING	Aural warning not working – latent failure	Analysis of OEM data (Design Analysis)		

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
9	DISCONNECT	Can dirt enter despite “dirt protection”?	Analysis of OEM data (Design Analysis)	What are “dirt protection” items found on disconnect plate assembly? Failure modes?	
10	LONGITUDINAL CONTROL SYSTEM	What if have dual failures on elev control system? Disconnect would not solve	Analysis of OEM data (Design Analysis)		
11	DISCONNECT VISUAL WARNING SYSTEM	Disconnect visual warning system does not indicate that mechanism is disconnected	Analysis of OEM data (Design Analysis)		
12	DISCONNECT VISUAL WARNING SYSTEM	Disconnect visual warning system gives false signal that mechanism is disconnected	Analysis of OEM data (Design Analysis)		

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
13	DISCONNECT	What is expected life or corrosion protection and grease?	Analysis of OEM data (Design Analysis)		
14	GENERAL	Dual load path controls where both circuits depend on a single-bolt	Analysis of OEM data (Design Analysis)	-Automatic retaining plates & split-pinned self-locking nuts	
15	CABLES	What are the criteria for cable inspection?	Analysis of OEM data (MRB Report), SkyWest interviews	- Can all portions of cable be accessed for inspection? -Design analysis docu has access information -Airline states detail mx info not put on task card, refer to Maint man -Partial rvw of Maint man found no criteria for typical tasks	

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
16	GENERAL	Are detailed lube specs available and followed?	Analysis of OEM data (MRB Report), SkyWest interviews	-Airline states detail mx info not put on task card, refer to Maint man -Partial rvw of Maint man found no criteria for typical tasks	
17	ELEVATOR TRIM	Uncommanded reversion of elev pitch trim tab during descent	NTSB ID: LAX001A106, NTSB ID: FTW00IA228, multiple SDRs	-AD 2000-19-10 was req'd within 100 flight hours of 9/28/2000 -did AD eliminate all subsequent events? -recheck SDRs to confirm or refute	

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
18	ELEVATOR TRIM	Elev trim freezing at altitude due to water contamination	NTSB ID: LAX01LA105, SkyWest interviews	-multiple events have occurred -some actuators submitted for repair had moisture or corrosion -SkyWest mods add seals -SkyWest mx records indicate mod and unmod parts have problems -Is more recent data avail?	
19	TRIM TAB AURAL WARNING	Trim Aural sounds at take-off	SDR study, SkyWest interviews	-variety of corrective actions indicate possible multiple failure modes -many labeled false alarms -aborted take-off often results	

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
20	ELEVATOR TRIM	Trim is frozen at cruise	SDR study	-see item #24 above, -same failure mode?	
21	ELEVATOR TRIM	Trim sticking or binding at various flight phases	SDR study		
22	ELEVATOR TRIM IDLER SPROCKET SUPPORT	Chain tracks worn on it	SDR study	-remove and replace damaged support - what is root cause? -why is chain in contact with support?	
23	GENERAL	FOD	SDR study	-FOD in trim wheel stop tracks -what is source of FOD?	
24	ELEVATOR TORQUE TUBES, MASS BALANCE WEIGHTS	Excessive corrosion due to lack of paint or protective coating	SkyWest interviews	-SB is out -NPRM is out; will it come out as AD? -Are other airlines checking? -Are other parts affected?	

Table J-1. Potential Studies List (Continued)

Item #	Aircraft Component(s)	Description of Potential Study Topic	Original Data Source	Notes	Final Disposition & Recommendation
25	GENERAL	Torque wrenches and gages out of calibration	SkyWest interviews	-SkyWest calibrates tools for its mechanics -Do all airlines have an active calibration process?	
26	GENERAL	Positive control of replacement parts	SkyWest interviews	-Is system adequate to keep new, repaired, and to be repaired parts isolated?	

APPENDIX K—INITIAL DATA REQUESTED FROM EMBRAER

K.1 PRIMARY DOCUMENTS.

- Maintenance Planning Documents Maintenance Review Board (MRB) reports
- System Safety Assessment Documents including:

  - System Description
  - Failure Modes and Effects Criticality Analysis (FMECA)
  - Fault Tree Analysis (FTA)/Hazard Analysis

- Maintenance Manuals
- Aircraft specifications and drawings for pitch control system
- Written description/training materials for pitch control system

K.2 ADDITIONAL INFORMATION.

- Airplane Flight Manual
- Maintenance and Material Management Data
- Service Difficulty Reports
- Brazilian Airworthiness Directive (AD) Reports
- EMBRAER Service Bulletins
- Maintenance Depot Data
- Extended Maintenance Task Requests
- Flight Statistics (hrs/flight, flights/yr, etc.)
- Certification Maintenance Requirements
- Age Exploration Studies
- Advisory Circular (AC) Reports
- Pilot Squawks
- Lead-the-Fleet Data
- Contact Names for Parts Suppliers
- Engineering Change Reports for Hardware or Software

Note: Only items related specifically to the EMB 120 pitch control system are needed. Some of this information may not be available in the form requested or may be available only through the airlines or other Non-Embraer databases. Any help Embraer can provide in identifying sources of data will be greatly appreciated.

K.3 EMBRAER RESOURCES.

- Management Resource (speak for Embraer on matters of nondisclosure agreements, approve reports, approve information transfer, allocate resources)

- Technical Resource (respond to phone and e-mail queries and clarify data)

- Review Resources (participate in kickoff meeting, provide input to program, provide input to reports)

APPENDIX L—EMB 120 OPERATIONS MANUAL

The portion of the EMB 120 Operations Manual that was received includes pages 6-8-1 through 6-8-21 dated 30 June 2001. Of this packet, four pages contain information relevant to the pitch control of the EMB 120. The operations manual provides good overview information regarding the design and operation of the pitch control system. Some of the basic data gained from the operations manual review includes:

- The primary pitch control is accomplished through an elevator, which consists of a left panel and right panel linked to the horizontal stabilizer through a joint.

- Pitch trimming is primarily controlled through thumb-activated pitch trim switches mounted on the outboard horn of the pilot's and copilot's control yoke.

- The elevators and trim tabs are mechanically actuated.

- Trim tab position is displayed at the tab control wheelbase.

- The pilot's and copilot's controls are mechanically interconnected, but may be disconnected to allow operation by only one system.

- The autopilot servo is connected to the left elevator control shaft and the pusher servos are connected to the right elevator control column. If the disconnection device is actuated, the servos will actuate only upon the elevator panel of their respective side.

APPENDIX M—EMB 120 MAINTENANCE REVIEW BOARD REPORT

The portion of the EMB 120 Maintenance Review Board (MRB) report that was received includes pages 3.27.1 through 3.27.8 dated 23 April 2004. This report is the product of a Maintenance Steering Group meeting conducted as part of the original certification process of the aircraft. The report consists of maintenance tasks that are recommended to ensure the ongoing safe operation of the aircraft. Airline customers use this report as the starting point for their individualized maintenance program. This information is typically modified by an airline to reflect their specific operating conditions or experiences.

Section 3 of the EMB 120 MRB report contains the items for Systems and Powerplant Inspection Requirements and includes 67 tasks. Of these 67, the following 13 (shown in table M-1) fall within the control volume defined for this case study.

Table M-1. Control Volume Tasks

No.	TASK	CAT	TASK DESCRIPTION (CHAPTER 27)	FREQ
21	OPC	SFT	Verify ELEVATOR CONTROL DISCONNECT and ALARM SYSTEM operation (MSI 27-31-01).	4000 FH
22	INS	SFT	Visually check ELEVATOR CONTROL DISCONNECT SYSTEM for condition (MSI 27-31-01).	4000 FH
23	LUB	8	Lubricate ELEVATOR CONTROL DISCONNECT SYSTEM (MSI 27-31-01).	C
24	INS	5	Visually check ELEVATOR CONTROL PATH from control column to FWD quadrants. Check control columns, rods and quadrants for wear, corrosion, crack and security (MSI 27-31-01).	C
25	INS	5	Visually check ELEVATOR CONTROL PATH from FWD QUADRANT to ELEVATOR. Check pulleys, quadrants, fairleads, turnbuckles, and control rods for wear, corrosion, cracks, and security. Check cables for wear, broken strands, corrosion, kinks, and bird caging (MSI 27-31-01).	2000 FH
26	INS	5	Check ELEVATOR CABLES and TRIM TAB CABLES tension. *NOTE: Check cables tension at first 400 FH before escalating to 2000 FH (MSI 27-31-01).	2000 FH NOTE
27	LUB	6	Lubricate ELEVATOR TAB ACTUATORS (MSI 27-31-01)	C
28	INS	SFT	Visually check ELEVATOR TAB DUAL RODS between tab actuator and tab (MSI 27-31-02).	1600 FH
51	FNC	SFT	Check elevator trim proximity switches.	3000 FH
54	INS	SFT	Check elevator trim for backlash.	1600 FH
61	LUB	9	Lubricate the elevator trim actuator chain.	C
64	FNC	8	Check pusher servo clutches for limiting torque	C
67	FNC	SFT	Check ELEVATOR TRIM ACTUATORS according to AVIAC CMM 27-10-01 (bench test).	4000 FH

APPENDIX N—EMB 120 MAINTENANCE MANUAL REVIEW

Over 150 pages of the EMB 120 Maintenance Manual dated April 10, 2002 were received with the original data package. These pages proved to be the most helpful resource in the early stages of the EMB 120 pitch control case study. The description and operation sections provided a more detailed understanding of the pitch control system than the previously reviewed operations manual, and the numerous drawings were instrumental in the system definition process. The following sections of the EMB 120 Maintenance Manual, shown in table N-1, were reviewed.

Table N-1. Embraer Maintenance Manual

SECTION #	SUBJECT
27-30-00	ELEVATOR – DESCRIPTION AND OPERATION
	Description
	Operation
27-31-00	ELEVATOR CONTROL SYSTEM – ADJUSTMENT/TEST
	Elevator Control System Adjustment
	Elevator Travel Adjustment
	Secondary Backstop Adjustment
	Elevator Travel Checkout
	Operational Test
	System Test
27-31-01	CONTROL COLUMN – REMOVAL /INSTALLATION
27-31-02	ELEVATORS – REMOVAL INSTALLATION
27-31-03	ELEVATORS TORQUE TUBE ASSEMBLY – REMOVAL/INSTALLATION
27-31-03	ELEVATORS TORQUE TUBE ASSEMBLY – REPAIR
27-31-04	ELEVATOR REAR QUADRANT ASSEMBLY – REMOVAL/INSTALLATION
27-32-00	ELEVATOR TRIM TAB SYSTEM – DESCRIPTION AND OPERATION
	Operation
27-32-00	ELEVATOR TRIM TAB SYSTEM – ADJUSTMENT/TEST
	Elevator Trim Tab System Adjustment
	Elevator Trim Tab Deflection Check
	Proximity Sensor Actuation Range Check and Adjustment
	Operational Test
	Functional Test
	Functional Test of Longitudinal Proximity Sensor
27-32-01	TRIM TABS – REMOVAL/INSTALLATION
27-32-02	TRIM TAB LINEAR ACTUATORS – REMOVAL/INSTALLATION
27-32-03	CONTROL WHEEL – REMOVAL/INSTALLATION
27-32-04	CHAIN - REMOVAL/INSTALLATION
27-32-05	PROXIMITY SENSORS – REMOVAL/INSTALLATION
27-32-06	CONTROL WHEEL INTERCONNECTING SHAFT – REMOVAL/INSTALLATION

APPENDIX O—EMB 120 SAFETY ANALYSIS DOCUMENT

This material was received from Embraer in July 2005. It consists of 72 pages of text, Failure Mode and Effect Analysis (FMEA), and failure trees documenting the safety of the Embraer EMB 120 control systems. A supplemental packet was received in January 2006, which contained 14 pages of failure rate data per follow-up requests. The sections covering the longitudinal control system and longitudinal trim system are relevant to the current pitch control study. The report also contains information about the lateral control system and lateral trim system, which, although not directly applicable to the study, do provide additional data regarding Embraer safety analysis methods. The material was originally published in June 1983, with a handful of documented revisions. The last revision date is October 1998.

The Safety Analysis was performed to show compliance with sections 25.671 and 25.1309 of the Federal Aviation Regulation and the Joint Airworthiness Requirements. The two analysis techniques employed include FMEA and Probability Fault Tree Analysis. The FMEAs were performed on groupings of elements whose failure effects on the system are assumed identical. The longitudinal control system (elevators) is broken into six groups. Based on primary failure model of fracture/separation and jammed, only eight failure modes are considered for the elevator control system FMEA. Similarly, the elevator trim system is broken down into four groups. Based on the primary failure model of fracture/separation and jammed, the FMEA analysis considers 12 failure modes. These elevator trim system failure modes include several dormant failures. Probability trees are also provided for each of the four systems included in the safety analysis.

In the results section, five operational recommendations are given:

- Elevator and aileron trim tab screwjacks and their connection to the trim tab surface.
- Aileron and elevator disconnecting mechanism and their alarm system-adjustment and operation.
- Ground gust locking mechanism adjustment, general condition.
- Primary and trim flight control cables-tension.
- Primary and trim flight control cables, pulleys, rods, actuators, cranks, control wheels, pedals, stops-adjustment, lubrication, general condition.

The failure rate data includes data on many individual components and several mechanical systems. The documentation indicates that the component failure rates are aggregate numbers for all potential failure modes based on the historical records of Douglas Aircraft Company. The aggregate failure rates assume both failure/separation and jamming modes. In addition to the component failure rates, failure analysis is provided for the following mechanical systems related to pitch control: stick pusher, stick shaker, automatic pilot, electric trim, disconnecting mechanism, and ground gust lock.

APPENDIX P—EMB 120 CONTROL SYSTEMS DESIGN ANALYSIS DOCUMENT

In January 2006, 208 pages of a Control Systems Design Analysis were received. These pages cover the primary control systems and trim controls for the longitudinal, lateral, and directional control systems. The report was dated 23 November 1984. The Design Analysis details the analyses completed in order to determine whether the proposed configuration is safe and complies with regulatory requirements. Unlike the Safety Analysis report (see appendix O) which identifies potential risks, this report is a detailed discussion of specific design principles and execution intended to mitigate risk.

A large portion of this document identifies specific design features, which are intended to mitigate risk. Several examples of EMB 120 pitch control design features that are relevant to this study include:

- Segregation of the forward and rear quadrants of the control systems (including separate axis mounts and independent supports).
- Segregation of pulley systems and their supports.
- Segregation of trim system components.
- Use of grommets, rubstrips, and pressure seals to prevent the control cables from contacting the aircraft structure.
- Automatic retaining plates and split-pinned, self-locking nuts are used at each end of any bolt that serves as a dual-load path for primary control systems (those that are required for safe flight and landing).
- Ordinary bolts with retaining plates and split-pinned, self-locking nuts are used at each end of any bolt that serves as a dual-load path for secondary control systems (those not required for safe flight and landing).
- Front cable quadrants and axes are fabricated with a reference tooth (different size) that ensures the quadrants can only be mounted in one position (to prevent mis-assembly).
- Rear quadrants are mounted on ball bearings held in place by three supports to ensure the quadrant axle is held in place if one support fails.
- Dirt protection features are included in the disconnecting plate assembly.
- Corrosion protection features and internal grease are specified for the mechanical disconnection mechanism.

- Duplication of the rotating and sliding splines as well as the duplication of connecting rods prevent the free floating of tab surfaces if a single failure occurs on the longitudinal trim tab mechanical actuator.

The analysis provides evidence of compliance with both Joint Aviation Requirements/Title 14 Code of Federal Regulations (JAR/14 CFR) and the Civil Aviation Authority (CAA) evaluation requirements. Specifically, the following regulations were addressed:

- JAR/14 CFR 25.611
- JAR/14 CFR 25.675a
- JAR/14 CFR 25.675b
- JAR/14 CFR 25.677d
- JAR/14 CFR 25.679
- JAR/14 CFR 25.689
- CAA Evaluation Summary Item 3.8.2

This document also contains detailed schematics including cable layouts and access panel locations for the EMB 120 pitch control system.

APPENDIX Q—FIXTURES, KITS, AND EQUIPMENT FOR EMB 120 PITCH CONTROL MAINTENANCE

Table Q-1 is a list of fixtures, kits, and equipment required for the completion of EMB 120 pitch control maintenance. This list was compiled using information in the EMB 120 Maintenance Manuals. This list can be used to evaluate compliance of actual maintenance activities by the airline operator to the maintenance manuals. Discrepancies should be added to the Potential Studies List for further assessment.

Table Q-1. Embraer 120 Pitch Control Maintenance List

Item	Maintenance Manual Reference No.
Rig Pin Kit – GSE 059	27-31-00, 27-31-01, 27-31-02, 27-31-04, 27-32-00, 27-32-02, 27-32-04
Elevator neutral position locking device – GSE 056	27-31-00, 27-31-02, 27-31-04, 27-32-00, 27-32-02
Platform – GSE 031	27-31-00, 27-31-02, 27-32-00, 27-32-01, 27-32-02, 27-32-05
Deflection Measuring Device – GSE 060 (or GSE 181 as an alternative)	27-31-00, 27-32-00
Elevator Trim Tab Actuator Rig Device (included in the flight kit stowage bag)	27-32-00, 27-32-02
DC Power Supply – GSE 050	27-32-00
Two ferrous metal plates (local fabrication)	27-32-00

Note: The following items are not specifically called out as they are assumed to be everyday materials in an aircraft maintenance shop: cotter pins, lockwire, feeler blades, wash primer, epoxy primer, polyurethane, lubricant, cable tie straps, and adhesive.

APPENDIX R—COMPARISON OF IDENTIFIED RISKS AND MAINTENANCE RECOMMENDATIONS

As part of the analysis of the EMB 120 pitch control maintenance data from Embraer, a correlation was attempted between the five operational recommendations given in the Safety Analysis Report (see appendix O) and the tasks listed in the Maintenance Review Board (MRB) report designed to mitigate those risks (see appendix M). This analysis is important because each identified risk should be addressed with a maintenance task. The converse is also true; each maintenance task should have its root in addressing a potential risk area. If there is not a clear link to a failure, then the purpose of the task needs to be identified to ensure that it is necessary. Because each maintenance task performed results in exposure to potential maintenance-induced errors, unnecessary maintenance items are both an economic drain and a safety risk.

Table R-1 lists the five recommendations from the Safety Analysis Report in the first column, and the corresponding maintenance task from the MRB report in the third column. The middle column indicates the recommended frequency from the Safety Analysis Report. A next step in the process would be to check with an airline operator to determine the current compliance with the MRB tasks as well as the actual frequency with which the tasks are performed.

Table R-1. Safety Analysis Report Recommendations

Recommendation/Identified Risk Area	Frequency (hours)	MRB Report Task No.
Elevator and aileron trim tab screwjacks and their connection to the trim tab surface	1600	#28 (freq=1600 FH)
Aileron and elevator disconnecting mechanism and their alarm system-adjustment and operation	2500	#21 (freq=4000 FH) #22 (freq=4000 FH), #23 (freq=C check)
Ground gust locking mechanism adjustment, general condition	3000	#34 (freq=C check)
Primary and trim Flight control cables-tension	300	#26 (freq=2000 FH, init=400)
Primary and trim Flight control cables, pulleys, rods, actuators, cranks, control wheels, pedals, stops-adjustment, lubrication, general condition	3000	#24 (freq=C check) #25 (freq=2000 FH) #27 (freq=C check) #51 (freq=3000 FH) #54 (freq=1600 FH) #61 (freq=C check) #64 (freq=C check) #67 (freq=4000 FH)

APPENDIX S—EMB 120 ACCIDENT AND INCIDENT DATABASE SEARCH

A search of the National Transportation Safety Board (NTSB) database (http://www.ntsb.gov/ntsb/query.asp) resulted in nine relevant files. An excerpt of the descriptive narrative or findings from each report is given below. Some of the texts contain two or more excerpted portions of the report. The NTSB identification (ID) number is provided in all cases so that the entire report can be reviewed if desired.

- NTSB ID: DCA91MA052 (09/11/1991) EMB 120 – ACCIDENT
- NTSB ID: DCA85AA004 (12/06/1984) EMB-110P1 – ACCIDENT
- NTSB ID: DCA021A021 (01/31/2002) EMB 145 – INCIDENT
- NTSB ID: LAX001A106 (02/21/2000) EMB 120 – INCIDENT
- NTSB ID: NYC02IA076 (03/26/2002) EMB 145 – INCIDENT
- NTSB ID: NYC01IA107 (04/25/2001) EMB 145 – INCIDENT
- NTSB ID: FTW00IA228 (08/12/2000) EMB 120 – INCIDENT
- NTSB ID: CHI01IA055 (12/27/2000) EMB 135 – INCIDENT
- NTSB ID: LAX01LA105 (02/25/2001) EMB 120 – ACCIDENT

APPENDIX T—EMB 120 FEDERAL AVIATION ADMINISTRATION PITCH CONTROL AIRWORTHINESS DIRECTIVES

The following Airworthiness Directives (AD) and Notices of Proposed Rulemaking (NPRM) issued by the Federal Aviation Administration (FAA) were identified for the Embraer EMB 120 pitch control study. These documents are resident on the FAA website (http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAD.nsf/MainFrame?OpenFrameSet).

- FAA ADs:

96-09-12	AFM—Icing (EMB-110)
96-09-24	AFM—Icing
99-17-04	Aileron Control Cables and Nylon Grommets
2000-19-10	Prevent Sudden Change in Pitch Attitude
2000-23-30	Elevator Control Cable
2001-17-01	Aileron and Elevator
2001-02-51	Maximum Speed for Retrimming After Takeoff (EMB 135/145)
2002-14-25	Actuator Clutches of the Horizontal Stabilizer (EMB 135/145)
2004-25-21	Pitch trim system (EMB 135/145)

- FAA NPRMs:

2000-NM-120-AD	Potentiometers for primary flight controls
2003-NM-33-AD	AFM autopilot instructions and pitch trim placards
2003-NM-81-AD	Gap between bellcrank and body of Rotary Variable Inductance Tranducers of aileron and elevator

APPENDIX U—EMB 120 CENTRO TÉCNICO AEROESPACIAL PITCH CONTROL AIRWORTHINESS DIRECTIVES

The following Airworthiness Directives (AD) issued by the Brazilian Centro Técnico Aeroespacial (CTA) were identified for the Embraer EMB 120 pitch control study. These records were obtained from the CTA website (http://webfdh.ifi.cta.br/).

- CTA ADs:

91-03-02R2	Elevator Trim Tab Control Servo
95-01-01R2	Aileron Upper Channel Fairings
E97-09-08R1	Elevator Trim Control
2001-05-02R2	Flight In Icing Conditions
2001-07-01R1	Aileron/Elevator Rotary Variable Inductance Transducers Bellcranck

APPENDIX V—FEDERAL AVIATION ADMINISTRATION PITCH CONTROL ADVISORY CIRCULARS

The following Advisory Circulars (AC) were pulled for the Embraer EMB 120 pitch control study. The list was derived from a Federal Aviation Administration database (http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/MainFrame?OpenFrameSet) query using the key words "pitch control" on 1/18/05. Note that these are not specific to the EMB 120.

- AC 23.143-1 Ice Contaminated Tailplane Stall (ICTS)
- AC 20-141 Airworthiness and Operational Approval of Digital Flight Data Recorder Systems
- AC 91-51A Effect of Icing on Aircraft Control and Airplane Deice and Anti-Ice Systems
- AC 35.37-1A Guidance Material for Fatigue Limit Tests and Composite Blade Fatigue Substantiation
- AC 65-15A [Large AC] Airframe and Powerplant Mechanics Airframe Handbook
- AC 20-37D Aircraft Metal Propeller Maintenance
- AC 61-27C [Large AC] Instrument Flying Handbook
- AC 25-21 Certification of Transport Airplane Structure
- AC 23-16A Powerplant Guide for Certification of Part 23 Airplanes and Airships
- AC 103-7 The Ultralight Vehicle
- AC 20-66A Vibration and Fatigue Evaluation of Airplane Propellers
- AC 00-54 Pilot Windshear Guide
- AC 120-40B Airplane Simulator Qualification
- AC 120-45A Airplane Flight Training Device Qualification
- AC 25.1419-1A Certification of Transport Category Airplanes for Flight in Icing Conditions
- AC 33-2B Aircraft Engine Type Certification Handbook
- AC 25-7A Flight Test Guide for Certification of Transport Category Airplanes

- AC 23.1419-2C Certification of Part 23 Airplanes for Flight in Icing Conditions
- AC 90-89A Amateur-Built Aircraft and Ultralight Flight Testing Handbook
- AC 91-74 Pilot Guide Flight in Icing Conditions
- AC 121-1A CHG 4 Standard Operations Specifications Aircraft Maintenance Handbook
- AC 65-12A [Large AC] Airframe and Powerplant Mechanics Powerplant Handbook

APPENDIX W—EMB 120 PITCH CONTROL SERVICE DIFFICULTY REPORT STUDY

On January 27, 2005, the Federal Aviation Administration Service Difficulty Report (SDR) database (http://av-info.faa.gov/isdr/SDRQueryControl.ASP?vB=IE&cD=32) was queried for records related to the EMB 120 pitch control study.

Using the SDR database proved to be a challenge. The search period was 01/28/1995 through 01/27/2005. There is a 10-year maximum on search windows. The initial search used the input "EMB" for the aircraft make field and "EMB120" for the aircraft model field. The result was 9495 records. In an attempt to narrow this list, various inputs were tested in the part name field. Using "elevator" returned one record. The next attempt was to keep the part name field blank and add an input to the problem description field. The first choice was "pitch control," which yielded eight records. Unfortunately, upon reviewing the records, seven were related to propeller pitch control, leaving only one record of interest.

The next query was performed with a problem description of "elevator trim." This query resulted in 140 records, which were retrieved and reviewed. These records included the one "elevator" record and the relevant "pitch control" record already identified in earlier searches.

SDR data is somewhat muddy, as it is reported by a large number of sources with varying and overlapping description of terms. Therefore, the SDR study was not a full statistical analysis; it was a review for trends. Four significant event groupings were identified. These events were all placed on the Potential Studies List for further study. In addition, six events that occurred three times or less in the ten-year period were documented. These infrequent events are important because they reveal an unplanned event, which may or may not be significant in the study. All event groupings from the 10-year database outlined above are documented in table W-1.

Table W-1. Event Groupings

Event Description	Phase of Flight	Documented Corrective Actions	Number of Reports
Trim Aural Warning Sounds	Takeoff	-replace elev trim prox sensor -adjust elev trim tab prox sensors -replace aural warning unit -repair broken wire splice at elev trim prox -replace loose wiring connecting elev trim tab prox sensors -replace wires chafing on steel braided wire shroud	63

Table W-1. Event Groupings (Continued)

Event Description	Phase of Flight	Documented Corrective Actions	Number of Reports
Elevator Trim "Frozen"	Cruise	-replace both trim actuators -inspect & lube both trim actuators -remove obstruction at water drain -remove water egress -remove debris from trim servo gear -clean auto hub, both actuators	37
Elevator Trim Sticking or Binding	Varies	-lube both elev trim actuators -replace elev trim actuator -trim switch cleaned -reposition console trim to eliminate rubbing on trim wheel -no action	11
Uncommanded Pitch-up	Varies	-replace elev trim switch -replace elev trim actuator	8
Elevator Trim Cables Worn	Inspection/ Maintenance	-remove and replace cables	3
Trim Failure Light On	Cruise, Climb	-remove and replace elev trim servo	3
Grinding Noise Under Cockpit Floor	Cruise	-clean debris from trim wheel stop tracks	1
Nose Very Heavy	Climb	-re-rig elev trim tab	1
Elevator Trim Wheel Sprang Forward and Auto-Pilot Kicked Off	Cruise	-clean residual moisture from all actuators and lube as necessary	1
Elevator Trim Idler Sprocket Support has Chain Tracks Worn in it	Inspection/ Maintenance	-remove and replace damaged support	1

APPENDIX X—SKYWEST VISIT PREWORK NOTES

Purposes:

1) Understand how a typical SkyWest maintenance facility operates

2) Learn about specific maintenance activities on the EMB-120 pitch control system

Important Items to Discuss with SkyWest:

1) Embraer resources suggested we use SkyWest as the source of our actual maintenance data based on their positive opinion of SkyWest and the number of EMB 120 aircraft that SkyWest operates.

2) Our team is currently involved in a research study, not an enforcement activity.

3) We have been researching aging aircraft maintenance from an academic point of view for almost a year. It is important to our study that we have some practical data and observations with which to validate the models.

4) We have developed a relationship with Embraer and they are supportive of our work. By getting involved with this project, SkyWest has the opportunity to take advantage of our communication channels with Embraer to discuss any difficulties/concerns regarding the EMB-120 maintenance requirements.

5) UDRI has a wealth of experience in aviation and other engineering disciplines. UDRI also has an extensive network of commercial and military contacts. Access to these resources may be of benefit to SkyWest in a variety of ways.

Agenda for Visit:

Our plan is to build an agenda with SkyWest. For now, we offer the following "skeleton agenda" to be filled in and revised once we have a contact at SkyWest.

1) Introductions

2) Background on FAA/UDRI research study of aging mechanical systems

3) Background on SkyWest maintenance organization

4) Tour of SkyWest maintenance facilities

5) Recap: unanswered questions and follow-up required

APPENDIX Y—FOLLOW-UP QUESTIONS FOR SKYWEST RESOURCES AT ST. GEORGE

1. What information did you originally receive from Embraer (MRB report, MM) and how do you use it to develop a maintenance plan?

2. Do you tend to add or eliminate tasks over the life of an aircraft? Are most changes over time due to safety, economic, or operational concerns?

3. What are your sources of information to update the maintenance plan (internal and external)?

4. Some researchers indicate that OEM-produced maintenance plans tend to include a high level of "over-maintenance". Is this characterization true based on your experience?

5. Do you follow the Reliability-Centered Maintenance program (e.g. designation of tasks as: scheduled restoration tasks, scheduled discard tasks, scheduled on-condition tasks, failure-finding tasks, and unscheduled repairs)?

6. Do the St. George offices do any staffing or prioritizing of work for the maintenance bases, or do you simply generate the tasks and deadlines and let staffing happen at the local level?

7. Who evaluates the maintenance tasks evaluated for safety (of personnel, equipment, and environment)? What is the typical personal protective equipment (PPE) that is required to perform the maintenance tasks outlined on the aircraft system?

8. What is the system used for maintenance documentation? Where are records kept?

9. What is the process for reporting any type of discrepancy (task incomplete, parts obsolete, additional issues found, etc.)?

10. Is there a system for the inventory and management of tools, equipment, and spares in place to prevent foreign object damage and unnecessary costs? How tightly are these items managed?

11. Research has indicated that the following 5 types of maintenance errors are typically responsible for accidents and incidents: (1) incorrect assembly (2) the carrying forward of defects or the incorrect diagnosis of defects (3) the leaving of loose objects (4) putting wrong fluid into vital systems (5) the lack of good housekeeping when making modifications and repairs. These failures are not typically included in OEM-provided materials. What is the SkyWest approach to minimizing maintenance-induced failures?

12. What type of proactive analysis is done by SkyWest to optimize the maintenance plan, spot new risks, and determine trends? Is there a "lead-the-fleet" program? What are the internal and external sources for data to support this analysis? Is there a "bad actor" type designation for parts or components that are often the source of trouble?

13. If an individual aircraft has suffered substantial damage in an accident or incident, how will its maintenance program be modified to protect against residual fatigue, secondary damage and other risks?

14. What metrics are used to evaluate the maintenance planning department? What drives a positive score?

15. What general comments do you have regarding the EMB 120 pitch control system maintenance program? How many items are regularly scheduled? What is the most common unplanned maintenance task? What tasks are burdensome, unclear, or overly difficult to perform? What tasks require special safety precautions?

16. What is unique about SkyWest? (company, operations, philosophy)

17. How is the industry-wide trend towards maintenance outsourcing affecting SkyWest?

18. What do you see as the future of aircraft maintenance?

19. What computer systems and software are used to support the maintenance program?