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Analysis of Regulatory Guidance for Health Monitoring

Thomas E. Munns, Richard E. Beard, Aubrey M. Culp, Dennis A. Murphy, Renee M. Kent
ARINC, Inc., Annapolis, Maryland

December 2000

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EXECUTIVE SUMMARY

The evolution of sensor, data acquisition, communications, and information analysis technologies enables the development of health monitoring (HM) systems for real-time condition assessment for predicting failures of aircraft components or subsystems. This information could be disseminated to ground stations to allow condition-based maintenance for long-term flight safety and operational capacity, or to the aircrew or air traffic control in a manner that allows effective in-flight response. There are two primary aspects to consider in the approval of HM systems for commercial aviation and acceptance by the operators of commercial air transports—(1) airworthiness certification of the on-board system and (2) qualification and approval of HM system capabilities as part of the airline maintenance program.

The purpose of this study was to assess the connection between current FAA regulations and the incorporation of HM systems into commercial aircraft. To address the overall objectives ARINC (1) investigated FAA regulatory guidance, (2) investigated airline maintenance practices, (3) systematically identified regulations and practices that would be affected or could act as barriers to the introduction of HM technology, and (4) assessed regulatory and operational tradeoffs that should be considered for implementation. The assessment procedure was validated on a postulated structural HM capability for the B757 horizontal stabilizer.

Airworthiness regulations that are applicable to on-board HM systems require that compliance would have to be shown primarily by analysis, supported by ground, flight, or simulator tests. In general, ARINC found that current regulations do not prohibit, but could represent barriers to the use of HM technologies. To reduce regulatory barriers to HM systems, ARINC recommends that the following general changes should be sought in the FAA's regulatory guidance.

- Revise airworthiness directives to explicitly allow "certificated condition-monitoring systems" as a means for compliance.
- Include guidance for utilizing the capabilities of HM systems in the development of maintenance and inspection tasks and intervals.
- Add provisions to realize maintenance credits for introducing HM systems in mandated inspection or maintenance requirements.

The timely introduction of HM systems requires that an alliance be developed between air carriers and the manufacturers of the integrated systems. ARINC recommends that initial development should focus on addressing the concerns of the air carriers—unscheduled maintenance problems, difficult or tedious inspections, accessibility problems, or component reliability problems.

ABBREVIATIONS AND ACRONYMS

AD	Airworthiness Directive
AC	advisory circular
ACARS	Aircraft Communications Addressing and Reporting System
ACO	aircraft certification office
AE	acoustic emission
AEG	airplane evaluation group
AI-ESTATE	Artificial Intelligence Exchange and Service Tie to All Test Environments
AMC	Air Mobility Command
ATA	Air Transport Association
ATC	air traffic control
ATOS	Air Transportation Oversight System
BITE	built in test equipment
BVID	barely visible impact damage
CFR	Code of Federal Regulations
CMR	certification maintenance requirement
CMV	Continuous maintenance visits
DER	designated engineering representative
EFPI	extrinsic Fabry-Perot interferometry
FAA	Federal Aviation Administration
FAR	federal aviation regulation
FOQA	flight operations quality assurance
FSF	Flight Safety Foundation
HM	health monitoring
LAN	local area network
LPG	long period grating
MEL	minimum equipment list
MM	maintenance manual
MPD	maintenance process data
MSG	maintenance steering group
MTM	module test and maintenance
NASA	National Aeronautics and Space Administration
NSS	network server system

O&M	operations and maintenance
OMS	On-Board Maintenance System
PCU	power control unit
PTDF	Parametric Test Data Format
PMA	parts manufacturing approvals
QAR	quick access recorder
RTCA	Requirements and Technical Concepts for Aviation
SB	service bulletin
STCM	stabilizer trim control module
SME	subject-matter expert
STC	supplemental type certification
TC	type certification
TIA	type inspection authorization
TSO	technical standard order
TSOA	TSO authorization

CONTENTS

ANALYSIS OF REGULATORY GUIDANCE FOR HEALTH MONITORING

SECTION 1
INTRODUCTION

1.0 BACKGROUND

Modern commercial transports are configured with sophisticated electronic, propulsion, flight control, and structural data systems. In recent years, an increased emphasis has been placed on the potential for using these data capabilities, in conjunction with emerging sensor, data processing, and conditioning technologies for health monitoring (HM) of aircraft condition during flight. Implementation of such HM technologies is expected to:

- Identify and correct (or mitigate) performance or airworthiness problems before they compromise safety
- Improve flight crew performance and decision support
- Enhance aircrew training and operating procedures, air traffic control (ATC) procedures, and aircraft operations, maintenance, and design
- Perform trend analyses to identify problems, implement and evaluate corrective actions, and assess performance over time

The fundamental intent is to use real-time flight data to detect unsafe conditions early enough to allow timely intervention. Initially, these efforts were focused on assessing and monitoring safety and airworthiness data only. However, over the last several years, they have been expanded to include the consideration of operations and maintenance (O&M), decision support, cost, and design data.

As currently envisioned, integrated HM capabilities would consist of on-board systems for sensing and real-time diagnostics and ground-based systems for longer-term diagnostics and prognostics. The onboard systems would include a variety of sensors; sensor data conditioning units; on-board diagnostic processors and algorithms; and interfaces with on-board power, data, and communications systems. The ground systems would include diagnostic and prognostic processors and algorithms, communications systems, and links to airline maintenance history records.

Acceptance and use of emerging HM by the air carriers will ultimately depend upon the objective demonstration of a number of factors. These factors include:

- Documented and convincing cost/benefit
- Feasibility to replace difficult or tedious inspections
- Potential to improve overall component reliability

- Ability to collect and analyze recurring problems
- Potential to move tasks from line maintenance checks and put them into base maintenance visits, where maintenance personnel have more time and access for inspection and maintenance tasks

Once the feasibility and cost-effectiveness of these HM systems have been demonstrated to air carriers, the ability to navigate the FAA's certification process will be a critical factor in their eventual implementation.

1.1. PURPOSE

As described above, aircraft health monitoring could offer many operational and logistical benefits, ultimately resulting in improved aircraft safety and reduced maintenance burden for the operators. However, commercial operators have pointed out that, for health monitoring systems to be operationally and economically viable, regulatory guidance from the FAA and the new capabilities provided by health-monitoring technologies must be compatible. The potential benefit of health-monitoring technology can only be realized with effective coordination between aircraft operators and regulatory authorities.

The purpose of this study was to provide a procedure for assessing the connection between current regulatory guidance and the incorporation of health monitoring systems into commercial aircraft. To accomplish this, an assessment was made of the implications of current regulatory guidance and of air carrier maintenance and preventive maintenance practices on the implementation of health-monitoring technologies. The resulting assessment procedure was validated on a postulated HM capability for a selected component.

This report summarizes the results of the ARINC analysis of regulatory issues on the implementation of HM systems.

1.2. SCOPE AND APPROACH

The scope of the study included: (1) an investigation of regulatory guidance that drives certification and maintenance practices, (2) an investigation of existing airline maintenance practices and how they were derived from the regulatory guidance, (3) a systematic identification of regulations and practices that will be affected by implementation of HM technologies, and (4) an assessment of regulatory and operational tradeoffs that should be considered during the implementation of HM technologies.

The approach to accomplishing the regulatory analysis included the following tasks:

- Research existing processes and procedures relative to the impact of implementation of HM

- Develop a set of evaluation categories that are common to Federal Aviation Regulations (FARs), maintenance operations/inspections, and HM systems that will be suitable for relational database adaptation. The relational database was used to identify those FARs and aircraft certification/maintenance requirements that will be impacted by installing an airborne HM system
- Obtain, archive, and categorize applicable regulatory guidance, including FARs, Advisory Circulars (ACs), and Airworthiness Directives (ADs)
- Obtain, archive, and categorize applicable FAA-required maintenance operations/inspection data on 737 and 757 models
- Categorize the features and capabilities of a postulated HM capability for a 757 horizontal stabilizer
- Populate a relational database with categorized data on FARs, as well as maintenance operations/inspection requirements
- Query the database to identify FAR and maintenance operations/inspection requirements that may be impacted by installing the postulated HM system on the selected aircraft
- Evaluate, using subject-matter experts, those areas where FARs and aircraft certification/maintenance requirements could act as barriers to the postulated HM system
- Summarize findings

The 757 horizontal stabilizer, including the main stabilizer assembly and the elevators, was chosen to establish postulated HM capability for assessment. The underlying goals were to identify implementation barriers and assess the compatibility of near-term health-monitoring technologies with the existing regulatory structure.

A number of sources were used in conducting this study. Regulatory documents (including FARs, ACs, ADs, and Orders) were obtained from a variety of public or corporate data sources. Preliminary input on air carrier maintenance programs was obtained through the Avionics Maintenance Conference and more detailed information was developed through discussions and data exchanges with maintenance program managers from selected air carriers (i.e., United Airlines, UPS, and Airborne Express). Maintenance program development guidance information was discussed with FAA maintenance program authorities (i.e., FAA Flight Standards National Resource Specialist for Maintenance Programs). Finally, manufacturers technical data on the 757, including the maintenance and maintenance training manuals, maintenance process data, and maintenance task cards were consulted.

The study results are organized into five sections:

- Section 2 includes an identification of the regulations that apply to aircraft certification and operations, a review of the requirements that are contained in the applicable regulations, and an overview of the certification process
- Section 3 includes a description of airline maintenance programs and of how they are developed

- Section 4 is a summary of the database development, the regulatory assessment approach, and the case study to validate the assessment approach
- Section 5 contains the study results
- Section 6 contains conclusions and recommendations

SECTION 2
REGULATION AND GUIDANCE

2.0 INTRODUCTION

The FAA regulates the safety of aircraft design and operations by their oversight of the certification process for aircraft design and manufacture and of the continued airworthiness process for operations, maintenance, and training. This section describes the regulations that are applicable to the approval of the design, manufacture, and operation of aircraft and products; the requirements for the type certification for an aircraft or aircraft modification; the certification process; and post-certification activities.

2.1 APPLICABLE REGULATIONS

There are a series of Federal Aviation Regulations (FARs) within Title 14 of the Code of Federal Regulations, as well as guidance documents, that pertain to most aspects of design, manufacture, and operation of civil aircraft. FARs establish certification requirements for aircraft designs, requirements for manufacturers' production quality control systems, the requirements for airworthiness certification of individual aircraft, and the operations and maintenance rules for air carriers and repair facilities [1]. The FAA Aircraft Certification Service and the Flight Standards Service administer these regulations. A listing of all of the FARs is included as in Appendix A. Even though this review includes regulations for all types of aircraft, the focus for this study was on large commercial transport aircraft.

The FAA's current approach to managing aircraft safety (Figure 2-1) includes oversight of design and manufacture through certification rules (airworthiness standards); flight operations, maintenance and training through operating rules (operating requirements); and continued airworthiness through mandated and voluntary service experience reporting requirements. The regulations that apply directly to aircraft design and operation include airworthiness certification regulations for aircraft and engines (Table 2-1) and operating regulations (Table 2-2). For large commercial transport aircraft, the applicable FARs include Part 21 (Certification Procedures for Products and Parts), Part 25 (Airworthiness Standards: Transport Category Airplanes), Part 33 (Airworthiness Standards: Aircraft Engines, Part 91 (General Operating and Flight Rules), Part 119 (Certification: Air Carriers and Commercial Operators), and Part 121 (Operating Requirements: Domestic, Flag, and Supplemental Operations. In addition, Part 39 incorporates all Airworthiness Directives into the FAR system.

This analysis focused on the regulations that would have the greatest applicability to design and implementation of health monitoring systems for transport category aircraft, including Part 25, Part 121, and selected Airworthiness Directives.

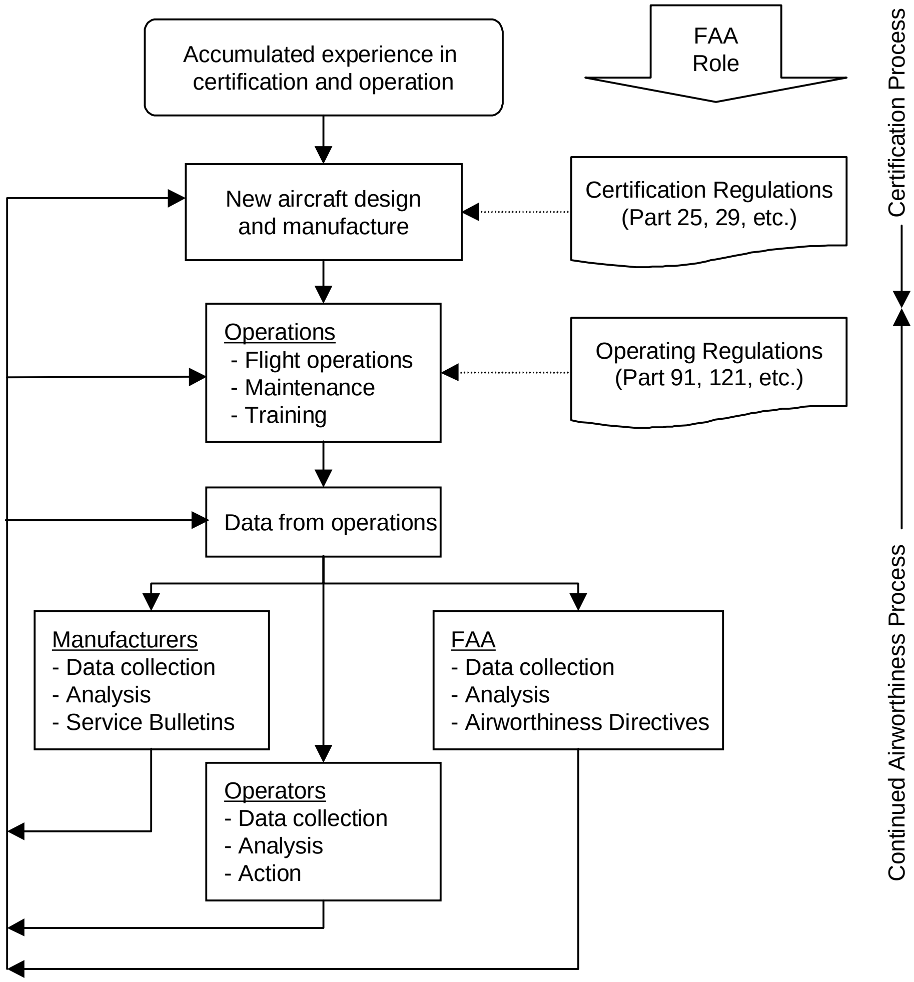

FIGURE 2-1. Aircraft Certification and safety management process. Source: *Improving the Continued Airworthiness of Civil Aircraft*, National Research Council, Washington, DC: National Academy Press (1998). Reprinted with permission. ©1998 by the National Academy of Sciences.

Table 2-1 Airworthiness Certification Regulations for Aircraft, Engines, and Propellers

CFR Part No.	CFR Subchapter and Title
Part 21:	Certification Procedures For Products and Parts
Part 23:	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
Part 25:	Airworthiness Standards: Transport Category Airplanes
Part 27:	Airworthiness Standards: Normal Category Rotorcraft
Part 29:	Airworthiness Standards: Transport Category Rotorcraft
Part 31:	Airworthiness Standards: Manned Free Balloons
Part 33:	Airworthiness Standards: Aircraft Engines
Part 35:	Airworthiness Standards: Propellers

Table 2-2 Operating Regulations

CFR Part No.	CFR Subchapter and Title
Part 119:	Certification: Air Carriers and Commercial Operators
Part 121:	Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft
Part 125:	Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More
Part 129:	Operations: Foreign Air Carriers and Foreign Operators of U.S.- Registered Aircraft Engaged in Common Carriage
Part 133:	Rotorcraft External-Load Operations
Part 135:	Air Taxi Operators and Commercial Operators
Part 137:	Agricultural Aircraft Operations
Part 139:	Certification and Operations: Land Airports Serving Certain Air Carriers

2.1.1 Airworthiness Standards

Airworthiness standards are administered by the FAA Aircraft Certification Service. These documents establish the general requirements that must be met for type certification. The purpose of airworthiness standards is to validate that the design and manufacture of the aircraft are such that the aircraft will meet the FAA's reliability requirements. Airworthiness standards include requirements for the following:

- *Flight characteristics*, including weight and balance and performance
- *Structures*, including flight load and failure load conditions, structural design criteria, and durability/damage tolerance
- *Design and construction*, including general materials and processing requirements as well as specific requirements for controls, landing gear, hulls, personnel and cargo accommodation, emergency provisions, ventilation and heating, cabin pressurization, and fire protection
- *Powerplants*, including installation and system integration, fuel and oil systems, cooling, exhaust systems, controls, and fire protection
- *Equipment*, including instruments, electrical systems, lights, and safety equipment
- *Operating limitations*

FAR 25 establishes airworthiness requirements for the certification of transport category aircraft (all aircraft designs with 10 or more seats [excluding seats for the flight crew] or a maximum takeoff weight of more than 12,500 pounds).

2.1.2 Operating Requirements

Operating requirements are administered by the FAA Flight Standards organization. These documents establish regulations and practices for owners and operators to ensure that aircraft are operated and maintained properly. Operating requirements include the following:

- approval of routes
- manual requirements
- aircraft requirements
- operating limitations
- special airworthiness requirements
- instrument and equipment requirements
- maintenance, preventive maintenance, and alterations
- airman and crewmember requirements, qualifications, and certification
- training
- dispatcher qualifications and duty time
- flight time limitations
- flight operations
- records and reports

FAR 121 establishes the operating requirements for domestic, flag, and supplemental carriers and organizations performing maintenance for air carriers. The requirements that will have the greatest effect on implementation of HM systems include maintenance program requirements, instrument and equipment requirements, and special airworthiness requirements (beyond Part 25 requirements).

2.1.3 Airworthiness Directives

Airworthiness Directives (ADs) are mandatory inspections, modifications, or maintenance actions that are implemented in response to safety-related service experience or potentially unsafe conditions. ADs are incorporated into the regulations by releasing them as amendments to FAR 39.

The aircraft owners and operators are responsible for assuring compliance with applicable ADs. Although some ADs are recurring (i.e., they require continued actions or inspections), most require terminating actions by the air carriers. Many ADs result from manufacturer's "Service Bulletins" or "All-Operator Letters" that suggest inspection, maintenance, or modification procedures and intervals (if applicable). Compliance with these types of manufacturer's alerts can be a condition of continued warranty coverage for the subject component, even if an AD is not issued.

The air carriers recognize that the AD process is necessary for correcting near-term safety concerns. However, many feel that ADs should not be used to impose routine maintenance requirements because they also impose administrative burdens on the air carriers and limit compliance options [2]. Although the air carriers are not amenable to ADs that must be kept open for scheduled inspections, structural inspection programs, modification programs, and corrosion protection and control programs for aging aircraft have been implemented through ADs (See tables 2-3, 2-4, and 2-5). These aging aircraft ADs are generally recurring requirements, which need to be incorporated into the air carriers' maintenance programs. Individual operators can request FAA approval of another approach to addressing the requirements of a particular AD (alternative means of compliance). Alternative means of compliance could include HM systems.

Table 2-3 Airworthiness Directives for Modification of Aging Structures. Source: FAA Flight Standards Service

Model	AD Number	Nomenclature	Reference
A300	96-08-08	Inspect Structure	Multiple Airbus Industries service bulletins
B707/720	91-07-19	Structural Modification	Boeing document D6-54996
B707/720	94-06-08	Structural Modification and Inspection Program	Boeing document D6-54996
B707/720	94-10-06	Aging Aircraft	Boeing document D6-54996
B727	90-06-09	Structural Modification	Boeing document D6-54860
B727	94-05-04	Modification and Inspection Program	Boeing document D6-54860
B727	94-07-08	Modification Program	Boeing document D6-54860
B737-100/200/200C	90-06-02	Structural Modification	Boeing document D6-38505
B737-100/200/200C	93-17-08	Structural Modification	Boeing document D6-38505
B737-100/200/200C	93-08-04	Inspect in Accordance with Appendix A.4 and B.4	Boeing document D6-38505
B737-200/200C/300/400/500	97-22-07	Inspect Lap Joint of Fuselage	Boeing Alert Service Bulletin 737-53A1177
B737-200/200C/300/400/500	94-26-13	Structural Modifications	Boeing Service Bulletin 737-57-1221 R2
B747-100/200/300/SR/SP	90-06-06	Flap Tracks	Boeing document D6-35999 plus multiple Alert Service Bulletins
B747-100/200/300/SR/SP	90-25-10	Elevator Control Inspection	Boeing Alert Service Bulletin 747-27A2253 R4
B747-100/200/300/SR/SP	90-06-18R1	Wing Landing Gear	Boeing Service Bulletin 747-32-2190R4
B747-100/200/300/SR/SP	92-27-04	Structural Capability Inspection	Boeing document D6-35999
B747-100/200/300/SR/SP	93-10-01	Port Latch Pin Support Fitting	Boeing Alert Service Bulletins 747-522186 R4 and 747-52A2233
B747-100/200/300/SR/SP	93-08-12	Fuselage Structural Inspection	Boeing Service Bulletin 747-53-2349
B747-100/200/300/SR/SP	94-12-04	Fatigue Cracking	Boeing Service Bulletin 747-53-2367
B747-100/200/300/SR	90-24-09	Flap Tracks	Boeing Service Bulletin 747-57-2231R2
B747-100/200/300	90-23-14	Fuselage Lap Joint	Boeing Service Bulletin 747-53-2253
B747-100/200/300	91-11-01	Inspect for Cracks	Boeing Service Bulletin 747-53A-2265R7
B747-100/200/300	92-08-02	Bulkhead Splice Strap	Boeing Service Bulletin 747-53-2283
B747-100/200	90-26-10	Fuselage Inspection	Boeing Alert Service Bulletin 747-53A-2321
B747-100/200	93-02-16	Cargo Door Latch Support Fitting	Boeing Service Bulletin 747-53A-2377
B747-100/200	94-12-09	Inspect Lap Joints	Boeing Service Bulletin 747-53-2307
B747-100/200	94-15-17	Inspect Longitudinal Lap Joints	Boeing Service Bulletin 747-53A-2366
DC-8	90-16-05	Inspect for Cracks	McDonnell-Douglas Report MDC-K-1579
MD-80	96-10-11	Inspect for Cracks	McDonnell-Douglas Report MDC-K-1572
DC-10	94-03-08	Inspect for Cracks	McDonnell-Douglas Report MDC-K-1571
F28	91-05-10	Structural Modifications	Fokker Report SE 243
L-1011	94-05-01	Inspect for Cracks	Lockheed Service Bulletin 093-51-035

Table 2-4 Airworthiness Directives for Corrosion Prevention and Control. Source FAA Flight Standards Service.

Model	**AD Number**	**Nomenclature**	**Reference**
A300	94-18-02	Corrosion Prevention	Airbus Industries document "A-300 Corrosion Prevention and Control Program"
BAC 1-11	93-02-14	Corrosion Control	British Aerospace Alert Service Bulletin 5-A-PM5987
B707/720	90-25-07	Corrosion Control Program	Boeing document D6-54928
B727	90-25-03	Corrosion Control Program	Boeing document D6-54929
B737	90-25-01	Corrosion Control Program	Boeing document D6-38528
B747	90-25-05	Corrosion Control Program	Boeing document D6-36022
DC-8	92-22-07	Bulkhead Splice Strap	McDonnell-Douglas Report MDC-K-4606
DC-9/MD-80	92-22-08R1	Corrosion Control and Prevention	McDonnell-Douglas Report MDC-K-4606
DC-10	92-22-09R1	Corrosion Inspection	McDonnell-Douglas Report MDC-K-4607
F27	94-15-11	Corrosion Control Program	Fokker Report SE-291
F28	94-05-02	Corrosion Control	Fokker Report SE-253
L-1011	93-20-03	Corrosion Control	Lockheed Service Bulletin Document L.R. 31889
L-1011	95-21-07	Corrosion Control	Lockheed Service Bulletin Document L.R. 31889, sec 7-2A
YS-11/YS-11A	95-14-05	Corrosion Control	Mitsubishi MHI Publication YS-MR-301

Table 2-5 Airworthiness Directives for Supplemental Structural Inspection Programs. Source FAA Flight Standards Service.

Model	AD Number	Nomenclature	Reference
A300	90-01-10	Longitudinal Lap Joint	Airbus Industries Service Bulletin A-300-53-211R1
A300	96-13-11	Structural Integrity	Airbus Industries A300 SSIP-R2
B707/720	85-12-01R1	SSD Inspection	Boeing document D6-44860
B727	84-21-05	DTR for each Supplemental Structural Inspection	Boeing document D6-48041-1
B727	98-11-03	DTR for each Supplemental Structural Inspection	Boeing document D6-48040-1
B737	91-14-20	Structure Inspection	Boeing document D6-37089
B737	98-11-04	Structural Integrity	Boeing document D6-37089
B747	94-15-12	Supplemental Structural Inspection	Boeing document D6-35655
B747	94-15-18	DTR for each SSIP	Boeing document D6-35022 (no US registered)
DC-3	90-05-08	Revised Inspection Program	McDonnell-Douglas Report I.26-013, DC-3 SIDR1
DC-6	93-11-07	Structure Integrity	McDonnell-Douglas Report I.26-014
DC-8	93-01-15	Inspection Program Revision	McDonnell-Douglas Report I.26-011, Volume I, II, and III
DC-9	96-13-03	Inspection Program Revision	McDonnell-Douglas Report I.26-008, Volume I, II, and III
DC-10	95-23-09	Inspection Program Revision	McDonnell-Douglas Report I.26-012, Volume I, II, and III
F28	93-13-04	Structural Inspection	Fokker document 28438, Part I
L-1011	95-20-04R1	SSD Inspection	Lockheed document G92ER0060
L188	87-16-05	Supplemental Inspection	Lockheed report LR 29428, Section IIIC
Convair 240/340	92-06-06	Inspection Program Revision	General Dynamics-Convair report 25-340-1000, Ad. I, II, and III
Dassault	92-17-05	Significant Structure Items	Dassault Aviation Service Bulletin FJF-002-26 (FJF-730)
Bombardier CL 44D4	91-06-06	Supplemental Inspection Program	Canadair document RHD-44-100RB

2.2 FAA CERTIFICATION REQUIREMENTS

FAA certification involves a series of assessments that lead to the issuance of an airworthiness certificate for individual aircraft by the FAA Administrator. A number of analyses support the airworthiness certification, including an assessment of the fundamental design (type certification), an evaluation of the processes used to produce the aircraft (production approval), and an evaluation of the capability of the operators to operate the aircraft safely and to maintain the aircraft in airworthy condition (continued airworthiness).

This section includes a general description of FAA certification requirements and examples of how the requirements apply to health monitoring systems.

2.2.1 Airworthiness Certification

Title 49 of the United States Code gives the Administrator of the FAA the responsibility to issue a Standard Airworthiness Certificate for each eligible aircraft registered in the United States. An airworthiness certificate indicates that the FAA has determined that the aircraft (1) conforms to an FAA-approved *type design* and (2) is in safe operating condition. Standard airworthiness certificates are supported by *type certificates* and *production approvals*. The airworthiness certificate is effective as long as the operations, maintenance, preventative maintenance, and alterations are performed in accordance with FAR parts 21 (Certification Procedures for Products and Parts), 43 (Maintenance Preventive Maintenance, Rebuilding, and Alteration), and 91 (General Operating and Flight Rules). Special airworthiness certificates, including primary, restricted, limited, provisional, and experimental, can also be issued.

2.2.2 Type Certification

The type certification process, which could include *initial type certification* or *supplemental type certification*, assesses the design of a new product or a proposed design modification to an existing product. Type certificates are issued upon (separate) approval of new and modified designs of aircraft, aircraft engines, and propellers.

Initial Type Certification (TC) is the FAA process for approval of new products. In general the basis for type certification includes (1) applicable *airworthiness standards* (FAR, part 25 for transports), (2) special conditions developed to address novel or unusual design features, (3) standards for fuel venting and emissions, and (4) exemptions to the above standards made "in the public interest."[a] Design changes can be made during

[a] FAR Part 21, §21.17 designates the applicable regulations to establish a certification basis.

the life cycle of the aircraft design. Minor[b] changes must be evaluated against the original type certification basis and relevant ADs. Minor changes to type designs are generally approved by the manufacturer's Designated Engineering Representative (DER). Major changes, which result in amendments to the original type certificate, usually involve the introduction of a derivative to an existing model. The type certification basis for a derivative design is generally considered to be the type certification basis for the original type design, supplemented by additional requirements to address novel and unusual design features of the derivative design. All ADs must be incorporated into the derivative design. Testing and analyses are only conducted where the original results are not applicable to the derivative design.

Supplemental Type Certification (STC) is the FAA process to approve modifications to improve existing products when someone other than the holder of the type certificate asks the FAA to approve the design changes. As is the case with derivative aircraft, the certification basis for STC is the type certification basis for the original type design modified as needed. However, because of the manufacturer's proprietary rights, the applicant might not be granted access to the supporting data for the original TC. In this case, the applicant might have to "reverse-engineer" the component to establish test and validation requirements. If unsuccessful, the applicant could be required to withdraw their application.

2.2.3 Production Approvals

The purpose of production approvals is to ensure that the manufacturers of certificated components are capable of repeatably producing components that represent the certification basis. There are three principal types of production approvals allowed in FAR Part 21—(1) production certificates, (2) technical standard order (TSO) authorizations, and (3) parts manufacturer approvals (PMAs). Alternatively, components may be manufactured under the authority of a TC (or STC) only.

The production approvals that will be most applicable to health-monitoring systems are production certificates for the integrated system and TSO authorizations for generally applicable system components.

2.2.3.1 Production Certificates

Production certificates are issued by the FAA Administrator to signify approval of the producer's quality system and quality control data. Production certificates may be issued to holders of current type certificates or STCs. Production certificates can simplify the certification process for individual aircraft because they allow the holder to obtain

[b] A minor change is defined in FAR Part 21 (§21.93) as "one that has no appreciable effect on the weight, balance, structural strength, reliability, operational characteristics, or other characteristics affecting the airworthiness of the product." All other changes are defined as major.

approval for installation on type certificated aircraft or to obtain an airworthiness certificate without further process inspections or audits.

Manufacturers of health-monitoring systems would need to apply for approval under a production certificate. Generally the application would be made at the same time as application for TC or STC, even though a production certificate cannot be issued until a TC or STC has been approved. Obtaining a production certificate for installation on a particular aircraft type would facilitate approval of subsequent installations on the same aircraft type.

2.2.3.2 Technical Standard Orders

Technical Standard Orders (TSOs) are minimum performance standards for specified materials, parts, processes, or devices used on civil aircraft. There are 2 principal ways that the FAA acknowledges compliance with a specified TSO: (1) A TSO authorization (TSOA), which is a design and production approval issued to the manufacturer, and (2) a letter of TSO design approval, which is a design approval for a foreign-manufactured article. An approved TSO Authorization (or letter of TSO design approval) signifies approval of the component design and the manufacturer’s facilities and processes.

Although TSOs are most often used for stand-alone electronics and avionics components, they could be used for any products, parts, and devices that are considered by the FAA to be generally applicable and useful. Hence, TSOs could facilitate the approval of health-monitoring system components, including sensors and signal-conditioning hardware and on-board processors. However, a TSO is applicable only to the particular product, part, and device and does not constitute approval for installation on an aircraft. The integrated HM system would require separate production approvals for installation.

2.2.3.3 Parts Manufacturer Approvals

Parts Manufacturer Approvals (PMAs) are required for the production of modifications or replacement parts for installation on a type certificated product. PMAs apply to parts that cannot be produced under a type or production certificate, by an owner or operator for maintaining or altering his own product, or under a TSO. An approved PMA signifies that the manufacturer has shown (through tests and inspections) that the design meets airworthiness requirements for the product on which the part is to be installed; and that the manufacturer’s fabrication and inspection system is acceptable.

PMAs would not be likely to apply to the initial certification of a HM system or components because they generally apply to individual replacement parts, not integrated systems.

2.2.4 Operations and Maintenance: Continued Airworthiness

Applicants for a TC or STC are required by FAR Part 21 to prepare "Instructions for Continued Airworthiness." The specific requirements are contained in applicable airworthiness standards (e.g., FAR Part 25 for large transports). These instructions are required to be given to the operator when the aircraft is delivered or when the first standard airworthiness certificate for the affected aircraft is issued, whichever occurs later. The instructions may be incomplete when the TC (or STC) is issued as long as the above delivery requirements are met (i.e., prior to delivery of the first aircraft or issuance of a standard certificate of airworthiness). The instructions for continued airworthiness include:

- the aircraft maintenance manual or section
- maintenance instructions
- access information
- special inspection techniques
- application of protective treatments to the structure after inspection
- data relative to structural fasteners such as identification, discard recommendations, and torque values
- special tools

Air carrier programs to maintain continued airworthiness are discussed in Chapter 4. The focus of HM systems is to improve programs to assure continued airworthiness. Thus, the required modifications to continued airworthiness programs and the resulting air carrier inspection and maintenance programs are critical considerations in the implementation of HM systems.

2.2.5 Summary

FAA certification of HM systems would include an assessment of the fundamental design (type certification), an evaluation of the processes used to produce the HM system (production approval), and an evaluation of operational safety (continued airworthiness). The most likely approach to type certification of HM systems for existing aircraft is STC because the manufacturers of the systems will make the applications for type certification. Production approvals for HM systems will probably be granted through production certificates, supplemented with TSOs for some system components. Modification of continued airworthiness programs to realize the potential benefits of HM systems would be evaluated during the type certification process.

2.3 CERTIFICATION PROCESS

A schematic of the type certification process, alongside a typical product development process, is shown in Figure 2-2. The certification process is outlined, from the FAA's point of view, in FAA order 8110-4A [3]. The detailed steps involved in a typical certification are described in this section with an emphasis on STCs, the most likely approach for the certification of health-monitoring systems. The following section describes the specific approach for the certification of HM systems.

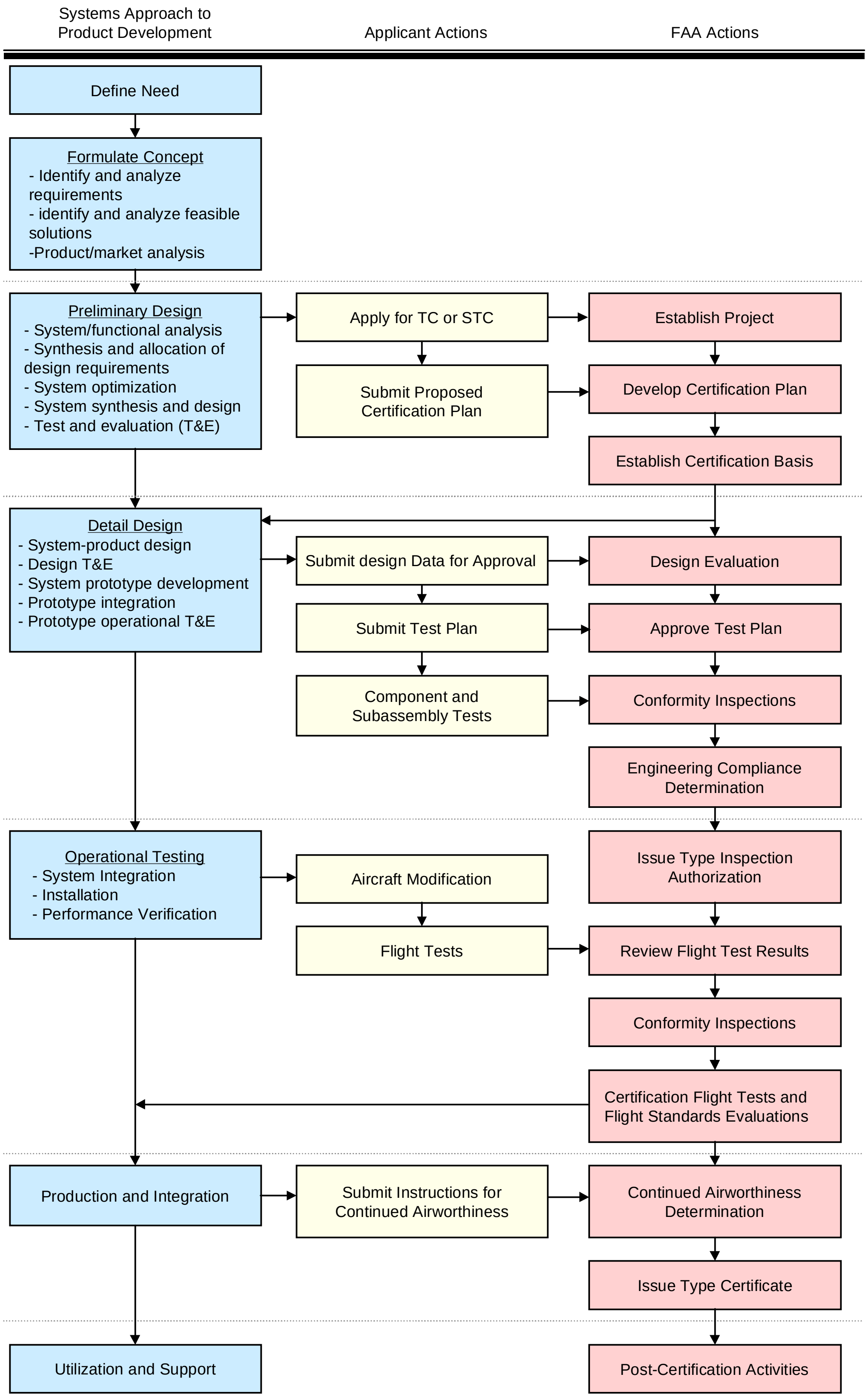

FIGURE 2-2. Type Certification Process

The first step in the certification process is to apply for a TC or STC, using FAA Form 8110-12, *Application for Type Certificate, Production Certificate, or Supplemental Type Certificate*. In the case of an STC, the application would be submitted to the applicable regional aircraft certification office (ACO). The application should specify either a "one-only" STC, which would apply to only one aircraft/engine/propeller serial number, or a "multiple" STC, which would apply to two or more aircraft/engines/propellers. For "multiple" STCs, the applicant must demonstrate that the modification can be duplicated. At the same time, the applicant should apply for a production certificate. The FAA, through the responsible ACO, then establishes the project by assigning a project number, a project manager, and notifying the accountable directorate. If necessary, the accountable directorate will assign a project officer.

The applicant develops and submits a proposed certification plan that includes [4]:

- High-level description of the design
- Proposed compliance documentation
- Proposed designees
- Suggested certification basis
- Compliance checklist
- Project schedule

The FAA develops a formal certification program plan that establishes roles of the FAA participants and the responsibilities of the applicant, and the program schedule. The FAA then identifies the certification basis that will be applied to the TC or STC program. The certification basis will consist of the initial certification basis plus those requirements effective on the date of the application that are generally related to the components or areas affected by the proposed modification. It is essential for the applicant to consider the certification basis in the development of the detail design so that the design data will address the issues identified in the certification plan.

Once the applicant has completed the detailed design, the type design and substantiating data are submitted to the FAA for evaluation to show compliance with applicable regulations and special conditions prescribed by the FAA. The type design includes:

- Drawings and specifications
- Information on dimensions, materials, and processes
- Airworthiness limitations
- Other data necessary to describe the design of the product

The FAA recommends using a compliance checklist that addresses all of the applicable regulations so that problem areas can be identified early in the type certification program. The FAA will approve the data when the product has been shown to conform to the type design and applicable airworthiness requirements.

The applicant prepares a test plan to show compliance to applicable regulations for design or modifications. The test plan should include:

- Description of test articles
- Required test equipment
- Description of calibration procedures
- Compliance requirements
- Step-by-step test procedures

The FAA will approve the test plan, perform conformity inspections (to ensure that the product complies with the type design), and witness testing. Prior to final installation, it may be required that individual components or subassemblies be subjected to inspections or tests.

Once the product has been found to conform to the type design, the installation will be inspected to determine compliance to applicable regulations. Extensive analysis and testing is generally required for compliance determination. Determination of compliance will include a detailed safety assessment, an evaluation of performance under service environmental conditions, and an assessment of the software aspects of certification. An engineering compliance inspection provides an opportunity to review an installation and its relationship to other installations on a product. Flight Standard's airplane evaluation groups (AEG) may conduct an evaluation of acceptability of operations and maintainability concurrently with engineering compliance inspections.

Once the aircraft has been modified and all data have been approved, the FAA prepares a type inspection authorization (TIA) for official conformity, airworthiness inspections, and flight tests necessary to fulfill certification requirements. If required, the FAA issues an experimental airworthiness certificate to permit flight testing. The applicant then conducts their own certification tests of the complete installation (without FAA inspectors) to assure that the installation will comply with all requirements. When testing has been completed, a flight test report is submitted to the FAA for review.

Upon acceptance of the applicants flight test report, conformity inspections are accomplished by FAA manufacturing inspection personnel or an FAA designee. Official certification tests are conducted or witnessed by FAA personnel or FAA designees.

The AEG participates in the aircraft certification engineering compliance inspections and flight test programs. The AEG will:

- Participate in compliance and TIA testing to evaluate operational suitability
- Review maintenance programs for continuing airworthiness and develop the maintenance review board report
- Review flight manuals and revisions
- Develop master minimum equipment lists (MELs)
- Establish type rating requirements

- Participate in crew complement determinations
- Participate in emergency evacuation demonstrations
- Establish acceptance of flight crew sleeping quarters
- Establish any unique or special training requirements
- Participate in functional and reliability testing
- Manage the Flight Standardization Board, Flight Operations Evaluation Board, and Maintenance Review Board

If required, the FAA prepares a certification summary report, which summarizes the record of the FAA examination of a type design, discusses significant safety issues, and describes how compliance with the applicable regulations was verified.

The applicant prepares instructions for continued airworthiness for submittal to the FAA. The instructions may be incomplete at the time of type certification, but the airworthiness limitations must be approved by the FAA.

Finally,the FAA issues the TC or STC.

2.4 CONTINUED OPERATIONS

Once certification requirements have been met and a standard airworthiness certification has been issued, the aircraft enters service. Operators and manufacturers are responsible for tracking the product performance and reliability according to the requirements for continued airworthiness. The FAA is responsible for monitoring continued compliance. As improved systems and data analysis technologies have become available, more quantitative means to monitor aircraft safety have been introduced. Air carriers have implemented Fight Operations Quality Assurance (FOQA) programs and the FAA has implemented the Air Transport Oversight System (ATOS). The following sections describe each of these programs.

2.4.1 Flight Operations Quality Assurance (FOQA)

Flight Operational Quality Assurance (FOQA) involves the analysis of flight data to identify and correct problems or anomalous occurrences before they adversely affect flight operations or safety. The implementation of a FOQA program by an airline requires them to have the capability to (1) capture critical flight data parameters, (2) process and analyze the collected data, and (3) use the analysis to improve future flight operations. HM systems could facilitate the implementation of FOQA programs by providing embedded data collection and evaluation capabilities.

European and Asian air carriers led the commercial aviation industry in the implementation of formal FOQA programs to quantify and assess flight performance and safety data as standard operating procedures. Most notably, eight non-US airlines—British Airways, Japan Airlines, KLM-Royal Dutch Airlines, Lufthansa German Airlines, and the

Scandinavian Airlines System—have been using FOQA programs for over 15 years. These air carriers are convinced that FOQA programs are a critical component of their respective safety, O&M, and training management efforts, and that such programs pay operational, maintenance, and economic dividends.

US air carriers have been reluctant to implement such programs primarily because of concerns over liability, data protection, and cost effectiveness [5]. Data protection and security has been a controversial and sensitive concern of the US air carriers, aircrew personnel, and professional associations who have been concerned that flight data developed under FOQA programs could be used for punitive or disciplinary action. However, as the benefits of FOQA programs have been demonstrated in the international aviation community, some US airlines have initiated efforts to adopt such systems on a trial basis.

In 1991, the FAA, recognizing the value of operational flight data and flight crew performance in preventing incidents and accidents, selected the Flight Safety Foundation (FSF) to study FOQA. In its subsequent report back to the FAA, FSF stated that:

> "…the appropriate use of FOQA data by airlines, pilot associations, and aircraft and equipment manufacturers would result in a significant improvement of flight safety by identifying operational irregularities that can foreshadow accidents and incidents." [6]

FSF concluded that FOQA programs should be implemented by US air carriers involved in FAR Part 121 operations (large transports). FSF recommended that the FAA promote the implementation of voluntary FOQA programs by instituting a demonstration program in partnership with the aviation industry. In response to the FSF recommendations, the FAA initiated a $5.5 million FOQA demonstration project in 1995. The purpose of the demonstration was to promote and facilitate the voluntary implementation of aviation quality assurance programs by US air carriers and to assess the potential costs, benefits, and safety enhancements.

The implementation of the FOQA demonstration project was voluntary, but highly recommended, for certificate holders operating under FAR Part 121. The FAA provided the participating air carriers with specialized equipment for continuously recording hundreds of different flight-data parameters from aircraft systems and sensors. For example, the FAA provided quick access recorders (QARs) to each of the participating airlines for installation on 15 of their Boeing 737 for capturing FOQA flight data. In addition, as necessary, the FAA also provided ground analysis systems—including hardware and software—for analyzing, correlating, and presenting FOQA-generated data. The participating carriers bore the cost of obtaining supplemental type certification of the airborne FOQA equipment; the cost of installing, integrating, testing, and maintaining this equipment; and the cost of providing personnel and resources to manage, execute, support, and monitor the FOQA program.

Even though only four US air carriers—Continental, United, US Airways, and Alaska—were initially selected to participate in this program, their experience with the FOQA program indicated that:

- FOQA provides more-objective, quantitative data on what occurs during flight than what is reported by individuals (e.g., aircrew).
- FOQA data yields information about flight operations, performance, and airworthiness that can be used to help objectively evaluate and address a wide range of safety-related issues.
- FOQA data facilitates the identification and characterization of previously unknown or suspected airworthiness problems that can result in timely, cost-effective corrective actions that significantly reduce safety-related risks. Furthermore, where problems are already known, FOQA data can help to confirm and quantify the extent and severity of these problems.
- FOQA programs can help air carriers accurately determine the frequency of certain flight occurrences and maintenance events, rather than relying on human judgement or subjective procedures, particularly with respect to maintenance, inspection, and airworthiness requirements.
- FOQA findings enable air carrier managers to responsibly update, refine, and modernize training and safety programs.
- FOQA data can help air carrier maintenance managers make more informed decisions about whether their aircraft need to be inspected, repaired, or overhauled due to damage or degradation.
- FOQA trends and metrics can help air carriers validate whether corrective actions and procedural changes are effective.

Although the focus of FOQA is primarily safety related, financial benefits can be realized as well. Although the actual cost benefits to be realized from implementing a FOQA program depend on a large number of factors, air carriers have found that the responsible use of FOQA-generated data can help to:

- Improve aircraft availability and O&M productivity
- Reduce unneeded maintenance, inspections, repairs, and overhauls
- Reduce maintenance delays and flight cancellations
- Lower insurance premiums, liability risk, and litigation expenses associated with accidents and incidents

FAA cost estimates project that, for an inventory of 50 state-of-the-art aircraft, air carriers could conceivably realize a net savings of approximately $892,000 per year from reduced expenditures for fuel, maintenance, and direct accident-related costs [7]. Potentially, additional O&M cost savings could be realized as a result of FOQA-enabled enhancements to aircrew performance and training, aircraft and ATC operating procedures, aircraft maintenance and operations support, and airport design and maintenance.

Based on the favorable results of the demonstration, the FAA has chosen to promote FOQA as a voluntary initiative (rather than a regulatory mandate) through a cooperative partnership with the US aviation industry. In addition to the four original participating carriers, several other airlines (e.g., America West Airlines, Continental Express, Delta Air Lines, Northwest Airlines, Southwest Airlines, Trans World Airlines, American Airlines, and United Parcel Service) are considering the implementation of FOQA (or FOQA-like) programs. In addition, NASA (under contract to the FAA) is developing an advanced system for conducting automated analysis and research on FOQA-generated data.

Implementation of HM systems could be an important factor in air carrier efforts to introduce FOQA programs. HM systems promise to automate the data collection and analysis functions associated with maintenance program review. These capabilities are consistent with the goals for FOQA programs.

2.4.2 Air Transportation Oversight System (ATOS)

The FAA has the responsibility to oversee post-certification activities to assure that aircraft and air travel remain safe. To perform this function, the FAA has recently introduced ATOS, which is based on a risk management approach to system safety, rather than just audits of regulatory compliance [8].

ATOS is a result of collaboration between the FAA and Sandia National Laboratories (SNL) to revitalize the FAA oversight process based on SNL's "accidents are unacceptable" nuclear safety policy. The goal of ATOS is to foster increased air carrier safety using a systematic, data-driven approach to identify safety trends and prevent accidents. Inspectors look at the air carrier's organizational and operational processes as a whole and determine how systems interact to maintain safety. Under the previous approach, air carriers received mandatory, scheduled inspections specified in an annual work program based on their level of operations. Additional inspections were conducted at the discretion of the carrier's principal FAA inspector. This "expert-based," non-systematic approach relied on the expertise of the inspectors assigned to an air carrier.

ATOS was first implemented in October 1998, with a focus on the 10 major US passenger air carriers (i.e., Alaska, America West, American, Continental, Delta, Northwest, Southwest, TWA, United and US Airways). Also, new carriers that seek operational certification will fall under ATOS surveillance. ATOS is continually evolving based on feedback from FAA inspectors and air carriers.

The implementation of ATOS is not expected to represent a barrier to the introduction of HM systems. In fact, the focus on risk management and data-driven oversight instead of an approach driven solely by regulatory compliance could facilitate the introduction of automated tools such as HM.

SECTION 3
AIR CARRIER MAINTENANCE PROGRAMS

3.0 INTRODUCTION

Operators of commercial aircraft develop and implement maintenance and preventive maintenance programs, not only to comply with regulations and guard against liability, but also to maximize the availability of individual aircraft (by minimizing aircraft down time) and to protect their considerable capital investment in aircraft and equipment. The objectives of an effective maintenance program are to accomplish the following in a cost-effective manner [9]:

- Ensure that the inherent component safety and reliability levels are realized
- Restore component safety and reliability to their inherent levels if deterioration occurs
- Obtain information necessary for design improvement of components with inadequate inherent reliability

As described in the previous chapter, FAR Part 21 requires that manufacturers provide complete instructions for continued airworthiness when the aircraft is delivered or when the first standard airworthiness certificate is issued. To implement these instructions, FAR Part 121 (for large transports) assigns responsibility for performing maintenance, inspections, and alterations to the operators.

Air carrier profitability relies critically on the productivity of individual aircraft. The requirements for aircraft utilization have been steadily increasing in recent years. Current schedules and route structures are such that aircraft could see as many as 16 hours per day of service. High utilization aircraft could approach 6000 hours in a year, a number that has been steadily increasing over the past 10–15 years, and results in fewer opportunities to bring an aircraft in for maintenance [10].

The primary consideration for assessing the effect of HM systems on continued airworthiness is to determine their potential influence on scheduled maintenance programs. HM systems could be an important factor in improving the effectiveness of inspection and maintenance programs and enabling focused, condition-based maintenance. Ultimately, these improvements would increase air carrier profitability.

This section describes the development of air carrier maintenance programs, the implementation of these programs by commercial operators, tracking of component reliability, and procedures for program review and modification.

3.1 MAINTENANCE PROGRAM DEVELOPMENT

Continuous airworthiness maintenance programs are developed by the aircraft operators and approved by the FAA. The basic elements of a continuous airworthiness maintenance program includes the following [11]:

- *Aircraft inspection*, including routine inspections, servicing, and tests performed on the aircraft at prescribed intervals
- *Scheduled maintenance* (i.e., maintenance tasks performed at prescribed intervals), including replacement of life-limited items, components requiring replacement for periodic overhaul, special inspections, checks or tests for on-condition items, and lubrication
- *Unscheduled maintenance* (i.e., maintenance tasks generated by the inspection and scheduled maintenance elements, pilot reports, failure analyses, or other indications of a need for maintenance)
- *Engine, propeller, and appliance repair and overhaul*
- *Structural inspection program and airframe overhaul*
- *Required inspection items* (i.e., safety-critical items)
- *Maintenance manuals*, which define the continuous airworthiness maintenance program

There has been a gradual evolution of aircraft maintenance philosophy to embrace reliability control methods as an integral part of an approved aircraft maintenance program [12]. This transition is evident in the three approaches to preventive maintenance currently applied to commercial transport components—hard time, on-condition, and condition monitored, as described in the following paragraphs.

Early (first-generation) air carrier maintenance programs were developed under the assumption that each functional component needed periodic disassembly for inspection. This led to the implementation of *hard time* maintenance processes, where components are removed from service when they reach a predetermined service parameter (e.g., flight hours, flight cycles, or calendar time).

However, the majority of aircraft components do not exhibit old-age wear-out that would be conducive to hard time maintenance. The principal reliability pattern for complex aircraft systems is high initial failure rates, followed by random incidence of failure throughout the remaining life [10]. Replacing such components at a prescribed age actually reduces overall reliability because the poor initial reliability is introduced more often. This led to the implementation of *on-condition* maintenance processes, where periodic visual inspection, measurements, tests or other means of verification are used to establish component condition without disassembly, inspection or overhaul.

Finally, the industry and regulatory authorities developed methods to establish maintenance program requirements by tracking component failure rates and maintaining an acceptable level of reliability. Reliability methods identified components that respond to neither hard time nor on-condition approaches. This led to the implementation of *condition monitoring* maintenance processes, where component performance is monitored and analyzed, but no formal services or inspections are scheduled.[c]

Airline maintenance programs include all three maintenance approaches as appropriate. Maintenance tasks are developed and implemented for individual components by component manufacturers and operators based on detailed analyses of component performance, potential failure modes and consequences, and reliability of similar components in service. The approaches used by air carriers to identify maintenance tasks are outlined in the following sections.

HM systems could provide benefit to the operators in each of the maintenance scenarios described above. First, hard time components could be converted to one of the reliability-based approaches by identifying faults that are precursors to failure and monitoring the components using a HM system. Second, HM systems could be used to automate the inspection, measurements, and tests for on-condition components. Finally, HM systems can be used to detect the precursors to failure for condition-monitored components so that maintenance or replacement activities can be anticipated and scheduled.

3.1.1 New Aircraft Programs (MSG process)

Airlines recommend initial maintenance tasks for new aircraft based on a detailed analysis approach [9]. Each major subsystem is considered by a Maintenance Steering Group (MSG) sanctioned by the Air Transport Association (ATA). These groups consist of senior maintenance engineers from each carrier that will operate the aircraft type, as well as representatives of the manufacturer and the FAA. The groups identify significant maintenance tasks in critical systems using a rigorous evaluation process that includes the following general steps:

- Identify subsystem function
- Predict potential failure modes based on analysis or experience with similar designs
- Analyze the failure modes using an established logic that considers consequences of failure (e.g., affects safety, undetectable, operational impact, economic impact)
- Write maintenance tasks and intervals based on the above assessment (e.g., lube/service, crew monitoring, operational check, inspection/functional check, remove and restore, or remove and discard)

Figure 3-1 shows a simplified logic diagram for developing maintenance tasks for systems and powerplant components. The logic approaches are extended to a detailed level to

[c] This definition of condition monitoring differs from the definition traditionally used in nondestructive evaluation or process controls. The traditional definition implies that parameters that would provide evidence of impending failure events are monitored. For the current definition performance relative to an alert value indicating failure is monitored.

evaluate and select appropriate maintenance tasks for each potential failure event [9]. Similarly, structural designs are evaluated to identify potential structural failure processes, assess the ability to detect indications of each failure mechanism, and determine the potential consequences of each failure event (or multiple events acting simultaneously). Inspection, maintenance, and modification tasks for structures are developed based on the results of these analyses.

Once the maintenance tasks are produced by the MSG-3, the individual carriers add or modify the tasks for their operations to develop a maintenance list. The list is submitted to the FAA regional office for acceptance (not approval). Although there is no requirement for the airlines to develop a maintenance list, submitting the list for acceptance can expedite the required FAA approval of the maintenance plan (Airline Maintenance Manual).

Separately (until the 777), the manufacturers develop a manufacturer's Maintenance Manual (MM), which includes structural airworthiness limitations, certification maintenance requirements (CMR)[d], and servicing and lubrication requirements. Based on their MM, the manufacturers develop maintenance process data (MPD) and maintenance task cards. In their evaluation of Airline Maintenance Manuals, the FAA makes sure that the maintenance tasks and intervals are consistent with the manufacturer's recommendations, although the carriers' processes can deviate from the MM requirements with FAA approval. Because the MSG-3 process does not continue after certification, new maintenance or modification tasks resulting from service experience (introduced through FAA Airworthiness Directives and Advisory Circulars, or manufacturer's All-Operators Letters and service bulletins), are formalized in the manufacturers MM.

As a result of the MSG-3 activities, second- and third-generation transport aircraft have formalized fault tree analyses for each major subsystem. These could be invaluable in the development of health-monitoring systems that target critical components and are consistent with the air carriers' maintenance programs.

3.1.2 Existing Aircraft

Operators who purchase new aircraft later in their manufacturing life-cycle or purchase aircraft previously operated by another carrier, are also required to develop maintenance plans and manuals to be approved by the FAA. The development of an air carrier maintenance program for an aircraft type that has been in service builds on existing analyses as well as service experience.

[d] Certification maintenance requirements (CMRs) are required periodic tasks that are established during airworthiness certification as operating limitations of the type certificate [9].

Generally, the operators develop maintenance tasks based on the manufacturer's guidelines for assuring continued airworthiness, which are included in the MPD and maintenance task cards. In addition, programs are often substantially influenced by previous service and maintenance history and by establish and approved maintenance programs. These resources are adapted to meet the operator's maintenance capability and operations (e.g., cargo vs. passenger operation; operator vs. contractor heavy maintenance). Most airline operators use the inspection and maintenance work processes as prescribed by the manufacturer. The program can be tailored by grouping individual tasks into an overall maintenance program that is compatible with the carriers capabilities and operations.

Additional mandated inspections, maintenance actions, or modifications are introduced through ADs. Although most ADs require terminating actions to restore the component to an airworthy condition, some require ongoing inspections and modification that must be incorporated in the maintenance program. The operator of purchased aircraft must assess the status of open ADs to ensure that the ongoing requirements are met.

It is often difficult for carriers who purchase previously owned aircraft to determine the status of previous service bulletins (SBs). Many SBs suggest an inspection and assessment followed by modification, depending on the results of the inspection. When compliance with a SB is indicated, the new operator must ascertain whether only the inspection was done or if the modifications were also made. If an operator executes a MPD-based maintenance program, most SBs will be implemented.

Existing HM systems could help airlines maintain the continuity in their inspection and maintenance programs when individual aircraft change ownership. Automated maintenance and inspection recording and flight data archives would enable the new owner to establish the condition of the monitored components.

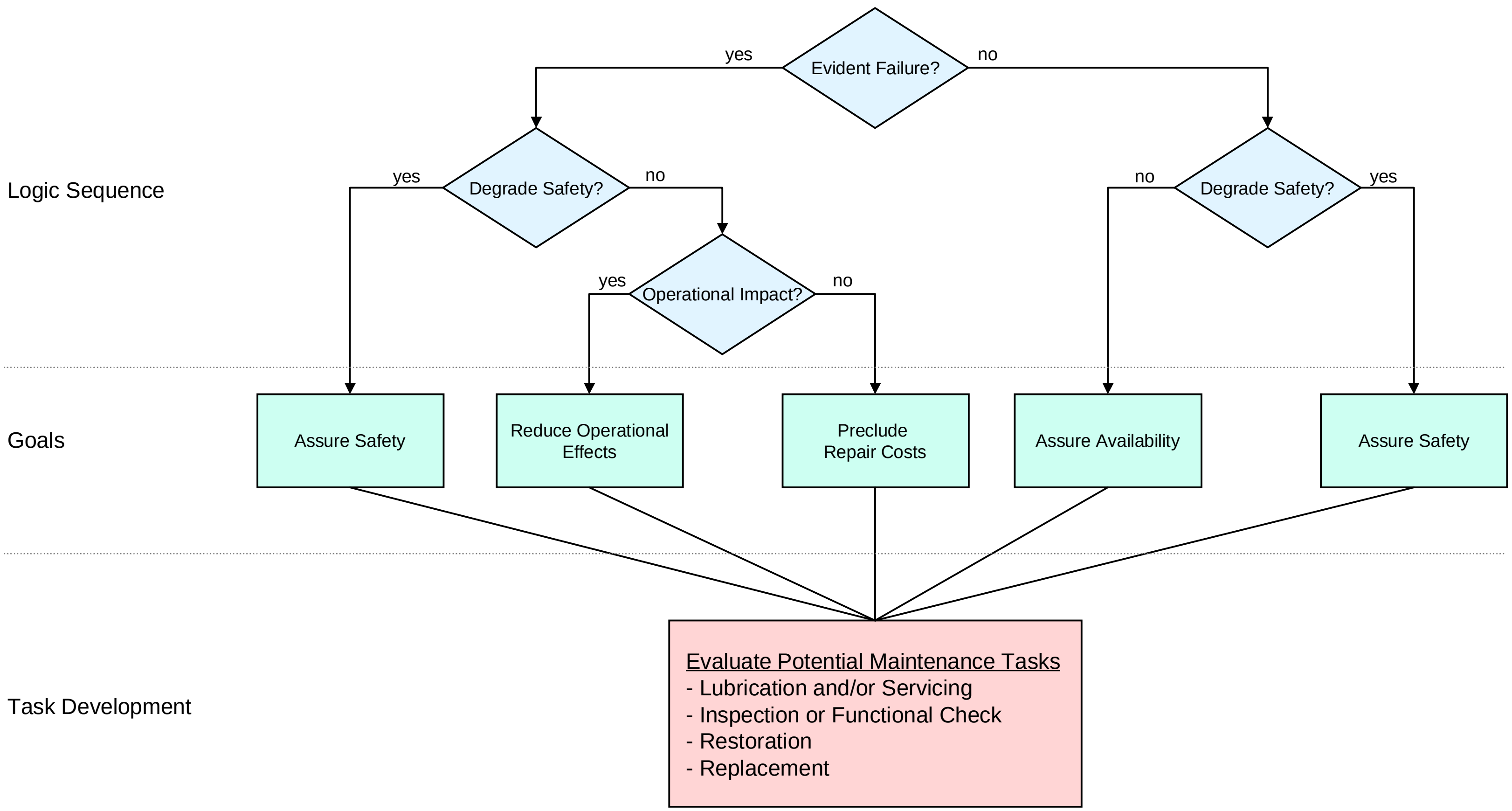

FIGURE 3-1. Simplified logic diagram for developing initial maintenance tasks for systems and powerplant components.

3.2 MAINTENANCE PROGRAM IMPLEMENTATION

Once maintenance tasks and intervals have been established, the air carrier must develop an implementation plan, consistent with their operations and capabilities, to accomplish scheduled maintenance tasks. A typical maintenance program has a series of scheduled maintenance "checks," where maintenance tasks are grouped so that they can be accomplished with minimal downtime.

There are a number of approaches to implementing inspection and maintenance intervals that comply with manufacturers' suggestions and are complementary with the carriers' operations. The following are examples of approaches to organizing maintenance tasks into checks [13]:

- **Block** programs, where the aircraft is broken into inspection areas (zones) or systems and all of the A-level or C-level checks are accomplished at an appropriate visit.
- **Segmented** programs, where each check interval is broken up into subintervals. For example, instead of performing one large A-check at 4000 hours, the carrier can perform 4 smaller checks at 1000, 2000, 3000, and 4000 hours. Either way, the required work is done within the specified time.
- **Phased** programs, which is similar to a segmented program except that all A-level segments are completed within each B-level increment, and similarly for higher-level checks.
- **Continuous maintenance visits** (CMV) programs, where individual tasks are assigned an initial check and a prescribed interval. For example a task might start at the second C-check (C2) and be repeated at every third C-check from then on (3C interval).

The FAA does not prescribe how the operators must organize their tasks, so an acceptable maintenance program could be organized using any of these methods or by combining the methods. The checks for a typical maintenance program are shown in Table 3-1.

Table 3 –1. Typical Airline Maintenance and Service Plan

When Service is Performed	Type of Service Performed	Impact on Airline Service
Prior to each flight	“Walk-around” – visual check of aircraft exterior and engines for damage, and leakage	None
Every 2-7 days	Service check (line maintenance opportunity) - service consumables (engine oils, hydraulic fluids, oxygen) and tire and brake wear	Overnight layover
Every 25-40 days	A-checks (line maintenance check) - detailed check of aircraft and engine interior, service and lubrication of systems (e.g., ignition, generators, cabin, air conditioning, hydraulics, structures, and landing gear)	Overnight layover
Every 45-75 days	B-checks (packaged A-checks) – torque tests, internal checks, and flight controls	Overnight layover
Every 12-15 months	C-checks (base maintenance visit) - detailed inspection and repair of engines and systems	Out of service 3-5 days
Every 2-5 years (depending on usage or mandatory inspection/modification requirements)	Heavy maintenance visit (or maintenance program visit) – corrosion protection and control program and structural inspections/modifications	Out of service up to 30 days

Source: Based on New Materials for Next-Generation Commercial Transports, NMAB-476, National Research Council, Washington, DC: National Academy Press (1996).

Scheduled maintenance is set at calendar intervals based on anticipated aircraft usage. Flight hours and cycles are monitored for each aircraft and aircraft are scheduled into the principal maintenance facilities for checks. Implementation of maintenance tasks is generally done by zone, not by subsystem. Zone groups perform all of the maintenance tasks that are required for all of the subsystems (e.g., hydraulics, electronics, structures, etc.) accessible within the given zone. There are exceptions to the zone grouping philosophy; for example, functional leak testing of hydraulic systems must be performed on the entire system during a C-check because of the complexity of instrumentation and test methods.

Some mandated inspections or maintenance actions are keyed to cycles or flight hours rather than calendar time. For instance, fatigue damage of fuselage structures develops as a function of the number of pressurization cycles whereas fatigue damage of wing and empennage structures develops as a function of gust and maneuver loads, which depend on flight hours. In cases where regulations or modifications are tied to cycles or hours, a separate tracking is established that can override scheduled maintenance intervals to accommodate the regulations.

Individuals who perform maintenance and alterations of aircraft are required to use methods, techniques, and practices acceptable to the FAA (FAR Part 43, §43.13). The

FAA prefers the methods set forth in the manufacturer's maintenance manual and the instructions for continued airworthiness. **Alternatively, air carriers can use different methods as long as they have been approved as part of their required maintenance manual. Therefore, air carriers have the authority to introduce new maintenance and inspection techniques and to implement those changes through their manual.** Because HM can be considered to be an alternative method to perform a scheduled inspection or maintenance check, HM systems could be implemented through approved changes in the carrier's maintenance manual.

3.3 PROGRAM REVIEW AND RELIABILITY TRACKING

Commercial operators are required by FAR Part 121, §121.373 to establish and maintain *continuous monitoring and surveillance* programs to ensure that inspection and maintenance programs are, and continue to be, effective. The operators are responsible for work performed at their own facilities as well as for work performed according to their inspection and maintenance program by others. The requirement to establish and maintain a continuous monitoring and surveillance program effectively establishes a quality control or internal audit function to assure that everyone involved in the inspection and maintenance program is in compliance with the operator's manuals and applicable regulations.

Reliability-based maintenance programs (per AC 120-17A) allow inspection and maintenance intervals and methods to be set (and modified) based on demonstrated reliability. Typically, operators track the mean time to unit failure[e] to identify reliability trends. These data are used to upgrade the maintenance program and to identify design flaws that should be addressed by the manufacturer.

Individual operators have different approaches to program review and to the collection and use of reliability data. Generally, these programs are designed to track the frequency of unscheduled parts replacement or need for unscheduled maintenance, the frequency of adjustment and calibration of equipment, and problems that affect operational capability or reliability. Many carriers "zero base" their maintenance program periodically to clear out added maintenance activity that has shown little improvement to aircraft availability or reliability.

Health monitoring systems could be an integral part of an airline's monitoring and surveillance and reliability tracking programs. HM systems promise to automate the data collection and analysis functions associated with maintenance program review. These capabilities are also consistent with the goals for FOQA programs.

[e] For aircraft types that are utilized in multiple roles, mean time to unit failure must also consider how the aircraft fleet is utilized (e.g., many short flights vs. fewer, longer flights).

SECTION 4
ASSESSMENT OF REGULATORY IMPACTS

4.0 INTRODUCTION

The objective for implementing HM technology on commercial aircraft is to augment, reduce, or replace difficult or unnecessary inspections required of FAA certificated operators in order to improve flight safety and aircraft availability and reduce operating costs. A key concern of certificated operators is whether the current regulations would allow the approval and introduction of automated HM systems. The purpose of this assessment was to identify the current regulatory guidance that would allow airworthiness certification and maintenance program development to implement HM systems on transport aircraft and to point out where regulations could act as barriers to HM system implementation.

Three key tasks were used to identify regulatory guidance that would serve as barriers to the use of HM systems on commercial aircraft:

- Develop a searchable data archive of regulatory information
- Develop and execute tailored queries of the data archive to identify, extract, and assess the regulatory information related to HM systems
- Use subject-matter experts (SMEs) to analyze the results of the queries and identify guidance that could act as barriers to the certification and use of HM systems on transport category aircraft

The assessment included two principal levels of analysis. First, general guidance for the certification of HM systems was assessed. The description of certification and regulatory requirements in Sections 2 and 3 was based, in part, on this assessment. Second, specific guidance was assessed for the certification of a postulated HM system for the B757 horizontal stabilizer as a case study by which to validate the method.

4.1 REGULATORY DATABASE

The regulatory data archive was developed to enable rapid, thorough, and repeatable identification of regulations and guidance related to aircraft certification, maintenance, inspection, and airworthiness. It also provided an efficient tool for examining related subject matter for analytical purposes and to report findings.

A similar archive has been developed previously to examine the regulatory impact of adding an all-weather flight control system (glass cockpit) and global positioning system/enhanced navigation system on the US Air Force Air Mobility Command's (AMC) C-141 Aircraft [21]. The findings allowed AMC to develop and issue regulatory guidance concurrent with the establishment of the increased C-141 operational capability. A similar archive was developed for the KC-10 aircraft regulatory guidance that allowed the identification of missing/conflicting guidance, redundant material and opportunities for standardizing guidance on operational issues.

The regulatory information contained in the data archive consists of those FARs and ACs that apply to aircraft certification, maintenance, inspection, and airworthiness, both generally and for transport category aircraft. The archive served as the reference source for current regulatory guidance. The regulatory information included in the data archive was identified by screening the indices of all FARs, ACs, and ADs applicable to the B737 and B757 aircraft. Specific data selection criteria included:

- All regulatory information generally applicable to inspection, certification, maintenance, airworthiness, or operations
- All regulatory information applicable to transport category (excluding rotor craft) aircraft and components
- All ADs applicable to the B737 and B757 aircraft

The AD archive for the B737 was developed because it included the supplementary inspection, maintenance, and modification tasks related to the aging of aircraft structures. The AD archive for the B757 was assembled specifically to support the B757 stabilizer case study.

The FARs contained in the data archive were identified and electronically downloaded from the FAA internet site [http://www.faa.gov]. The ACs were identified from the Advisory Circular Checklist, Appendix 3, Numerical List of Advisory Circulars, as presented on the FAA internet site [http://www.faa.gov/ac-chklst/actoc.htm]. The ACs were obtained in electronic form from various internet and public information sources. The B737 and B757 ADs were obtained from a CD Document Library [14].

The regulatory data archive was created as a Microsoft Access 97 database. The records are structured such that the standard features of Access 97 can be used to enter and extract data, review record content, and generate reports. The data archive contains the following FARs, ACs, and ADs:

FEDERAL AVIATION REGULATIONSs

Part 11	General Rule Making Procedures
Part 21	Certification Procedures for Products and Parts
Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
Part 25	Airworthiness Standards: Transport Category Airplanes
Part 39	Airworthiness Directives
Part 43	Maintenance, Preventive Maintenance, Rebuilding, and Alteration
Part 119	Certification: Air Carriers and Commercial Operators
Part 121	Operating Requirements: Domestic, Flag, and Supplemental Operations

Part 125	Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6000 Pounds or More and Rules Governing Persons on Board Such Aircraft
Part 145	Repair Stations
Part 183	Representatives of the Administrator

ADVISORY CIRCULARS

AC 20-65	U.S. Airworthiness Certificates and Authorizations for Operation of Domestic and Foreign Aircraft
AC 20-77	Use of Manufacturers Maintenance Manuals
AC 20-107A	Composite Aircraft Structure
AC 25-7	Flight Test Guide for Certification of Transport Category Airplanes
AC 25-19	Certification Maintenance Requirements
AC 120-16C	Continuous Airworthiness Maintenance Programs
AC 120-17A	Maintenance Control by Reliability Methods
AC 121-1A	Standard Operations Specifications: Aircraft Maintenance Handbook
AC 121-22A	Maintenance Review Board Procedures

AIRWORTHINESS DIRECTIVES

Boeing 737 ADs	All
Boeing 757 ADs	All

Each record contains, if applicable, the fields and information shown in Table 4-1, Database Fields. Each record contained all the available information to identify the data source and provide the exact text of a specific paragraph or section (e.g., FAR subsection). Each record also contains fields for categorizing regulatory guidance for the purpose of sorting information according to established criteria. These category fields were chosen because they identified regulatory subject matter that could be related to HM systems requirements, capabilities, use, and certification. Some category fields – those indicated as “Entry – TBD” in the “Entry Information” column - were established in the database structure but not used for this study. These fields will have use in future studies and analyses such as selection of target systems and components for HM utilization, cost/benefit trade studies, identification of operational considerations for HM systems, analysis of requirements for data collection and recording, and requirements for training of maintenance personnel.

Table 4-1 – Database Fields

Field Name	Field Description	Entry Information
ID	Record Identification Number	Automatically assigned
Document Type	Self Explanatory	FAR, AC or AD
Document Number	Self Explanatory	As applicable
Document Title	Self Explanatory	As applicable
Document Date	Self Explanatory	As applicable
Document Sub Part	Self Explanatory	As applicable – If used
Sub Part Title	Self Explanatory	As applicable – If used
Paragraph Number	Self Explanatory	As applicable – If used
Paragraph Title	Self Explanatory	As applicable – If used
Paragraph Text	Self Explanatory	Entire text of paragraph (limited formatting)
General	Record has general Application	Entry – TBD
Inspection	Record relates to Inspection	N – Not impacted by HM I – Impacted by HM P – Prohibits use/certification of HM
MRB (Maintenance Review Board)	Record relates to MRB	Entry – TBD
Certification	Record relates to Certification	N – Not impacted by HM I – Impacted by HM P – Prohibits use/certification of HM
Airworthiness	Record relates to Airworthiness	N – Not impacted by HM I – Impacted by HM P – Prohibits use/certification of HM
Alterations	Record relates to aircraft alterations	Entry – TBD
Maintenance	Record relates to maintenance	N – Not impacted by HM I – Impacted by HM P – Prohibits use/certification of HM
CMR (Certification Maintenance Requirements)	Record related to CMR	Entry – TBD
Aircraft	Record applies to specific aircraft or type of aircraft	B737, B757, Others – TBD
Engine	Record applies to aircraft engines	Entry – TBD

4.2 ASSESSMENT OF GENERAL REGULATORY GUIDANCE

Broad data queries were used to identify and assess general regulatory requirements applicable to HM systems. The roots (shown in bold) of the words “**certif**ication”, “**maint**enance”, “**inspect**ion”, and “**airworthiness**” are common terms used in the regulatory guidance contained in the FARs, ACs, and ADs that can be generally related to the capabilities of and requirements for HM systems. Tailored queries were used to search the regulatory document archive for these roots to identify the regulatory requirements that apply to aircraft or components, with an emphasis on structures and structural components.

There were two phases to the SME analysis. In the first phase, individual SMEs examined the results of the tailored queries and classified each record hit as either [I]mpacted, [N]ot impacted, or [P]rohibited.

- "Impacted" means that the guidance contained in that record could act as a barrier to the use or certification of the postulated HM system.
- "Not impacted" means that the guidance in that record is not expected to act as a barrier to use or certification of HM systems (i.e., the guidance is not applicable or already permits use or certification of HM systems).
- "Prohibited" means that the regulatory guidance, as written prohibits the use or certification of the postulated HM system.

The SMEs entered the results of their analysis in the appropriate fields of the database by coding each record hit with an "I", "N", or "P".

In the second phase, the database was queried to identify all records that were classified as "I" or "P". A similar query was used to identify records with "I" or "P" classifications in three, two and one field(s). The SMEs then collectively collated, analyzed, compared, and documented the results of these queries. The intent of this effort was to enable the identification, validation, and characterization of cross-relationship, pattern, association, and impact dependencies.

The results of this analysis are presented in Section 5 of this report.

4.3 CASE STUDY: POSTULATED HEALTH MONITORING SYSTEM

The purpose of this section is to validate the analysis approach described in the previous sections by identifying a postulated health monitoring capability for a selected component. For this analysis, it was not necessary to develop a complete HM system design. It was only necessary to identify the sensing and monitoring approach and the primary features of the postulated capability.

The case study that was chosen for this analysis is the realization of structural HM capability on the 757 horizontal stabilizer and elevators. The 757 was selected because:

- The 757 is a current-generation jet transport, which has sensing, electronic, and data handling capabilities (e.g., ARINC 717 characteristic) that are more advanced than earlier aircraft.
- The service times for high-time 757 aircraft (in terms of calendar time as well as flight hours and cycles) are reaching levels where the structures will need to be considered in structural aging assessments.

- Technical data related to the 757 were available from NASA, which operates a 757-200 as a test aircraft.

The horizontal stabilizer and elevators were chosen because they have a variety of structures (aluminum skin-stringer and composite honeycomb panels); a mix of mechanical, hydraulic, and electronic components; and interfaces to critical aircraft control systems.

The analysis assumes that the structural HM capability is part of an integrated HM system, which would have access to FOQA-type flight-recorder data to provide information to the HM modules. Considerations for the implementation and certification of integrated HM systems were discussed in previous sections of this report, but are beyond the scope of this case study assessment.

The assumed structural HM capability was developed based on sensor and system capabilities that will available in the near- to mid-term. The overall certification process identified in Chapter 3 was used to identify applicable regulation and guidance documents for search. Database queries were developed based on the functional and operational requirements of the individual components. The results of this case study are presented in this section.

4.3.1 757 Horizontal Stabilizer and Elevator Descriptions

The 757 horizontal stabilizer and elevators provide pitch control for the aircraft. Pitch control components can be found in the flight deck (e.g., control columns), below the flight deck floor (e.g., torque tubes, column and “feel” controls), and in the tail (e.g., elevators, power control units [PCUs], horizontal stabilizer, stabilizer jackscrew, stabilizer position modules, and trim control modules).

The stabilizer structural arrangement is shown in Figure 4-1. The horizontal stabilizer includes (from forward to aft) the leading edges, stabilizer tips, a forward torque box, the aft (main) torque box, trailing edge panels, and elevators. Structural descriptions of the horizontal stabilizer components follow.

- (Removable) leading edge – aluminum alloy sheet mounted to the auxiliary spar of the forward torque box
- Stabilizer tip – composite honeycomb (aramid/epoxy[f] with glass/epoxy outer ply) mounted to the stabilizer torque box tip rib
- Forward torque box – built up from aluminum alloy components, including upper and lower skin sheets, an auxiliary spar, and ribs mounted to the front spar of the main torque box

[f] Later aircraft (and spares) have glass/epoxy tip construction

- Main torque box - built up from aluminum alloy components and includes forward and rear spars, stiffened skins (sheet-stringer construction), and ribs. The left and right torque boxes are connected at an aluminum root fitting.
- Fixed trailing edge – stiffened aluminum alloy ribs with composite honeycomb skins (hybrid constructions[g] of carbon/epoxy and aramid/epoxy) mounted to the rear spar of the main torque box
- Elevators – composite honeycomb construction (carbon/epoxy) upper and lower panels, front spar and ribs mounted to the rear spar of the main torque through eight hinges

The focus of this analysis will be on the most significant structures—the main torque box (with ballscrew and actuators) and elevators (with hinges and actuators).

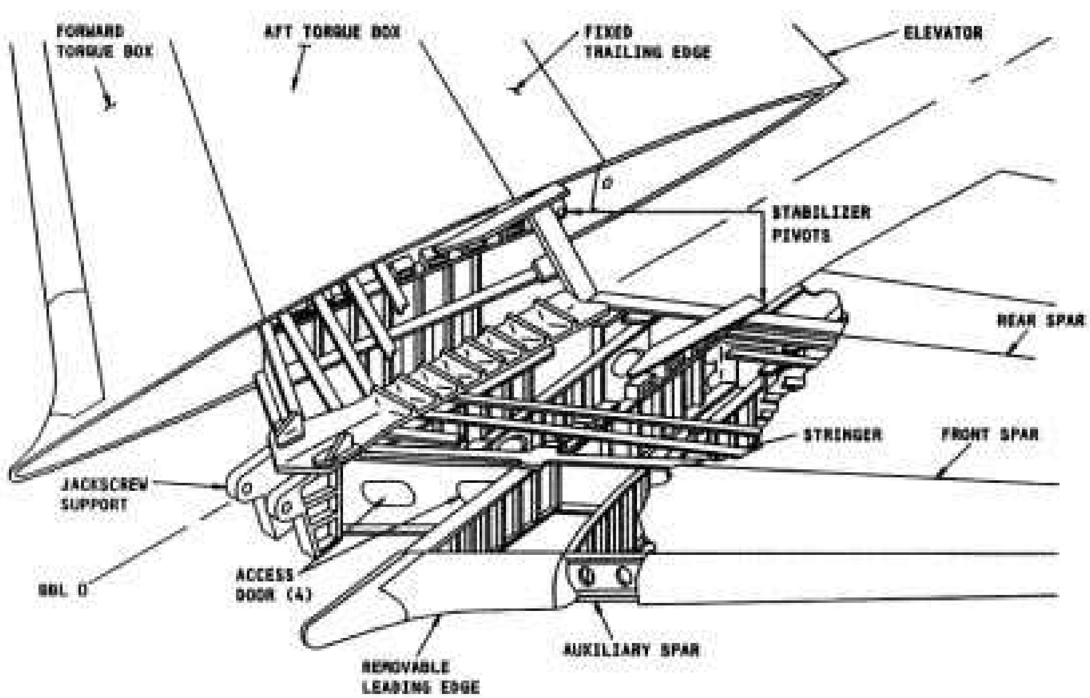

FIGURE 4-1. Structural arrangement of the B757 horizontal stabilizer. Source: Boeing 757 Maintenance Training Manual. ©1992 The Boeing Company. All Rights reserved. Reprinted with permission of FlightSafety Boeing Training International L.L.C., under license from the Boeing Company.

4.3.1.1 Main Torque Box

The horizontal stabilizer provides long-term control of aircraft pitch. A ballscrew actuator assembly (Figure 4-2), driven by two hydraulic motors, attaches at the center of the front spar and mounts through a gimbal to the structure at the bottom of the stabilizer

[g] Later aircraft (and spares) have glass/epoxy trailing edge panel construction

compartment of the aft fuselage. Two stabilizer trim control modules (SCTMs) control the hydraulic power to the ballscrew actuator. Two pivot fittings attached near the center of the rear spar of the main torque box establish the stabilizer pivot point.

The main torque box is the primary structural element of the horizontal stabilizer. It carries moderate structural loads including the aerodynamic loads experienced during flight and supports the weight of, and induced torsion from, the elevators. The torque box is a conventional aluminum skin-stringer construction. The outer skin sheets are stiffened with stringers riveted to the skins in a spanwise orientation (i.e., from inboard to outboard). The stiffened skins are fastened to the front and rear spars. Rib structures provide torsional stability.

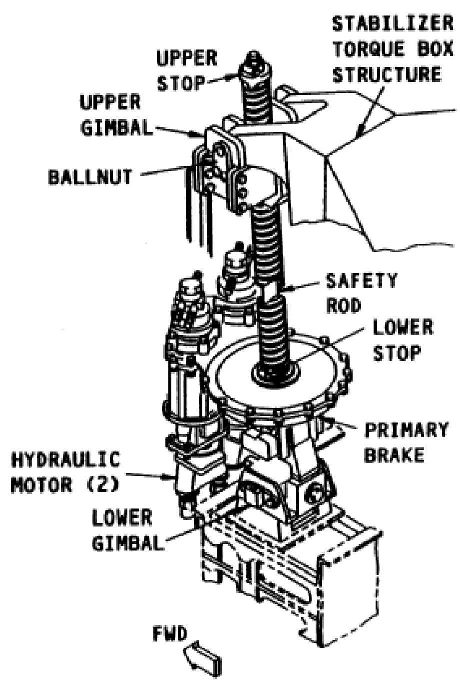

FIGURE 4-2. Horizontal stabilizer ballscrew actuator assembly. Source: Boeing 757 Maintenance Training Manual. ©1987 The Boeing Company. All Rights reserved. Reprinted with permission of FlightSafety Boeing Training International L.L.C., under license from the Boeing Company.

4.3.1.2 Elevators

The elevators provide short-term corrections of aircraft pitch (long-term pitch control is transferred from the elevators to the stabilizer). The elevators are attached to the rear spar of the main torque box of the horizontal stabilizer at 8 hinge fittings. Elevator actuation is accomplished by 6 (3 on each side) parallel power control units (PCUs; see Figure 4-3).

The PCUs are powered by three separate hydraulic systems (left, right, and center), which each drive two PCUs (1 on each side). The PCUs are attached to the rear spar of the stabilizer rear spar by a block and an idler link. Reaction links transmit the hinge loads from the elevator to the rear spar of the stabilizer. Control rods connect the PCUs to the aft mechanism components—left and right aft quadrants, autopilot servos, a feel and centering unit, and a neutral shift and override component. The aft mechanism components transmit flight deck inputs to the elevator actuation systems, control elevator feel and centering, and limit relative motion of the two elevators for structural protection.

The principal structural element of the elevators consists of skin panels, ribs, and front spar honeycomb sandwich constructions fabricated from carbon/epoxy composite pre-impregnated fabric facesheets cocured with aramid honeycomb core. The skin panels are mechanically fastened to the front spar and a bonded trailing edge. Mechanically fastened ribs provide torsional stability. Elevator hinge and actuator fittings are constructed from aluminum and mechanically fastened to the front spar, with glass/epoxy isolation plies and surface sealant to prevent galvanic corrosion.

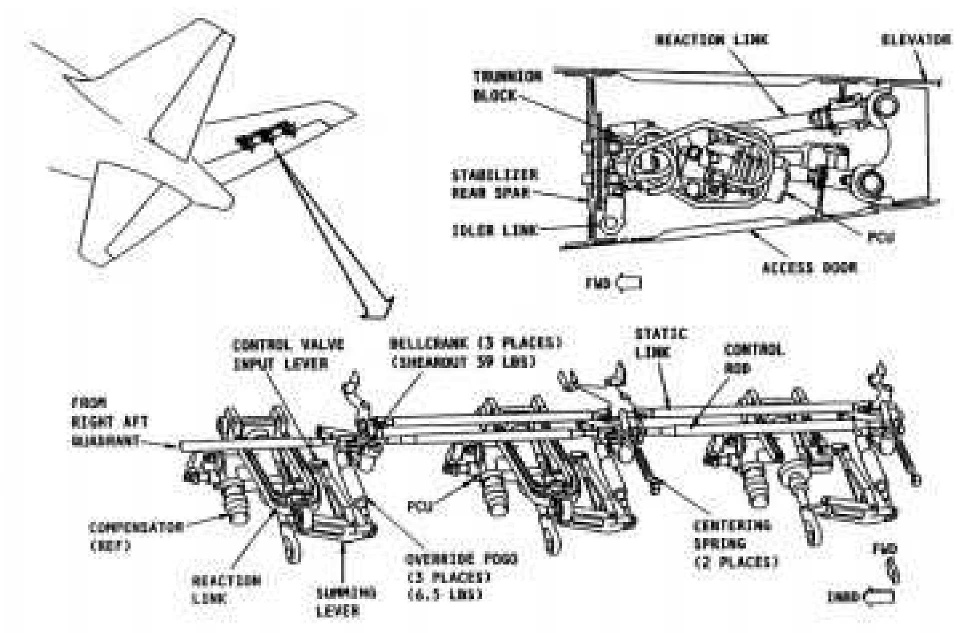

FIGURE 4-3. Elevator actuation systems. Source: Boeing 757 Maintenance Training Manual. ©1992 The Boeing Company. All Rights reserved. Reprinted with permission of FlightSafety Boeing Training International L.L.C., under license from the Boeing Company.

4.3.2 Structural Considerations

Large commercial transport aircraft (FAR Part 25) and most large military aircraft are designed to be fail-safe, relying on multiple, redundant load paths or crack arrest features to preclude catastrophic failures in the event of fatigue, corrosion, manufacturing defects, or accidental damage.[h] In some cases, fail-safe requirements are impractical for specific components. In these cases FAR 25 requires that safe-life analyses be performed. Safe-life structure must be shown by analysis, supported by test evidence, to be able to withstand the operational cycles without detectable cracks.

Only three principal degradation modes—accidental damage, environmental deterioration, and fatigue damage—are considered in developing structural inspection and maintenance tasks. However, these three modes (and combinations thereof) are inclusive of virtually all of the mechanisms observed for aircraft structure. This section applies these modes to the stabilizer and elevator structures so that strategies for structural HM can be formulated.

4.3.2.1 Main Torque Box

Accidental damage to the stabilizer could arise from a number of rare events. These events could include:

- Unexpected flight or maneuver loads
- Failure of stabilizer or elevator control components
- Bird strikes
- Damage from in-flight failure of other components
- Ramp and maintenance damage [15]

Environmental damage to the stabilizer main box would be in the form of corrosion. Susceptible areas include lower skin panel areas where corrosion protection or drainage provisions fail or exposed areas with mechanically fastened joints (e.g., attachment points for elevator actuation or hinge fittings) or components susceptible to fretting or wear (e.g., ballscrew assembly and attachments). The maintenance program includes a mandatory corrosion protection and control program, which includes inspection and preventive maintenance tasks.

Fatigue damage of the horizontal stabilizer would most likely be limited to low-cycle fatigue, unless elevator damage or repair introduced unexpected flutter modes. The stabilizer structure could develop low cycle fatigue, either from the growth of a single crack from discrete source damage or from the development of widespread fatigue damage (WFD). Empennage structure that is susceptible to WFD includes chordwise splices, rib-to-stiffener attachments, skin runouts of large doublers, and stringer runouts at end ribs [16].

4.3.2.2 Elevators

---

[h] Durability and damage tolerance requirements are specified in §25.571.

Accidental damage to the composite structure of the elevators would arise from similar scenarios as described above for the stabilizers. In addition, one of the primary concerns with damage tolerance in composites, especially thin-skinned structures, is the detection of damage from low-velocity, discrete source impacts, either during flight or due to ramp or maintenance damage. Composite structures are designed to be damage tolerant in the case of barely visible impact damage (BVID), that is, damage at the threshold of detectability [17]. These criteria require that components maintain their structural integrity following any impact event that does not cause damage that is detectable using visual methods and that the damage not grow under service environmental conditions. For compliance with §25.571(b), it must be considered that BVID could occur early in the life of the aircraft and would go undetected for the life of the structure.

Environmental damage to the elevators could include moisture incursion into honeycomb core, galvanic corrosion of adjacent metallic structure, or lightning strike damage.

To date, fatigue damage of composite structures is rare in commercial aircraft. This is largely because damage tolerant criteria and environmental knock-down factors for composites keep allowable operating strains for composites well below threshold levels required for the growth of damage. The exception is the growth of interply delaminations resulting from over-tightened fasteners. Also, metal hinge and actuator fitting structures could be susceptible to low-cycle fatigue. Finally, elevator damage or poorly-devised structural repairs could cause the development of flutter modes that lead to the development of high-cycle fatigue. If undetected, high-cycle fatigue could lead to rapid growth of existing manufacturing or service damage.

4.3.3 Postulated HM System Capability (757 Horizontal Stabilizer)

This section develops a postulated structural HM capability for the 757 horizontal stabilizer based on the structural degradation considerations discussed in the previous section, the system capabilities that were described in Section 2, and the assumed availability of state-of-the-art sensors.

The postulated health monitoring system assumes the availability of system elements, including sensor systems; sensor data conditioning units; on-board diagnostic systems and algorithms; interfaces with on-board power, data, and communications systems, and a ground-based diagnostic system.

Multiple types of structural sensors will be needed to detect the indications of degradation described in the previous section. For the most part, the postulated structural HM system focuses on fiber optic and fiber ultrasonic sensors. These sensors are attractive because of their small size, the ability to multiplex sensor elements, and because they are not likely to interfere with adjacent flight systems and are not susceptible to electromagnetic interference effects.

The strategy for corrosion monitoring is to focus on early detection of incipient corrosion or, preferably, detection of when the corrosion prevention scheme has failed. Candidate sensors have been identified to (1) identify when corrosion protection has broken down to a point where moisture can intrude, (2) identify the presence of corrosion by detecting corrosion products, and (3) identifying the conditions for corrosion by monitoring pH. For example, preliminary assessments by Luna Innovations have shown that long-period-grating (LPG) optical fiber chemical sensors, with tailored coatings, could effectively discern the presence of significant moisture, the metal ions indicative of corrosion products, or the pH of a potential electrolyte solution [18, 19]. LPG sensors can be multiplexed, that is multiple sensing elements can be deposited on a single optical fiber. Multiplexing sensor elements could be an effective way to provide dense sensor placement with minimum intrusiveness.

To effectively monitor materials degradation from fatigue, the sensor system must be capable of detecting crack initiation or the propagation of very small cracks. Candidate sensors have been identified to (1) identify when a fatigue crack has initiated or when an existing crack grows, and (2) monitor crack growth. The sensing strategy is to detect initiation and crack-growth events using acoustic emission sensors and to monitor subsequent crack growth by measuring near-field strains and comparing them to far-field strains to infer, with the aid of structural analysis models, crack growth characteristics. Fiber-optic strain and acoustic emission sensors (AE) based on extrinsic Fabry-Perot interferometry (EFPI) are being evaluated for these applications [22].

Sensors to detect discrete-source events include the EFPI strain and AE sensors described above. In addition, out-of-plane AE sensors, also based on EFPI technology, but with a cantilever sensing element, would be needed to detect out-of-plane acoustic waves resulting from impact events. Finally, grids of embedded fiber ultrasonic sensors have been shown to be sensitive to impact damage in composites. These types of sensors, in combination with acoustic emission sensors, would be required to detect and characterize low-velocity impact damage in thin sheet composites.

To effectively monitor damage events, corrosion and environmental deterioration, and fatigue, an array of multiple sensor types will be required. For example:

- A chordwise splice in the lower stabilizer skin could have moisture, corrosion product, and pH sensor elements distributed adjacent to the splice joint to monitor corrosion protection; strain sensors along rows of fasteners and in-plane AE sensors to detect fatigue cracking events and monitoring crack growth; and strain and out-of-plane AE sensors to detect discrete damage events.
- An upper elevator skin could have out-of-plane AE sensors to detect discrete damage events or lightning strikes; embedded fiber ultrasonic sensors to locate and characterize impact damage; and moisture sensors to detect moisture intrusion into honeycomb core.

Signals from these multiple sensor inputs would pass through multiplexing and signal conditioning systems and sent through existing data buses to the diagnostic processor.

Strategies for sensor interrogation, data management, and diagnostics/prognostics will depend on the attribute being sensed, the kinetics of the degradation processes, and the phase of flight that is under consideration. For example, measurements for corrosion monitoring would be most meaningful between flights (under ambient conditions) and would only have to be taken on the order of once per day. For the purpose of this case study, we have assumed that measurements would be analyzed with off-board diagnostics and prognostics at approximately the same intervals as A-checks (approximately monthly) to flag areas for inspection and maintenance actions. Fatigue and discrete damage monitoring for the stabilizer and elevator would require a focus on flight load conditions, requiring frequent interrogation during transitional phases of flight, limited on-board diagnostics for preliminary evaluation of measured conditions, and off-board diagnostics and prognostics to characterize structural condition.

4.3.4 Assessment of Regulatory Guidance: Case Study

The applicability of airworthiness and operating regulations are described in Section 2 of this report. The following FARs apply to the certification and operations of the 757. For the purpose of this case study, it was assumed that the airworthiness requirements of Part 25 would apply. The 757 is also available in freighter variations (i.e., 757-200F), which would be subject to the (similar) airworthiness requirements of Part 23.

Part 21	Certification Procedures for Products and Parts
Part 25	Airworthiness Standards: Transport Category Airplanes
Part 39	Airworthiness Directives
Part 43	Maintenance, Preventive Maintenance, Rebuilding, and Alteration
Part 119	Certification: Air Carriers and Commercial Operators
Part 121	Certification and Operations: Domestic, Flag, and Supplemental Operations
Part 145	Repair Stations
Part 183	Representatives of the Administrator

In similar fashion to that employed for the assessment of general regulatory guidance, tailored queries were developed to interrogate the regulatory archive. A number of related terms (shown in bold) were searched, including **actuator**, **controls**, **corrosion**, **elevator**, **fatigue**, **structur***, and **stabilizer**. The queries resulted in a number of "hits," which were assessed by a SME in materials and structures. The results are described in Section 5.

SECTION 5
ASSESSMENT RESULTS

5.0 INTRODUCTION

This section includes the results of the assessment of regulatory impacts on the implementation of HM systems for commercial transport aircraft. First, the results of the regulatory assessment are discussed for general HM systems applications and for the specific case study example. Second, the factors to be considered in the certification and approval of HM systems are identified.

5.1 REGULATORY ASSESSMENT RESULTS

This section summarizes the results of the systematic assessment of regulations to identify barriers to the implementation of HM systems. The regulatory data archive contained almost 2600 records. The search of general terms resulted in approximately 800 “hits” of records that were subsequently assessed for their impact on the implementation of HM systems. Of the records reviewed, 131 were identified as barriers to the implementation of HM systems. Of the 131 records, 44 were FAR paragraphs, 32 were AC sections, and 55 were 737 or 757 ADs. The archive data results are tabulated in Appendix B.

<u>FARS</u>

Table B-1 of Appendix B summarizes the impacted records for FAR sections. No regulations were identified that explicitly prohibited the general utilization of HM systems or the implementation of the postulated HM system for the 757 stabilizer and elevators. For the most part, regulatory guidance is general in nature and does not restrict the application of advanced technology for compliance. In general, the impacted records were one of three types.

The first type calls for the use of nondestructive inspection methods or tools where a proven HM system could take the place of the inspection as well as the assessment tasks.

For example, §25.611 (Accessibility Provisions), requires that:

> “Means must be provided to allow inspection (including inspection of principal structural elements and control systems), replacement of parts normally requiring replacement, adjustment, and lubrication as necessary for continued airworthiness.”

And allows that:

> “Nondestructive inspection aids may be used to inspect structural elements where it is impracticable to provide means for direct visual inspection if it is shown that the inspection is effective and the inspection procedures are specified in the maintenance manual required by Sec. 25.1529.”

Expanding the section to recognize HM capabilities would allow "certificated health-monitoring systems" to be used "to assess the condition of the structural elements." In some cases (e.g., §H25.3, [Maintenance Manual] Contents), specific inspection methods such as radiographic or ultrasonic methods are called out as examples of "special inspection techniques. In these cases reference to HM system instruction should be made.

The second type of impacted record is when instructions are given to establish inspection intervals based on an assessment of detectability and consequence of failure.

For example, FAR 23, §G23.4 (Airworthiness Limitations Section) requires that the airworthiness limitations section:

> "…must set forth each mandatory replacement time, structural inspection interval, and related structural inspection procedure required for type certification."

An attractive target for structural HM systems will be to replace mandatory structural inspections that are based primarily on service intervals, irrespective of actual structural condition. HM systems will allow continuous monitoring and assessment of structural condition, making invasive periodic inspection unnecessary. The regulations should be updated to allow HM systems as a means for complying with mandatory structural inspections.

FAR Part 25, §25.603 requires that:

> "The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must--
>
> (a) Be established on the basis of experience or tests;
>
> (b) Conform to approved specifications (such as industry or military specifications, or Technical Standard Orders) that ensure their having the strength and other properties assumed in the design data; and
>
> (c) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service."

Hence, the effects of placing sensors on, or embedding sensors in, structural materials must be accounted for. For example, the surface preparation and bonding processes used to attach sensors need to be evaluated to show that materials performance is not affected. Of particular concern would be the restoration of corrosion protective finishes once sensors are applied. Another example is embedding a grid of sensor fibers (as described above for detection of BVID using fiber ultrasonic techniques) within composite structures. This could require the applicant to show that the material properties and the long-term durability of the finished components are equivalent to the original certificated configuration.[i] Depending on the coverage of the sensor grid and the process used to

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[i] Recognizing the potential barrier to implementation of embedded sensors that could change the qualified materials, work is underway to use the existing reinforcement fibers as the ultrasonic waveguide in the fiber ultrasonic technique.

embed the sensor fibers, the composite material could be required to go through an extensive qualification program.

The airworthiness requirements of §25.571 require that structural inspections and CMRs be developed to monitor structural durability based on the ability to detect the development of structural damage that could progress to primary component failure or degrade residual strength to a point where fail-safety is compromised. Sensor-based HM systems would be likely to improve the ability to detect the precursors to structural failure. Therefore, once the accuracy, effectiveness, and reliability of HM approaches have been shown to improve the ability to detect structural degradation, provisions will need to be made in FAR 25 allowing HM systems to be used to fulfill mandatory inspection and maintenance requirement (i.e., obtain maintenance credits) so that structural inspection programs, corrosion prevention and control programs, and CMRs can be modified to eliminate unnecessary inspections or increase inspection intervals.

The third type of impacted record included operational considerations such as personnel training, authority for approving the analysis results and releasing the aircraft for passenger service, and inspection and maintenance process recording and approvals. As described earlier in this report, HM systems could facilitate the implementation of FOQA or FOQA-like programs by automating the analysis and record-keeping functions. However, current regulations could require revision to ensure that HM system recording procedures are compatible with required documentation practices. Also, operational protocols must be developed to respond to indications of component degradation, reset the HM system after maintenance or modification, and authorize return to service. Although it is not clear that changes to regulations will be needed, these sections should be considered in design processes as the operational issues for HM systems are resolved.

Advisory Circulars

Table B-2 of Appendix B summarizes the impacted records for AC sections. In general, these ACs provide guidance and regulatory interpretations for compliance with FAR requirements. The indicated sections should be examined and updated to include guidance for utilizing the capabilities of HM systems in the development of maintenance and inspection tasks and intervals.

For example, Chapter 4 of AC 120-16C, "Continuous Airworthiness Maintenance Program," provides descriptions of the elements of a continuous airworthiness program. The subsections that aircraft inspection and scheduled maintenance refer to "prescribed intervals" for inspection and scheduled maintenance. The most-effective procedures for application of HM systems would consider "continuous inspection and assessment" and "condition-based" maintenance, scheduled based on indications of precursors to failure.

Another example is Chapter 2 of AC 120-17A, "Maintenance Control by Reliability Methods," which specifies "typical" reliability control systems, which would include a data-collection system, and data-analysis system, corrective-action system, statistical performance standards system, and data display and report system. An HM system would combine and automate much of the functionality of reliability control systems.

Airworthiness Directives

An argument could be made that ADs, especially those pertaining to structural inspections and modifications (e.g., the ADs shown in Table 2-3), are barriers to implementation because they prescribe specific methods of compliance. Most ADs allow for "alternative means of compliance," as long as they have been approved by the FAA. However, because of the conservatism of the airline industry and the potential liability in safety-related actions, air carriers would generally be reluctant to seek alternative methods to those suggested by the manufacturer. Therefore, once HM technologies have been proven, ADs should be revised to explicitly allow "certificated health-monitoring systems" as a means for compliance.

5.2 CERTIFICATION OF HEALTH MONITORING SYSTEMS

To be certified by the FAA and approved for use on commercial transports, the HM systems would be subjected to the general type certification process described in Section 2. However, there are unique considerations for HM systems that must also be addressed during the design and certification processes. This section identifies those unique considerations and suggests means for showing compliance with the applicable regulations.

Unless developed by the holders of the initial TC, the design and manufacture of health-monitoring systems would be approved with an STC. There are two primary aspects to consider in the implementation of HM systems for commercial aviation—(1) airworthiness certification of the on-board system and (2) qualification and approval of HM system capabilities as part of the airline maintenance program.

5.2.1 Airworthiness Certification: System Design and Analysis

The airworthiness certification requirements that apply to on-board HM systems for large commercial transports (Part 25) are described in §25.1309 "Equipment, Systems, and Installations." This section requires that:

> "The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that:
>
> > (1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and

> (2) The occurrence of any other failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable."

This section also requires that compliance be shown primarily by analysis that considers:

> (1) Possible modes of failure, including malfunctions and damage from external sources
> (2) The probability of multiple failures and undetected failures
> (3) The resulting effects of failures on the airplane and occupants, considering the stage of flight and operating conditions
> (4) The crew warning cues, corrective action required, and the capability to detect faults

Although the guidelines emphasize that compliance would be shown principally by analysis, this analysis must be supported by ground, flight, or simulator tests. Examples of special requirements to show compliance with the airworthiness regulations could include the following:

- The installation would have no adverse effect on the function or performance of existing aircraft systems
- Sensors and on-board systems would be reliable, durable, and self-diagnostic
- Misleading information or false alerts passed to the flight crew would be rare
- Power requirements are compatible with power management considerations under failure conditions (e.g., engine-out requirements)
- All HM system software would comply with requirements for the software aspects of certification set forth in RTCA/DO-178B
- The application or embedding of sensors would not affect the structural integrity or function of existing components

FAA-suggested guidelines for compliance with §25.1309 are explained in FAA Advisory Circular AC 25.1309-1A. Fundamentally, installations must adhere to the fail-safe design concept, which identifies the effects of failures (including combined failure events) on the safety of the design. The tenets of a fail-safe aircraft design are that:

- The failure (regardless of probability) of any single element, component, or connection in any system or subsystem would not prevent continued safe flight or landing or significantly reduce the capability of the aircraft or flight crew to cope with the resulting failure conditions
- Unless the joint probability of occurrence with an initial failure can be shown to be extremely improbable, subsequent failures during the same flight (either detected or latent) would not prevent continued safe flight or landing or significantly reduce the capability of the aircraft or flight crew to cope with the resulting failure conditions

Several qualitative (e.g., design appraisal, installation appraisal, failure modes and effects analysis, and fault tree analysis) and quantitative (e.g., probability analysis) techniques to assess potential failure conditions are considered to be acceptable for showing compliance with airworthiness criteria. As would be expected, the applicable techniques will depend on the nature of the system components, design approach, and similarity with proven systems. In general, these techniques consist of a structured and detailed assessment of the overall system as well as individual components or subassemblies.

An important consideration in the analysis of HM systems for certification is the assessment of software design. However, the compliance methods described for systems hardware are not applicable to software because it is not feasible to identify the numbers and kinds of software errors that could remain in a system. In response to this difficulty, the aeronautical industry, through a special committee of RTCA (Requirements and Technical Concepts for Aviation), developed guidelines for the production of software for airborne systems and equipment that assure levels of safety in compliance with airworthiness requirements [20]. The guidelines establish industry best practices for safety-critical software and impose the technical discipline to ensure that these practices are followed and documented.

5.2.2 Operational Evaluations of HM Systems

The conformance of the airborne components of HM systems to TC airworthiness requirements is only one of the regulatory hurdles that must be cleared. In addition, HM systems will require approval of the total system, including the airborne and ground system components, as an inspection and diagnostic tool to fulfill the operator's requirements for continued airworthiness, continuous monitoring and surveillance, supplemental structural inspections, and CMRs.

As described in previous sections, the AEG will evaluate operational suitability and reliability of the system as part of the type certification process. The HM system manufacturer must also demonstrate that the system is suitable to perform automated inspections or checks as part of airline maintenance program. In effect, the HM system would have to be shown to provide equivalence with existing inspection methods and intervals. The introduction of new HM systems could be simplified if the initial applications were to fall within the FOQA program guidelines, that is, limited to collection and post-flight analysis of flight performance measurements.

As discussed in Section 3, the manufacturer would work with the operator to develop maintenance task revisions based on the expected maintenance credits that would be enabled by the automated HM system. These task revisions (described above for the postulated capability) would be incorporated into the air carrier's maintenance manual and submitted to the FAA for approval. The operators will rely on the ability to simplify inspection and maintenance tasks for cost effective implementation of HM systems.

5.2.3 Industry Standards Applicable to Health Management

Several commercial and military standards have been developed to assist in the test and diagnosis of complex systems. Military standards are only weakly supported at this time, in that US DoD policy requires a waiver to use these in favor of industry, consensus standards or performance specifications. In many instances, commercial standards replacements are not available. Most commercial standards related to testing and diagnostics are oriented around digital test and are limited to the chip or board levels. Frequently, the best use of standards in support of aircraft health monitoring and health management lies in providing standard communication protocols and interfaces between elements in the system being monitored, ground-based support systems, and the health monitoring system itself.

The following is a brief compilation of available standards that would impact aircraft health management. The focus of this compilation is on the integration of ARINC and IEEE standards within the framework outlined by RTCA/DO-178B.

5.2.3.1 RTCA Standard

RTCA/D0-178B Software Considerations in Airborne Systems and Equipment Certification—This document provides the aviation community with guidance for determining, in a consistent manner and with an acceptable level of confidence, that the software aspects of airborne systems and equipment comply with airworthiness requirements. The very fact that an on-board health management system resides on the aircraft brings its development under DO-178B. Further, since the health management system will impact maintenance processes, thereby likely having a direct impact on the airworthiness of the aircraft, it would most likely be classified as important to safety (Level C or above, probably Level B)[j] [4].

5.2.3.2 ARINC Standards

ARINC 429 Mark 33 Digital Information Transfer System—Defines the air transport industry's standards for digital data transfer between avionics equipment elements. These standards apply to intra-system communications where system elements or equipment are defined in the various ARINC 700-series Characteristics. It is expected that, on older aircraft, the 429 bus will be the primary communications path for capturing and transferring health management data.

ARINC 620 Data Link Ground System Standard and Interface Specification—Sets forth the desired interface characteristics of the data link service provider to the data link user.

[j] Software level classifications are assigned based on assessments of the contribution of software to potential failures and the consequences of failure. D0-178B [20] defines Level C as software whose failure "would cause or contribute to a failure of system function resulting in a major failure condition for the aircraft" and Level B as software whose failure "would cause or contribute to a failure of system function resulting in a hazardous/severe major failure condition for the aircraft."

Provides data link users the information needed to develop applications and to encourage uniformity and standardization (to the extent possible) among various data link service providers. Contains general and specific guidance concerning the interfaces between the data link service providers and both the airborne and ground user. This is the specification that defines the message formats for the Aircraft Communications Addressing and Reporting System (ACARS). Health management messages can be formatted according to ARINC 620 for communications with ground-based maintenance personnel.

ARINC 624 Design Guidance for Onboard Maintenance System—Avionics maintenance practices continue to improve through On-Board Maintenance System (OMS) recording. The OMS incorporates fault monitoring fault detection, BITE, and aircraft condition monitoring system. On-board health monitoring and health management systems are likely to interact with the existing OMS and, perhaps, be integrated directly with the OMS.

ARINC 629 Multi-Transmitter Data Bus—Defines the aviation industry standards for transfer of digital data between avionics system elements using a multiple access, bi-directional protocol. Developed to provide an efficient data distribution system resulting in a reduction in the amount of aircraft wiring and equipment interfaces. It is expected that, on new aircraft, the 629 bus will be used (probably in conjunction with 429 buses) as the primary communications path for capturing and transferring health management data.

ARINC 763 Network Server System—The network server system specification defines a common file server, data processing, mass storage and interface capabilities to a number of terminals connected via an onboard aircraft Local Area Network (LAN). The Network Server System (NSS) is a central node through which terminals are able to communicate with avionics systems, access data and applications stored in the NSS mass memory storage. Given the data-intensive nature of on-board health management, the NSS will most likely serve as the central repository for storage of health monitoring and management data.

5.2.3.3 IEEE Standards

IEEE Std 1232 Artificial Intelligence Exchange and Service Tie to All Test Environments—The AI-ESTATE standard is an information exchange standard for test and diagnosis. The original standards, the 1232 series, developed a means of exchange of information between diagnostic reasoners. By defining standard diagnostic model formats and standard interfaces to diagnostic systems, AI-ESTATE provides a means to incorporate diagnostic components to on-board and off-board health management systems. These reasoners would form the core analysis capability within the health management system.

IEEE Std 1545 Parametric Data Logging—The Parametric Test Data Format is defined as a log file and transport format for captured, parametric test information. The parameters recorded and reported covered a wide frequency range, and the PTDF files are intended to be transferred to a common data repository for analysis and tracking. Much of the data captured during health monitoring will be parametric data. By providing a standard format for this data, speed and accuracy of data transfer and analysis can be improved.

IEEE Std 1149.1 The Test Access Port and Boundary Scan Architecture—Defines a specific form of scan architecture for integrated circuits and Application Specific ICs (ASICs). The standard is typified by scan cells on inputs and outputs of ICs or multi-chip models (MCM) to provide observability and controllability without direct probing of the circuit. Many avionic systems incorporate ASICs and other complex digital system that make use of boundary scan. Access to the boundary scan information could provide tremendous benefit in health monitoring.

IEEE Std 1149.4 System Level Mixed Signal Scan Architecture Protocol—Defines a standard for extending digital test and the boundary scan architecture to include mixed signal test. Health monitoring will not be limited to digital or discrete information, thus raising the specter of having to process both digital and analog information.

IEEE Std P1149.5 Standard Module Test and Maintenance (MTM) Protocol—Defines a standard for extending the boundary scan architecture to the system level with a test maintenance bus and protocols for triggering and reporting tests. This is done by providing a dedicated, backplane test bus operating at a system or subsystem level. It is possible the MTM could be overlayed on a 429 or 629 bus as a logical layer integrating the test information across scan-enabled subsystems.

SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

Modern commercial transports are configured with sophisticated electronic, propulsion, flight control, and structural data systems. In recent years, an increased emphasis has been placed on using these data capabilities, in conjunction with emerging sensor, data processing, and health monitoring and assessment technologies to characterize the condition of aircraft components. The goal is to use real-time flight data to detect system flaws or defects or abnormal operating conditions early enough to allow timely intervention.

The implementation of advanced health monitoring technologies will depend on (1) acceptance by operators, (2) the ability to gain approval in the FAA certification process, and (3) compatibility with continued airworthiness requirements. Once the feasibility and cost-effectiveness of health-monitoring systems has been demonstrated to air carriers, the ability to navigate the FAA's certification process will be a critical factor in their eventual implementation. Fundamentally, it must be shown that the system is passive with respect to existing flight systems, that is, the health monitoring system must not interfere with safe operation. Second, it must be shown that health-monitoring systems can improve continuous airworthiness maintenance programs. The primary consideration for assessing the effect of health-monitoring systems on continued airworthiness programs is to determine their potential influence on scheduled maintenance programs.

The purpose of this study was to assess the connection between current FAA regulations and the incorporation of health-monitoring systems into commercial aircraft and to validate the assessment method on an assumed health monitoring capability. To address the overall objectives ARINC (1) investigated FAA regulatory guidance, (2) investigated airline maintenance practices, (3) systematically identified regulations and practices that would be affected or could act as barriers to the introduction of HM technology, and (4) assessed regulatory and operational tradeoffs that should be considered for implementation.

6.1 ACCEPTANCE BY OPERATORS

Air carriers are required to balance the increasing need for scheduled and unscheduled maintenance with requirements to move aircraft through maintenance and keep them as productive as they need to be for the airline to remain profitable. Current schedules and route structures are such that aircraft could be expected to see as much as 16 hours per day of service. High aircraft utilization results in fewer opportunities to bring an aircraft in for maintenance. Because of the high hours, "maintenance must be very specific and very effective."[10] HM systems could be an important factor in improving the effectiveness of inspection and maintenance programs and enabling focused, condition-based maintenance.

Based on the air carrier's operating requirements and the business climate under which they work, there are several requirements or expectations that must be met before HM systems can be accepted:

- documented and convincing cost/benefit relationships
- potential to improve overall component reliability
- potential to replace difficult or tedious inspections
- ability to collect and analyze recurring problems
- potential to move tasks from line maintenance checks and put them into base maintenance visits

The FAA prefers the methods set forth in the manufacturer's maintenance manual and the instructions for continued airworthiness. Alternatively, air carriers can use different methods as long as they have been approved as part of their required maintenance manual. Therefore, air carriers have the authority to introduce new maintenance and inspection techniques and to implement those changes through their manual. Health monitoring systems could be an integral part of an airline's monitoring and surveillance and reliability tracking programs. HM systems promise to automate the data collection and analysis functions associated with maintenance program review. These capabilities are consistent with the goals for FOQA programs.

6.2 CERTIFICATION

The objective for implementing HM technology on commercial aircraft is to improve flight safety and aircraft availability, and reduce operating costs by augmenting, reducing, or replacing difficult or invasive inspections. A key concern that has been voiced by commercial transport operators is whether the current regulations would allow the approval and introduction of automated HM systems.

Although the volume of regulations and guidance is daunting, the certification process is relatively straightforward. Unless the systems are developed by the holders of the initial type certificate for the targeted aircraft model, the design and manufacture of health-monitoring systems would be approved with a supplemental type certificate. There are two primary aspects to consider in the approval of HM systems for commercial aviation—(1) airworthiness certification of the on-board system and (2) qualification and approval of HM system capabilities as part of the airline maintenance program.

The airworthiness certification requirements that apply to on-board HM systems for large commercial transports (Part 25) are described in §25.1309 "Equipment, Systems, and Installations." The guidelines emphasize that compliance would have to be shown primarily by analysis, supported by ground, flight, or simulator tests. In the case of health-monitoring systems the analyses and tests would have to show that:

- The installation would have no adverse effect on the function or performance of existing aircraft systems
- Sensors and on-board systems would be reliable, durable, and self-diagnostic
- Misleading information or false alerts passed to the flight crew would be rare
- Power requirements are compatible with established power management considerations under failure conditions (e.g., engine-out requirements)
- All HM system software would comply with requirements for the software aspects of certification
- The application or embedding of sensors would not affect the structural integrity or function of existing components

In general, current regulations do not prohibit, but certainly do not encourage, the use of HM technologies.

Production approval would need to be provided to ensure that the manufacturers of certificated components are capable of repeatably producing components that represent the certification basis. Obtaining a production certificate for installation on a particular aircraft type would facilitate approval of subsequent installations on the same aircraft type. Approval of generally applicable HM system components through Technical Standard Orders (TSOs) could facilitate the approval of health-monitoring system components, including sensors and signal-conditioning hardware and on-board processors.

6.3 CONTINUED AIRWORTHINESS

The conformance of the airborne components of HM systems to airworthiness requirements is only one of the regulatory hurdles that must be cleared. In addition, approval of the total HM system, including the airborne and ground system components, must be sought. The total system must be approved as an inspection and diagnostic tool to fulfill the operator's requirements for continued airworthiness, continuous monitoring and surveillance, supplemental structural inspections, and certification maintenance requirements.

The FAA will evaluate the operational suitability and reliability of the system during the type certification process. The manufacturer must demonstrate that the system is suitable to perform automated inspections or checks as part of an airline maintenance program. In effect, the HM system would have to be shown to provide equivalence with existing inspection methods and intervals.

The manufacturer of the HM system will have to work with commercial operators to develop maintenance task revisions based on the expected maintenance credits that would be enabled by the automated HM system. These task revisions would be incorporated into the air carrier's maintenance manual and submitted to the FAA for approval. The operators will rely on the ability to simplify inspection and maintenance tasks for cost effective implementation of HM systems.

The FAA has the responsibility to oversee these post-certification activities to assure that air travel remains the safest form of transportation. The FAA has recently introduced an oversight strategy, call the Air Transportation Oversight System (ATOS) that is based on a risk management approach to system safety, rather than just audits of regulatory compliance. The implementation of ATOS is not expected to represent a barrier to the introduction of HM systems. In fact, the focus on risk management and data-driven oversight could facilitate the introduction of automated tools like HM.

6.5 RECOMMENDATIONS

6.5.1 Implementation of HM Systems

The goals for implementing HM systems are to reduce operational and maintenance costs and to improve aircraft safety. A stepwise approach to certification and introduction of HM systems is recommended. This measured approach would allow certification and approval processes to be established on simpler systems and expanded to include more advanced applications. Specific recommendations include the following.

Select initial applications carefully. Work with air carriers to identify target parts and components for initial applications. Focus on targets that would address certification maintenance requirements, unscheduled maintenance problems, difficult or tedious inspections, accessibility problems, or component reliability problems. Avoid initial applications where HM systems could be viewed as invasive, e.g., where sensors will be embedded or integrated into a component (requiring requalification of material or recertification of the component).

Focus initial efforts on the goals of FOQA. ARINC believes that emerging HM capabilities will support the data collection and analysis activities required for an effective FOQA program. Advanced health monitoring capabilities, which would include prognostic capabilities, could identify components with service problems and/or inadequate reliability and support improvements in maintenance programs to consider these components. It could simplify the introduction of new HM systems if the initial applications were to fall within the FOQA program guidelines, that is, limited to collection and post-flight analysis of flight performance measurements. The eventual capabilities of HM systems will allow real-time diagnostics and aircrew cueing.

Develop standard system components. Approval of generally applicable HM system components through Technical Standard Orders (TSOs) could facilitate the approval of health-monitoring system components, including sensors and signal-conditioning hardware and on-board processors.

Focus on proving reliability of systems and approaches. The operators will only seek to use HM systems if they can be shown to be reliable substitutes for existing methods.

Developers should focus on validating the technical approach to sensor-based HM systems. This assessment will also facilitate approval of production certificates.

Obtain maintenance credit for automated HM systems. Air carriers have the authority to introduce new maintenance and inspection techniques and to implement those changes through their maintenance manual. The application of HM systems as a method to perform a scheduled inspection or check could be implemented in this manner.

Once the applicability and reliability of HM systems have been proven, the following general changes should be sought in the FAA's regulatory guidance.

- ADs should be revised to explicitly allow "certificated condition-monitoring systems" as a means for compliance.
- Guidelines and procedures for developing and monitoring maintenance programs should include guidance for taking advantage of HM systems in the development of maintenance and inspection tasks and intervals.
- Provisions should be added to the appropriate airworthiness requirements so that structural inspection programs, corrosion prevention and control programs, and certification maintenance requirements can be modified to realize maintenance credits by eliminating unnecessary inspections or increasing inspection intervals.

6.5.2 Further Data Archive Analysis

The regulatory data archive was a powerful tool to accomplish a systematic assessment of applicable regulatory guidance. As the HM system development and design progresses, similar analyses of archives containing aircraft safety, maintenance task, and maintenance history data, side-by-side with analyses of regulatory considerations, could enable systematic analysis of design considerations and trade studies. Examples of the types of analyses that could be accomplished include selection of target systems and components for HM utilization, cost/benefit trade studies, identification of operational considerations for HM systems, analysis of requirements for data collection and recording, and requirements for training of maintenance personnel. This section recommends enhancements to the data archive system that would facilitate the further utilization of this method.

The regulatory data archive was one of the principal analytical tools used for identifying the regulatory areas that could represent barriers to the certification and use of HM systems on Transport Category aircraft. The current regulatory data archive was structured to use the standard features of Access 97 to enter and extract data, review record content, and generate reports.

This prototype database was sufficient for generally assessing the impact of adding a HM capability on current regulatory guidance and for access/use by a small number of colocated users. However, updating current records, adding new information, maintaining configuration control, accessing information from remote locations, efficiently generating queries and reports required moderately more effort or time than would be required for more efficient database structures.

The current regulatory data archive should be rehosted as a web site to improve accessibility and provide proper security provisions. This improvement would eliminate the need for individual users to download the entire database into a personal file before use, thus improving configuration management and discouraging development of spin-off databases. It is also recommended that a more powerful database application be used to expand the data archive. These suggested enhancements could:

- Allow the use of “regular expression” queries to extract information
- Allow easily tailorable reports on results of queries
- Allow quick access/linkage with full text documents referred to in a record or as desired by the user
- Allow rapid location of records of interest and visibility on record content
- Allow controlled entry and update of data in individual records
- Provide real time visibility on the standards used for categorizing data
- Provide side by side comparisons of data categorization assignments by multiple analysts
- Allow database size to increase to beyond 20 gigabytes of data

An expanded database could include such information as aircraft safety data, maintenance history data, specific maintenance tasks, supplemental structural inspection requirements, and corrosion protection and control tasks. ARINC has developed a database structure which provides the above capabilities, that is hosted on an internet web site, and that can be used as the basic element of enhancing the current regulatory data archive.

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APPENDIX A – FEDERAL AVIATION REGULATIONS

CFR Part No.	CFR Subchapter and Title
	Subchapter A — Definitions and Abbreviations
Part 1:	Definitions and Abbreviations
	Subchapter B — Procedural Rules
Part 11:	General Rule-Making Procedures
Part 13:	Investigative and Enforcement Procedures
Part 14:	Rules Implementing the Equal Access to Justice Act of 1980
Part 15:	Administrative Claims under Federal Tort Claims Act
Part 16:	Rules of Practice for Federally-Assisted Airport Enforcement Proceedings
Part 17:	Procedures for Protests and Contracts Disputes
	Subchapter C — Aircraft
Part 21:	Certification Procedures For Products and Parts
Part 23:	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
Part 25:	Airworthiness Standards: Transport Category Airplanes
Part 27:	Airworthiness Standards: Normal Category Rotorcraft
Part 29:	Airworthiness Standards: Transport Category Rotorcraft
Part 31:	Airworthiness Standards: Manned Free Balloons
Part 33:	Airworthiness Standards: Aircraft Engines
Part 34:	Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes
Part 35:	Airworthiness Standards: Propellers
Part 36:	Noise Standards: Aircraft Type and Airworthiness Certification
Part 39:	Airworthiness Directives
Part 43:	Maintenance, Preventive Maintenance, Rebuilding, and Alteration
Part 45:	Identification and Registration Marking
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Part 49:	Recording of Aircraft Titles and Security Documents
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Part 61:	Certification: Pilots and Flight Instructors
Part 63:	Certification: Flight Crewmembers other than Pilots
Part 65:	Certification: Airmen other than Flight Crewmembers
Part 67:	Medical Standards and Certification
	Subchapter E — Airspace
Part 71:	Designation Of Class A, Class B, Class C, Class D, and Class E Airspace Areas; Airways; Routes; and Reporting Points
Part 73:	Special use Airspace
Part 77:	Objects Affecting Navigable Airspace
	Subchapter F — Air Traffic and General Operation Rules
Part 91:	General Operating and Flight Rules
Part 93:	Special Air Traffic Rules and Airport Traffic Patterns
Part 95:	IFR: Altitudes
Part 97:	Standard Instrument Approach Procedures
Part 99:	Security Control of Air Traffic
Part 101:	Moored Balloons, Kites, Unmanned Rockets and Unmanned Free Balloons
Part 103:	Ultralight Vehicles
Part 105:	Parachute Jumping
Part 107:	Airport Security
Part 108:	Airplane Operator Security
Part 109:	Indirect Air Carrier Security
	Subchapter G — Air Carriers and Operators for Compensation or Hire: Certification and Operations
Part 119:	Certification: Air Carriers and Commercial Operators

CFR Part No.	CFR Subchapter and Title
Part 121:	Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft
Part 125:	Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More
Part 129:	Operations: Foreign Air Carriers and Foreign Operators of U.S.- Registered Aircraft Engaged in Common Carriage
Part 133:	Rotorcraft External-Load Operations
Part 135:	Air Taxi Operators and Commercial Operators
Part 137:	Agricultural Aircraft Operations
Part 139:	Certification and Operations: Land Airports Serving Certain Air Carriers
	Subchapter H — Schools and Other Certificated Agencies
Part 141:	Pilot Schools
Part 142:	Training Centers
Part 145:	Repair Stations
Part 147:	Aviation Maintenance Technician Schools
	Subchapter I — Airports
Part 150:	Airport Noise Compatibility Planning
Part 151:	Federal Aid to Airports
Part 152:	Airport Aid Program
Part 155:	Release of Airport Property from Surplus Property Disposal Restrictions
Part 156:	State Block Grant Pilot Program
Part 157:	Notice Of Construction, Alteration, Activation, and Deactivation of Airports
Part 158:	Passenger Facility Charges (PFC's)
Part 161:	Notice and Approval Of Airport Noise and Access Restrictions
Part 169:	Expenditure of Federal Funds for Nonmilitary Airports or Air Navigation Facilities Thereon
	Subchapter J — Navigational Facilities
Part 170:	Establishment and Discontinuance Criteria for Air Traffic Control Services and Navigational Facilities
Part 171:	Non-Federal Navigation Facilities
	Subchapter K — Administrative Regulations
Part 183:	Representatives of the Administrator
Part 185:	Testimony by Employees and Production of Records in Legal Proceedings, and Service of Legal Process and Pleadings
Part 187:	Fees
Part 189:	Use of Federal Aviation Administration Communications System
Part 191:	Withholding Security Information from Disclosure Under The Air Transportation Security Act of 1974
	Subchapter N — War Risk Insurance
Part 198:	Aviation Insurance

APPENDIX B – DATA ARCHIVE ASSESSMENT RESULTS

TABLE B-1. FAR sections with identified potential impacts on HM system introduction.

id	Document Number	Document Subpart	Subpart Title	Paragraph Number	Paragraph Title	Inspection	Certification	Airworthiness	Maintenance
56	Part 21	Subpart B	Type Certificates	Sec. 21.31	Type design.			I	
74	Part 21	Subpart C	Provisional Type Certificates	Sec. 21.81	Requirements for issue and amendment of Class I provisional type certificates.			I	
75	Part 21	Subpart C	Provisional Type Certificates	Sec. 21.83	Requirements for issue and amendment of Class II provisional type certificates.			I	
76	Part 21	Subpart C	Provisional Type Certificates	Sec. 21.85	Provisional amendments to type certificates.			I	
116	Part 21	Subpart H	Airworthiness Certificates	Sec. 21.181	Duration.				I
118	Part 21	Subpart H	Airworthiness Certificates	Sec. 21.183	Issue of standard airworthiness certificates for normal, utility, acrobatic, commuter, and transport category aircraft; manned free balloons; and special classes of aircraft.	I		I	
119	Part 21	Subpart H	Airworthiness Certificates	Sec. 21.184	Issue of special airworthiness certificates for primary category aircraft.	I		I	
162	Part 21	Subpart L	Export Airworthiness Approvals	Sec. 21.329	Issue of export certificates of airworthiness for Class I products.	I		I	
166	Part 21	Subpart L	Export Airworthiness Approvals	Sec. 21.337	Performance of inspections and overhauls.			I	
231	Part 23	SFAR No. 23	Miscellaneous	35	Maintenance information.	I	I		
381	Part 23	Subpart C--Structure		Sec. 23.573	Damage tolerance and fatigue evaluation of structure.		I		
389	Part 23	Subpart D	Design and Construction	Sec. 23.611	Accessibility provisions.		I		
391	Part 23	Subpart D	Design and Construction	Sec. 23.619	Special factors.		I		
650	Part 23	Appendix G to Part 23	Instructions for Continued Airworthiness	G23.3	Content.		I	I	I
651	Part 23	Appendix G to Part 23	Instructions for Continued Airworthiness	G23.4	Airworthiness Limitations section.			I	
1521	Part 25	Subpart D -Design and Construction	General	Sec. 25.611	Accessibility provisions.		I		I
1794	Part 25	Appendix H	Instructions for Continued Airworthiness	H25.3	Content.		I	I	I
1795	Part 25	Appendix H	Instructions for Continued Airworthiness	H25.4	Airworthiness Limitations section.			I	
667	Part 43	Subpart B	Airworthiness Directives	Sec. 43.3	Persons authorized to perform maintenance, preventive maintenance, rebuilding, and alterations.			I	I
669	Part 43	Subpart B	Airworthiness Directives	Sec. 43.7	Persons authorized to approve aircraft, airframes, aircraft engines, propellers, appliances, or component parts for return to service after maintenance, preventive maintenance, rebuilding, or alteration.				I
670	Part 43	Subpart B	Airworthiness Directives	Sec. 43.9	Content, form, and disposition of maintenance, preventive maintenance, rebuilding, and alteration records…			I	
671	Part 43	Subpart B	Airworthiness Directives	Sec. 43.11	Content, form, and disposition of records for inspections…			I	I
673	Part 43	Subpart B	Airworthiness Directives	Sec. 43.13	Performance rules (general)			I	I
674	Part 43	Subpart B	Airworthiness Directives	Sec. 43.15	Additional performance rules for inspections.			I	
675	Part 43	Subpart B	Airworthiness Directives	Sec. 43.16	Airworthiness Limitations.			I	

id	Document Number	Document Subpart	Subpart Title	Paragraph Number	Paragraph Title	Inspection	Certification	Airworthiness	Maintenance
722	Part 119	Subpart C	Certification, Operations Specifications, and Certain Other	Sec. 119.49	Contents of operations specifications.			I	
865	Part 121	Subpart G	Manual Requirements	Sec. 121.135	Contents.			I	
1010	Part 121	Subpart K	Instrument and Equipment Requirements	Sec. 121.344	Digital flight data recorders for transport category airplanes.				I
1035	Part 121	Subpart L	Maintenance, Preventive Maintenance, and Alterations	Sec. 121.365	Maintenance, preventive maintenance, and alteration organization.				I
1037	Part 121	Subpart L	Maintenance, Preventive Maintenance, and Alterations	Sec. 121.369	Manual requirements.	I	I		I
1039	Part 121	Subpart L	Maintenance, Preventive Maintenance, and Alterations	Sec. 121.373	Continuing analysis and surveillance.		I		I
1045	Part 121	Subpart L	Maintenance, Preventive Maintenance, and Alterations	Sec. 121.380	Maintenance recording requirements.	I		I	I
1183	Part 121	Subpart T	Flight Operations	Sec. 121.537	Responsibility for operational control: Supplemental operations.				I
1277	Part 121	Subpart U	Dispatching and Flight Release Rules	Sec. 121.628	Inoperable instruments and equipment.			I	
1336	Part 121	Subpart V	Records and Reports	Sec. 121.709	Airworthiness release or aircraft log entry.			I	I
1827	Part 125	Subpart C	Manual Requirements	Sec. 125.73	Contents.		I	I	I
1871	Part 125	Subpart F	Instrument and Equipment Requirements	Sec. 125.201	Inoperable instruments and equipment.			I	
1892	Part 125	Subpart G	Maintenance	Sec. 125.247	Inspection programs and maintenance.		I	I	
1893	Part 125	Subpart G	Maintenance	Sec. 125.249	Maintenance manual requirements.	I	I		
1956	Part 145	Subpart A	General	Sec. 145.2	Performance of maintenance, preventive maintenance, alterations and required inspections for an air carrier or commercial operator			I	I
1967	Part 145	Subpart B	Domestic Repair Stations	Sec. 145.33	Limited ratings.	I			
1970	Part 145	Subpart B	Domestic Repair Stations	Sec. 145.39	Personnel requirements.	I		I	
1973	Part 145	Subpart B	Domestic Repair Stations	Sec. 145.45	Inspection systems.			I	
1980	Part 145	Subpart B	Domestic Repair Stations	Sec. 145.59	Inspection of work performed.			I	

TABLE B-2. Advisory Circular sections with identified potential impacts on HM system introduction.

id	Document Number	Document Subpart	Subpart Title	Paragraph Number	Paragraph Title	Inspection	Certification	Airworthiness	Maintenance
2004	AC 121-22A	Introduction				I			I
2006	AC 121-22A	Chapter 1	General	2	Maintenance Review Board Report.				I
2012	AC 121-22A	Chapter 2	Industry Participation	13	Working Groups.	I	I		I
2013	AC 121-22A	Chapter 2	Industry Participation	14	Manufacturer.			I	
2015	AC 121-22A	Chapter 3	FAA Participation	26	General.				I
2016	AC 121-22A	Chapter 3	FAA Participation	27	Maintenance Review Board.				I
2028	AC 121-22A	Chapter 6	Recommended MRBR Format and Content	56	Recommendations	I	I	I	I
2046	AC 25-7	Section 1	General	Chapter 3	Proof of Compliance - §25.21.			I	
2078	AC 120-16C	Chapter 3	General.					I	I
2079	AC 120-16C	Chapter 4	Continuous Airworthiness Maintenance Program Elements.				I	I	I
2080	AC 120-16C	Chapter 5	Responsibility for Airworthiness.					I	I
2081	AC 120-16C	Chapter 6	Maintenance Inspection Organization.					I	
2084	AC 120-16C	Chapter 9	Continuing Analysis and Surveillance.					I	I
2090	AC 120-17A	Chapter 2	Reliability Control Fundamentals	13	General.	I			I
2092	AC 120-17A	Chapter 2	Reliability Control Fundamentals	15	Reliability Control Systems.		I	I	I
2104	AC 121-1A	Chapter 1	Introduction	3	Definitions.			I	
2105	AC 121-1A	Chapter 1	Introduction	4	General.		I	I	
2106	AC 121-1A	Chapter 1	Introduction	5	Revision Of Time Limitations - General.		I	I	
2107	AC 121-1A	Chapter 1	Introduction	6	Airframe - Revision of Time Limitations.		I		
2108	AC 121-1A	Chapter 1	Introduction	7	Powerplant and Associated Appliances - Revision of Time Limitations.			I	
2109	AC 121-1A	Chapter 1	Introduction	8	Appliances - Revision of Time Limitations.			I	
2110	AC 121-1A	Chapter 1	Introduction	9	Reliability vs. Hardtime Conversion.				I
2115	AC 121-1A	Chapter 2	Proration	17	Application.				I
2116	AC 121-1A	Chapter 2	Proration	18	Scope and Limitations.			I	I
2117	AC 121-1A	Chapter 2	Proration	19	Data Required.		I		I
2120	AC 121-1A	Appendix 1	Additional Proration Sample Data.						I
2125	AC 25-19	5	CMR Definition.				I	I	
2132	AC 25-19	12	Documentation and Handling of CMRs.				I		
2134	AC 25-19	Appendix 1	Guidance for CMR's						
2155	AC 20-107A	6	Proof of Structure - Static.				I		
2156	AC 20-107A	7	Proof of Structure - Fatigue/Damage Tolerance.				I		
2158	AC 20-107A	9	Additional Considerations.			I	I		I

TABLE B-3. Airworthiness Directives with identified potential impacts on HM system introduction.

Id	Aircraft	Document Number	Document Title	Inspection	Certification	Airworthiness	Maintenance
2162	737	69-12-06	Aileron tab mast fittings	I			
2165	737	70-04-03	Placard APU fire extinguisher		I		
2169	737	73-09-04	Crack in entry door hinge		I		
2180	737	76-11-05 R1	Control system vibration	I			
2181	737	76-26-02	Cargo doors		I		
2183	737	78-13-07	Trailing edge flap	I			
2193	737	82-01-09	Lower body skins corrosion	I			
2196	737	84-20-03 R1	Aft pressure bulkhead insp.		I		
2197	737	84-23-05	Horizontal stabilizer	I			
2198	737	85-01-06	Forward airstair frames insp	I			
2199	737	85-01-07	BBL 70.85 rib upper chord insp	I			
2201	737	85-03-06 R1	Upper drag angles insp.		I		
2205	737	85-22-02	BBL rib upper chord insp.	I			
2208	737	86-12-04	Horizontal stabilzer center	I			
2209	737	86-12-05	Horizontal stab. attach lug	I			
2217	737	88-11-04	Wing spar chords	I			
2218	737	88-11-12	Cargo door frames	I			
2223	737	88-22-11 R1	Fuselage lap joints	I	I		
2230	737	89-09-03	Lap joints	I			
2231	737	89-11-06 R1	Inspect for cracks	I	I		
2242	737	90-17-20	Flap track bolts			I	
2244	737	90-21-15	Horizontal stabilizer	I	I		
2246	737	90-25-01	Corrosion control program	I	I		
2250	737	91-07-04	Inspect for cracks		I	I	
2252	737	91-08-12	Inspect for cracks		I		
2265	737	92-25-09	Corrosion inspection		I		
2267	737	93-05-17	Cabin window		I		
2269	737	93-08-04	Inspection time changes		I		
2270	737	93-14-10	Frame cracking	I			
2274	737	95-01-06 R1	Cargo doors		I		
2276	737	95-06-05	Fuselage frame cracking		I		
2278	737	95-12-17	Outboard chords		I		
2284	737	96-17-04	Flap actuator		I		
2299	737	97-22-07	Lower skin cracking		I		
2304	737	98-04-41	Actuator Box and Upper Jamb		I		
2305	737	98-11-04	Structural inspection		I		I
2306	737	98-11-04 R1	Continued structural integrity of the entire Boeing Model 737-100 and -200 fleet				I
2309	737	98-14-09	FEMS fitting		I		
2311	737	98-22-10	Forward service door		I		
2312	737	98-25-06	Cracking of the corners of the door frame and the cross beams of the aft cargo door		I		
2316	737	99-04-23	Reduced structural integrity		I		
2318	737	99-08-23	Aft pressure bulkhead		I		
2319	737	99-10-12	Actuator beam arm		I		
2484	757	88-08-04	Boost pump bypass valves	I			
2489	757	89-03-05	Elevator bearings	I			
2503	757	90-12-04 R1	Anti-ice system	I			
2507	757	90-23-06	Leading edge slats	I	I		
2514	757	91-06-12	Passenger door springs	I			
2522	757	91-14-21	Trailing edge support clips		I		
2525	757	91-22-51	Trailing edge wedges	I			

Id	Aircraft	Document Number	Document Title	Inspection	Certification	Airworthiness	Maintenance
2564	757	97-06-04	Eddy current inspection	I			
2567	757	97-18-04	Fuse pin cracking	I			
2568	757	97-18-05	Midspar fuse pins	I			
2584	757	99-24-07	Fatigue cracking in primary strut structure	I			
2586	757	99-27-06	Engine thrust control cable failure	I			

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The purpose of this study was to assess the connection between current FAA regulations and the incorporation of Health Management (HM) systems into commercial aircraft. To address the overall objectives ARINC (1) investigated FAA regulatory guidance, (2) investigated airline maintenance practices, (3) systematically identified regulations and practices that would be affected or could act as barriers to the introduction of HM technology, and (4) assessed regulatory and operational tradeoffs that should be considered for implementation. The assessment procedure was validated on a postulated structural HM capability for the B757 horizontal stabilizer.

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