CRANFIELD UNIVERSITY

FEI GAO

Continuing Airworthiness Policy and Application to Flying Crane Aircraft

School Of Engineering
Aircraft Design

MSc by Research
Academic Year: 2010 - 2011

Supervisor: Mr. Phil Stocking
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This thesis has been assessed as of satisfactory standard for the award of a Master of Science degree by research. This thesis covers the part of the assessment concerned with the Individual Research Thesis. Readers must be aware that the work contained is not necessarily 100% correct, and caution should be exercised if the thesis of the data it contains is used for future work. If in doubt please or to the supervisor named in the thesis, or the Department of Aerospace Technology.

ABSTRACT

This project is part of a collaborative MSc training programme between the Aviation Industries of China (AVIC) and Cranfield University, aiming at enhancing the competitiveness of AVIC in both international and domestic aviation market through applying continuing airworthiness policies in the whole aircraft development process.

The arrangement of the research project is that all students start with a Group Design Project which is based on the Flying Crane Project provided by AVIC. Individual research projects will address some aspects of the Flying Crane Project during the Group Design Project, and then further developed during the period for individual projects. The aim of this research is to apply the airworthiness requirements and the methodology of the Maintenance Steering Group logic (MSG-3) in the Flying Crane Project. This is because that maintenance is one of the key factors of Continuing Airworthiness, and MSG-3 logic is the most accepted and approved method to develop scheduled maintenance for civil aircrafts.

The main objectives of this project include: (1) To investigate current Continuing Airworthiness regulations, including European airworthiness requirements (as the main regulation to comply with) and Chinese airworthiness regulations (as an important reference and supplement to the research); (2) To investigate the main analysis methodology of reliability and maintainability, including Damage Tolerance and Failure Mode and Effect Analysis (FMEA); (3) To analyse the data resulted from the Group Design Project using MSG-3 logic to produce a set of Continuing Airworthiness instructions, for the operator and maintenance organisation of the aircraft, from the design organization’s perspective; (4) To develop Continuing Airworthiness instructions for airline operators to compose maintenance programmes for Flying Crane aircrafts, including maintenance tasks and intervals for the selected airframe systems and structural components; and (5) To identify applicable maintenance organisations in China for Flying

Crane aircrafts in accordance with both European and Chinese airworthiness requirements.

On completion of this research, two aspects of Continuing Airworthiness have been investigated, including maintenance programme and maintenance organization. With MSG-3 logic, the author developed the maintenance plan for three structural components (fuselage skin panel, wing root joint, and fin-fuselage attachment) and one airframe system (fuel system) based on results from the Group Design Project. The author also investigated the Chinese domestic aircraft maintenance companies, and selected suitable maintenance organizations based on technical and economical criteria.

Keywords:

Airworthiness Regulations, Regulatory Authority, Continuing Airworthiness instructions, Scheduled Maintenance Tasks and Intervals, MSG-3, Cabin Layout, Floor Beam

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GLOSSARY OF TERMS

AC	Advisory Circular
AD	Accidental Damage
AMC	Acceptable Means of Compliance
ATA	Air Transport Association
AVIC	Aviation Industry Corporation of China
CAAC	Civil Aviation Administration of China
CATIA	Computer Aided Three-dimensional Interactive Application
CCAR	Chinese Civil Aviation Regulation
CS	Certification Specification
EASA	European Aviation Safety Agency
ED	Environmental Deterioration
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FD	Fatigue Damage
FMEA	Failure Mode and Effects Analysis
GDP	Group Design Project
GM	Guidance Material
MSG	Maintenance Steering Group
MSI	Maintenance Significant Item
ICAO	International Civil Aviation Organization
IRP	Individual Research Project
ISRP	International Standards or Recommended Practices
JAA	Joint Aviation Authorities

JAR	Joint Aviation Requirements
SSI	Structural Significant Item
TC	Type Certification
TCH	Type Certification Holder

1 Introduction

1.1 Project Background

This is a collaborative project between Aviation Industries of China (AVIC) and Cranfield University. With the aim of enhancing competitiveness in both international and domestic aviation industry, the Aviation Industries of China, the biggest aeronautical product manufacturer in China, started this training and research project in collaboration with the School of Engineering, Cranfield University in 2008. Since 2008 to 2010, AVIC has sent three cohorts of aircraft engineers to Cranfield University.

The research project assigned to the students in the first three cohorts was mainly based on the design of the “Flying Crane”, a 130-seat civil aircraft under development in AVIC. All students started a Group Design Project, in which AVIC students experienced the whole procedure of civil aircraft design, including the Conceptual Design Phase, Preliminary Design Phase and Detailed Design Phase, followed by an individual project, all completed each within one year. Most of these students (including the author) extended or spread their research in Group Design Project phase as their topic of Individual Research Project. The author’s individual research topic is the application of continuing airworthiness policy in the whole aircraft development process, especially in the Chinese aviation industry.

1.2 Airworthiness in the Chinese Aviation Industry

Ever since the end of World War II, the development of civil aviation in the United Kingdom, the United States, and Russia has proved that, the capability of airworthiness certification is one of the critical factors in civil aircraft development.

Nowadays, Chinese aviation industry is experiencing a period of rapid development. However, compared with western countries which have mature aircraft development processes, procedures and technologies, airworthiness is still a weak point in the Chinese aviation business chain.

Airworthiness certification of independent civil aircraft design in China started from the ARJ-21 (Advanced Regional Jet of 21st Century) project. Due to the certification plan, the Type Certificate of AJR21 is proposed to be released by the end of 2011. Therefore it is clear that, China still has no experience of maintaining an independent civil aircraft design under any airworthiness regulations.

Consequently, Continuing Airworthiness, which covers operation and maintenance in aircrafts' service life, is considered as one of the most serious "short board" of Chinese aviation industry.

1.3 Overview of the Group Design Project

As mentioned above, all students started with a Group Design Project. In the academic year 2010-11 Group Design Project, the author's group focused on the Detailed Design Phase of the Flying Crane project, which is considered as the extension and continuance of the Preliminary Design Phase accomplished in the academic year 2009 project. In this group, the author was responsible for three parts of the work: passenger cabin layout, floor structure design, and airworthiness management.

1.4 Overview of the Individual Research Project

As mentioned previously, because of the lack of experience in designing and maintaining civil aircraft independently, airworthiness certification, especially Continuing Airworthiness is one of the main weak areas of Chinese aviation industry. Based on this background, the author carried out a research into

Continuing Airworthiness work during Type design phase of civil aircrafts, using data from the Flying Crane project. Note that the terminology 'Type' stands for a specific aircraft model in this thesis.

Continuing Airworthiness is a series of tasks, covering almost every aspect of a Type of aircraft including design, certification, operation, and maintenance.

Among those aspects, the author selected 'maintenance' as an application area aiming at developing the maintenance plan. The reasons behind the decision are the following:

- The maintenance plan is supposed to be accomplished by the end of Detailed Design Phase and approved by the Regulatory Authority as a main supportive document for Type certification;
- Most of required design and analysis data are available from the results of the Group Design Phase; and
- In both the Chinese Civil Aviation Regulation (CCAR) and the European Aviation Safety Agency (EASA) regulation systems, the same logic Maintenance Steering Group – 3 (MSG-3) was employed as the guideline to developing the maintenance tasks and intervals.

1.5 Project Aims and Objectives

As previously mentioned, this research is an extension of the Group Design Project, which is based mainly on the results of airframe system and structural components design, and will address issues related to Continuing Airworthiness from aircraft manufacturer's perspective.

Therefore, the aim of this research is to prove one means of compliance to satisfying the EASA requirements related to Continuing Airworthiness, by applying the airworthiness requirements and the methodology of the Maintenance Steering Group logic (MSG-3) in the Flying Crane Project of the Chinese Aviation Industries (AVIC).

For the purpose of achieving the research aim, the following objectives were established:

- To investigate current Continuing Airworthiness regulations, including European airworthiness requirements (as the main regulation to comply with) and Chinese airworthiness regulations (as an important reference and supplement to the research);
- To investigate the main analysis methodology of reliability and maintainability, including Damage Tolerance and Failure Mode and Effect Analysis (FMEA);
- To analyse the data resulted from the Group Design Project using MSG-3 logic to produce a set of Continuing Airworthiness instructions, for the operator and maintenance organisation of the aircraft, from the design organization's perspective;
- To develop Continuing Airworthiness instructions for airline operators to compose maintenance programmes for Flying Crane aircrafts, including maintenance tasks and intervals for the selected airframe systems and structural components; and
- To identify applicable maintenance organisations in China for Flying Crane aircrafts in accordance with both European and Chinese airworthiness requirements.

1.6 Thesis Structure

The first Chapter of this thesis gives a general introduction to the research project, including the origin and purpose of the project, the main content of the Group Design Project and Individual Research Project, and the aim and objectives of this research.

In Chapter Two, the author's work accomplished in the Group Design Project is described, including passenger cabin layout, floor structure design, and airworthiness management.

Literature review is the content of Chapter Three, as well as the methodology Maintenance Steering Group – 3 (MSG-3) logic and input from detailed design phase of this research.

The research methodology is applied to specific design data in Chapter Four. In addition, it comes to a proposed scheduled maintenance plan, including maintenance tasks and intervals for selected structures and systems.

Chapter Five contains an assessment of the Chinese aircraft maintenance organizations in accordance with airworthiness regulations and manufacturer's requirements.

In the end, the research outcome is concluded in Chapter Seven. And some comments from the author's perspective are proposed for future research.

2 The Group Design Project

During the Group Design Project phase in academic year 2010 – 2011, the author's group focused on the Detailed Design Phase of a 130-seat airliner Flying Crane, based on the results of the preliminary design phase from the previous group in academic year 2009 – 2010.

In this chapter, the author will present the main results from his work in Group Design Project phase:

- Cabin Layout;
- Floor Design; and
- Airworthiness Management.

2.1 Cabin Layout Design

For the cabin layout design, the author mostly kept the design style and functional components from the preliminary design phase.

To verify the internal arrangement, the author collected and compared the seat pitch and seat width of several most satisfactory airline worldwide with Flying Cranes. And then, based on the investigation and comparison of several most professional aerospace internal suppliers on the market, the author selected Recaro Aircraft Seating as the seating supplier of the Flying Crane. Their products BV3510 and BL4400 were the prototypes with those the CATIA CAD models of economy class and Business class seats were developed.

In addition, the author finalised the 3D-model of passenger cabin with CATIA V5 R17. The CATIA model contained passenger seats (economy and business class), galleys, wardrobes, lavatories, emergency equipments (including fire extinguishers and emergency lights).

2.2 Cabin Floor Design

This part of work includes the floor panel design and floor supporting structure design.

For the floor panel, there were three general requirements: to strengthen the high load areas, to avoid corrosion, and to use materials with light weight and high resistance.

The author designed the entire floor panel combined with two different types of composite materials, which are different in their facing thickness and core density. Their upper and lower facing materials are glass reinforced epoxy; meanwhile the fill-ins are aramid honeycomb. The floor panel designed is shown in Figure 2-1.

This type of material is widely used and soundly verified by world's main airliner manufacturers such as Boeing, Airbus and Bombardier.

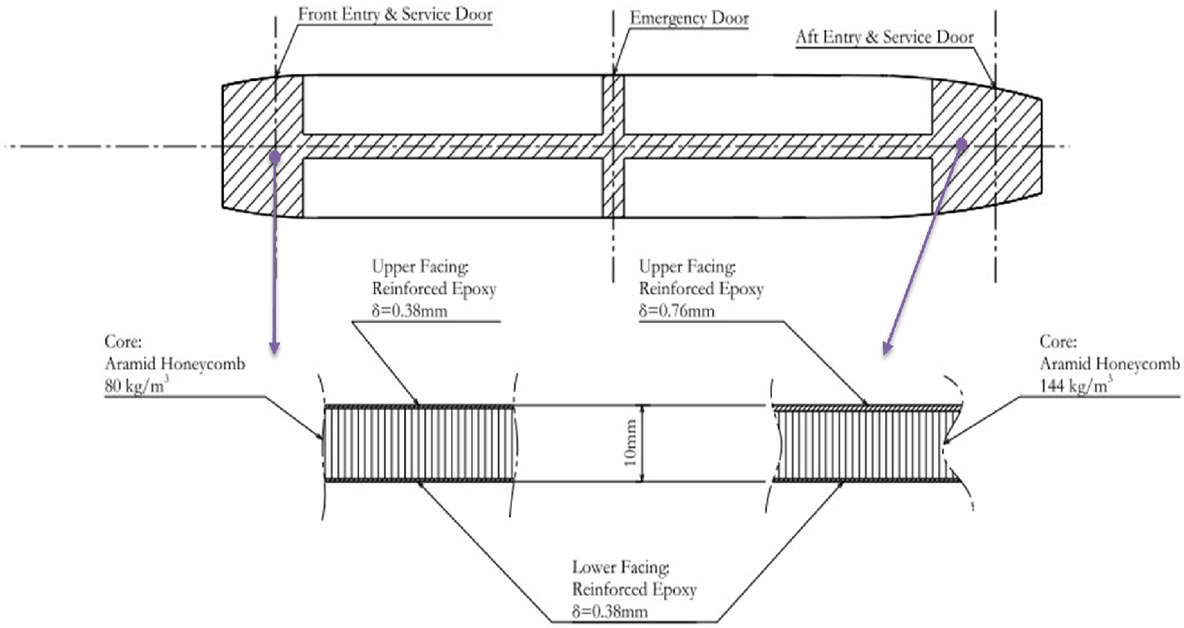

Figure 2-1 Floor Panel Designed

For the floor beam and floor vertical struts design, on the basis of the preliminary design, the author changed the material and redesigned the cross section of floor beam. And the vertical floor struts design, which had not been covered in preliminary design phase, was finished in this work.

The specific analysis and calculation process is shown in Appendix A.

2.3 Airworthiness Management

In the Preliminary Design Phase, other researchers have already determined the Airworthiness Regulations to comply with, the airworthiness management workflow, and the main method of airworthiness management. Therefore, in the Detailed Design Phase, the author followed the airworthiness work related to the structure design from the Preliminary Design Phase, and updated in accordance with the results accomplished in the Detailed Design Phase.

In the Group Design Project, the author was responsible for:

- Making the Type certification plan for Flying Crane project;
- Adding and adjusting the choice of clauses in CCAR-25;
- Updating the Airworthiness Compliance Matrix.

This part of work will be described in Appendix B.

2.4 Group Design Project Conclusion

In the Group Design Project, the author was responsible for passenger cabin layout, cabin floor, and airworthiness.

From passenger cabin and cabin floor design, the author learnt much about internal components of aircrafts, component supplier assessment, as well as aircraft structure design and analysis, which were all totally new to the author.

On the other hand, with the research of airworthiness, the author deeply understood the concept and tasks of airworthiness as the role of manufacturer, which were considered as the basis of the author's Individual Research Project in Continuing Airworthiness.

3 Literature Review

In this chapter, the author presented a general introduction to airworthiness, including main airworthiness organisations and their regulations, especially those related to Continuing Airworthiness. In addition, the methodology of MSG-3 (Maintenance Steering Group - 3) logic was presented. Finally, seven of the most common non-destructive testing methods were investigated.

3.1 Definition of Airworthiness

According to a number of published articles, the concept of AIRWORTHINESS is defined in a variety of ways. However, there are commonalities among these articles, i.e., the close link between airworthiness and safety.

"*Safety is the condition of being safe from undergoing or causing hurt, injury, or loss*" (Merriam-Webster Online, available at: http://www.merriam-webster.com/, accessed 10 Sep 2010).

When talking about safety related to aviation industry, the concept of Airworthiness is used to assess whether an aircraft is safe enough or not.

The following shows several different definitions of airworthiness based on different perspectives and understanding:

"*Fit for operation in the air*" (Merriam-Webster Online available at: http://www.merriam-webster.com/, accessed 10 Sep 2010).

"A definition of airworthiness can be found in the Italian RAI-ENAC Technical Regulations: for an aircraft, or aircraft part, [airworthiness] is the possession of the necessary requirements for flying in safe conditions, within allowable limits" (Filippo De Florio, 2006).

The author understands airworthiness as an inherent property of aeronautical products, which can be created and maintained by human-being, with the aim to ensure the safety of flight within expected environment.

Filippo De Florio (2006) stated that, there are three main conventional flight safety factors: man, the environment, and the machine. These factors act in series, not in parallel, just like three links of chain representing flight safety, which is illustrated in Figure 3-1.

Figure 3-1 Flight safety represented as three links in a chain

(Filippo De Florio, 2006)

From the above definitions, airworthiness is a baseline, in other words, a series of minimum requirements for an aircraft's manufacturer and operator to meet.

Note that in this thesis, a specific aircraft model is called a 'Type'. In the Type design and manufacture phase, "machine" is the primary factor of the three safety factors (man, environment and machine) to be focused on. The manufacturers of aircrafts and components concentrate on the acquisition of

TC (Type Certificate), PC (Production Certificate), and C of A (the Certificate of Airworthiness).

Once an aircraft is delivered to an operator and/or a maintenance organisation, accompanied by the introduction of Continuing Airworthiness (which will be explain in more detail later) during operation phase, the other two factors, man and environment come into the stage.

There's one point needs to be emphasized, which is that, there is no strict boundary between the phase of type design/manufacture and operation. For instance, before the delivery of an aircraft, the manufacture should issue the maintenance plan to the operator. The document would include required qualification and operation guide for maintenance personnel. The operator has the obligation to feedback about the aircraft's defect and performance to the manufacturer to improve the maintenance plan as well.

3.2 Main Airworthiness Authorities and Standards

3.2.1 The International Civil Aviation Organization

The International Civil Aviation Organization (ICAO) was initially launched and headquartered in Montreal, Canada. It has a history of over 60 years. Having been developed continuously since its establishment, ICAO has over 180 contracting states at present. ICAO concentrates on developing a safe, sound, effective and retainable civil aviation industry. (ICAO, available at: http://www.icao.int/)

To achieve its objective in civil aviation, ICAO established and has been implementing and completing 18 annexes, which are also entitled ISRP, International Standards and Recommended Practices. The International Standards are commonly agreed and executed as directives by every member states. Recommended Practises are the most accepted but not the restricted approach to achieve the standards. Among all these 18 annexes, Annex 6 (Operation of Aircraft) and Annex 8 (Airworthiness of Aircraft) have close relationship with Continuing Airworthiness.

3.2.2 The European Aviation Safety Agency

When talking about the European Aviation Safety Agency (EASA), the Joint Aviation Authorities (JAA) has to be mentioned. Before EASA, the competent authority was JAA, which established and implemented the Joint Aviation Requirements (JARs), and enabled the collaboration among member states, as well as external authorities. (EASA, available at: http://easa.europa.eu/home.php)

However, JAR was not able to perform legally to every member states within JAR. Member states needed to develop their own aviation regulation systems, which delayed the integrity of European Union in a certain level.

In that condition, EASA was organized as an independent European legal body, which administrates and issues requirements in a legal level.

EASA takes responsibility for drafting new legislation, implementing safety rules, issuing approvals for products and organisations, and authorizing non-EU operators.

EASA's regulation structure could be clearly illustrated in Figure 3-2.

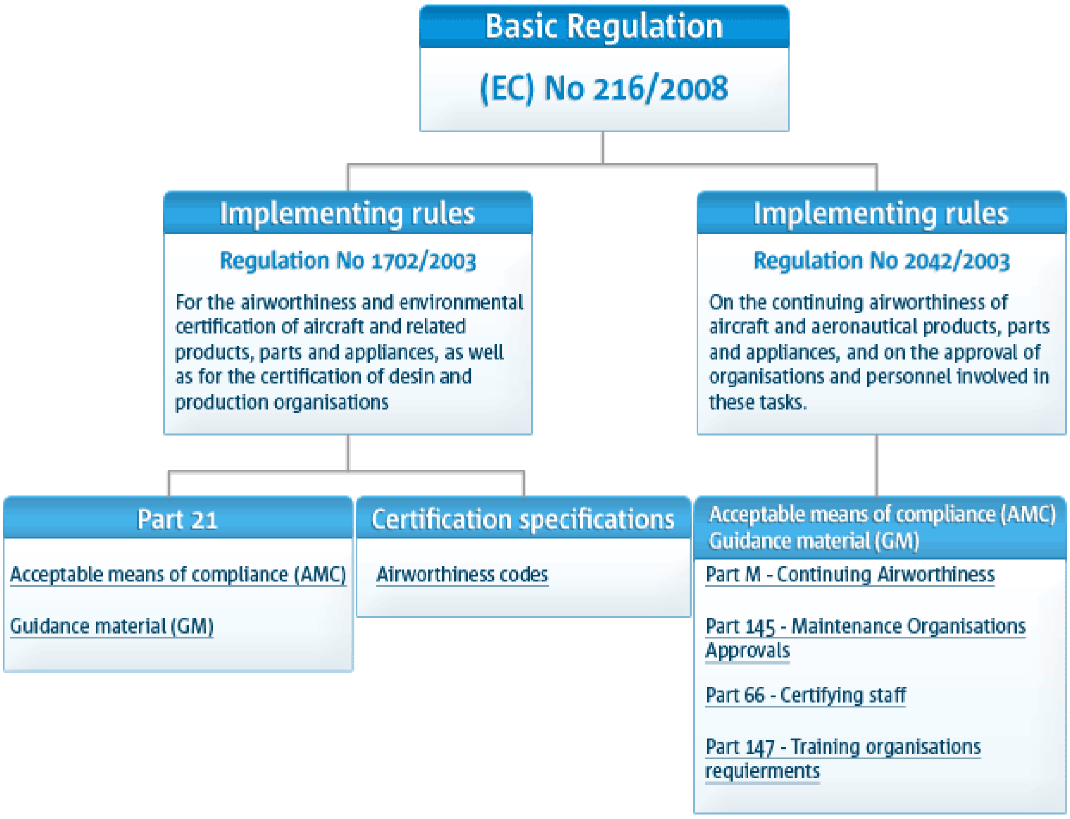

Figure 3-2 Regulations Structure of EASA (EASA, 2010)

The Basic Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 Feb 2008 states common rules in the field of civil aviation and establishes the EASA. It is applied to design, production, maintenance and operation of aeronautical products, parts, appliance, and personnel and organisations involved in these procedures as well. And the principal objective is to establish a high uniform level of civil aviation safety in Europe. (The European Parliament and the Council, 2008)

One of the Implementing Rules, Regulation No 1702/2003, is “for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations” (EASA, 2003). It contains Part-21 as its Annex I, and 10 appendices consisting of EASA unified forms related to certification procedures including application, authorisation, permits, release, etc. The Part

21 is about certification of aircraft and related products, parts and appliances, and of design and production organisations. Some clauses selected out from Part 21 are closely related to the author's study. These clauses will be list later on in this chapter.

The EASA airworthiness codes, which are Certification Specifications, derived from and have replaced JARs step by step since the establishment of EASA. The CS codes are compulsorily prescribed and implemented by the authority. The technical requirements defined in CS codes are mostly impact on aeronautical products' design and manufacture phase, which is considered as initial airworthiness stage.

The CS-25, Certification Specification for Large Aeroplanes, altogether with its AMCs and GMs (which will be introduced later on) have been taken into the author's study. The particular clauses will be list later in this chapter.

The Regulation (EC) No 2042/2003 is the Implementing Rule on the Continuing Airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks. It establishes common technical requirements and administrative procedures for the Continuing Airworthiness of aeronautical products. Annex I, Part-M, Continuing Airworthiness management and Annex II, Part-145, Maintenance Organization Approval, is both closely related to the author's work. The Annex III, Part-66, Certifying staff and Annex IV, Part-147, Training organizations requirements are both involved in the study as well.

Part M – Continuing Airworthiness

Part-145 is the Annex II of Regulation (EC) No 2042/2003. It presents the requirements for the maintenance organisations to get qualified as approved maintenance organisations from the Continuing Airworthiness point of view, and activities and procedures the competent authorities would take to have a maintenance organisation under certification due to different conditions.

Part-145 regulates applicant organisations from aspects of, such as, personnel, facilities, system (including data transfer and occurrence reporting, etc.), quality, etc. Likewise, ACMs and GMs to Part-145 are important supplement and directive material during the process of study.

Part-145 Maintenance Organization Approval

Part-145 is Annex II of Regulation (EC) No 2042/2003. It presents the requirements for the maintenance organisations to get qualified as approved maintenance organisations from the Continuing Airworthiness point of view, and activities and procedures the competent authorities would take to have a maintenance organisation under certification due to different conditions.

Part-145 regulates applicant organisations from aspects of, such as, personnel, facilities, system (including data transfer and occurrence reporting), and quality. Likewise, ACMs and GMs to Part-145 are important supplement and directive material during the process of study.

Acceptable Means of Compliance and Guidance Material

Refer to the definition officially given by EASA, the Acceptable Means of Compliance (AMC) serves as “means by which the certification requirements contained in the Basic Regulation, and its implementing rules, and more specifically in their annexes (also referred as ‘Parts’) can be met by the applicant”. (EASA, 2010)

From the definition, AMC is a means extremely strongly recommended by the Agency for the applicant to meet the requirements from EASA airworthiness codes and implementing rules. However, it is not compulsory. The applicant is always free to choose other means to show compliance. But the assessment and judgement on the alternative would in most situations cause much more unnecessary and avoidable extra matters and costs. Therefore, in this study, the author directly takes the means provided via AMC for the most part. It will be clearly identified when an alternative is taken.

The Guidance Material (GM) is an illustrative document to help understanding the related requirement. It is worked out to promote the application of airworthiness related rules as well as AMC. (Yongke Yang, 2009)

3.2.3 The Civil Aviation Administration of China

The Civil Aviation Administration of China (CAAC) is the aviation competent authority in China.

Within effects of years, China has established her own airworthiness regulation and management system. The structure of China's airworthiness regulation, CCARs, is built mainly based on the US FARs, and being synchronously updated where applicable as well.

The CCAR regulations selected and utilised by the author will be list later in this chapter.

3.2.4 Relevant Airworthiness Requirements

- EASA Regulation (EC) No 1702/2003, Annex Part 21, Certification of aircraft and related products, parts and appliances, and of design and production organisations;
- EASA CS 25, Large Aeroplanes;
- EASA Regulation (EC) No 2042/2003, Annex I, Part-M;
- EASA Regulation (EC) No 2042/2003, Annex II, Part-145;
- CCAR25, Airworthiness standards: transport category aircrafts;

- CCAR43, Maintenance, preventive maintenance, rebuilding, and alteration;
- CCAR145, Maintenance Organisation Approval;
- CCAR, AC-121-53, Civil aircraft maintenance plan;
- CCAR, AC-121/135-67, Maintenance Review Board Report
- CCAR, AC-121/135-49, Establishment and approval of Main Minimum Equipment List for Civil Aircraft.

The author decided to select the EASA airworthiness system as the main requirements to comply with meanwhile taking the Chinese CCAR regulations as references for the following reasons:

1. Experimental materials, reference sources related to EASA requirements are much more abundant and accessible than that related to CCAR regulations.
2. This project is a research project. The CCAR regulations have already been involved in the GDP phase. The author would like to investigate the EASA requirements during the Individual Research Project phase to extend the scope of his knowledge.

3.3 Continuing Airworthiness

As previously mentioned, safety is what airworthiness always focus on, undoubtedly not only temporarily, but also continuously. Ever since the issuing of Type Certificate and the delivery to the owner/operator, the aircraft must be maintained in the same airworthiness condition as when it was certified.

Generally speaking, the ultimate objective of Continuing Airworthiness is to keep the aircraft (or other aeronautical products) maintained at the Type Certificate airworthiness standard throughout the whole operational life.

The following is an official definition of Continuing Airworthiness.

"Continuing or continued airworthiness is all of the processes ensuring that, at any time in its life, an aircraft complies with the technical conditions fixed to the issue of the certificate of airworthiness and is in a condition for safe operation" – ICAO DOC 9713(John W Bristow and Simon Place, 2010)

Figure 3-3 shows the relationship and collaborative type of the three main participants (the Regulator, the Type Certificate holder, and the operator) of Continuing Airworthiness.

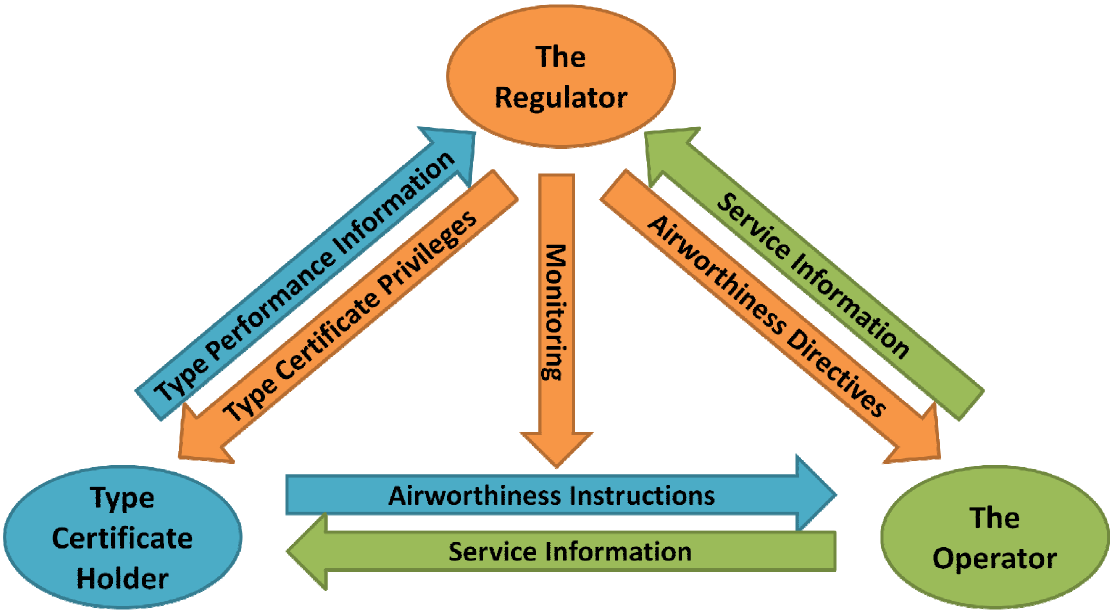

Figure 3-3 Main Players in Continued Airworthiness (John W Bristow and Simon Place, 2010)

With the definition of Continuing Airworthiness and the relationship of Continuing Airworthiness participants shown in Figure 3-3, it won't be too hard to get a conceptual realization of what Continuing Airworthiness aims to (to keep the aircraft airworthy), who does Continuing Airworthiness (Type

Certificate Holder, operator and competent authority – there will be maintenance and management organisations due to further investigation), and how to implement Continuing Airworthiness (which will be expanded upon in the following chapters).

3.3.1 Content of Continuing Airworthiness

It's necessary to declare in advance that, due to the limitation of time, this project is based on the Type Certificate holder's perspective. Consequently, from this point on, we will mainly investigate from the Type Certificate holder's point of view as well.

About Continuing Airworthiness, It is clearly indicated in Part-21 that,

i. The Type Certificate holder has the responsibility to, and should have a system to collect, investigate, and analyse data of failure, malfunctions and defects.

ii. When an airworthiness directive has to be issued by the agency to correct the unsafe condition, or to require the performance of an inspection, the Type Certificate holder shall follow and execute.

iii. The Type Certificate holder shall furnish at least one set of complete instructions for continued airworthiness.

Because of the limitation of actual conditions, it is not possible to deal with the first and second item. Therefore, in this study, the author has narrowed his investigation on the Continuing Airworthiness document provided to the operator from the Type Certificate holder.

3.3.2 Continuing Airworthiness Instruction

In accordance with point M.A.302 (d) of Part-M (EASA, 2003), the aircraft maintenance programme must establish compliance with instructions for Continuing Airworthiness issued by the holders of the Type Certificate.

From this point, the Continuing Airworthiness instruction is the basis of maintenance programme, and the maintenance programme is derived from Continuing Airworthiness instruction.

Basically, the maintenance programme should contain check periods, pre-flight maintenance tasks details, inspection tasks and periods (intervals/frequencies) for parts, check periods for components, specific structural maintenance programmes, CDCCL (Critical Design Configuration Control Limitations), component overhaul/replacement periods, mandatory life limitations, CMR's (Certification Maintenance Requirements), AD's (Airworthiness Directives) , reliability programme details.

3.3.3 Comparison between CCAR & EASA Continuing Airworthiness Regulation System

Continuing Airworthiness is identified and interpreted in different approaches by CCAR and EASA regulation system.

However, the internal safety standard and the final intentional objective of these two regulation systems are almost the same. For instance, both CCAR and EASA regulation take MSC-3 logic as the philosophy to determine the maintenance programme for aircrafts.

i. Regulations Structure

In CCAR, the concept of Continuing Airworthiness is not directly explained by one single requirement. The CCAR Continuing Airworthiness system is combined by several individual regulations, together with their AC (Advisory Circular, another denomination of Acceptable Means of Certification), which cover every main aspect of Continuing Airworthiness, including (but not only):

- CCAR-121, Certification Requirements for Air Transport Operator of Large Aircrafts
- CCAR-135, Management Regulations for General Aviation Operation
- CCAR-145, Certification Rules for Maintenance Organisations of Civil Aircrafts
- CCAR-43, General Rules for Maintenance and Rebuilding

In EASA, Continuing Airworthiness requirements are more structured and systemized. All the requirements for design organizations, operator, maintenance organizations, and Continuing Airworthiness management organizations are all integrated in the implementing rules and its annex, Part M (and AMC's).

ii. Acceptable Means of Certification

In CCAR Advisory Circulars, it could be clearly realized that, which organization the AC is based on specifically, and what that organization should do due to the AC.

For instance, the CCAR AC-91-11, Requirements for Continuing Airworthiness documents of aircrafts, clearly identifies that, in the type certification stage, what kinds of documents the design organization is required to provide to obtain the Type Certificate. Meanwhile, the contents, specifications, formality, and schedule of these documents are identified in this AC as well.

Comparatively, EASA AMCs are not described as directly as CCAR ACs.

In conclusion, EASA and CCAR Continuing Airworthiness regulation system have almost the same safety standard and philosophy (MSG-3 logic). However, EASA's Continuing Airworthiness system has a more structured and systemized regulation structure than CCAR's do. To make up this shortage, CCAR provides more clear description to the regulations via Advisory Circulars than EASA do with AMCs. Thus, when we develop the Continuing Airworthiness plan in accordance with EASA requirements, CCAR ACs can be a significant reference and supplement to the investigation.

3.4 Introduction to ATA MSG-3 Logic

Within the type design stage, the Continuing Airworthiness would be initially established. During this period, the identification of maintenance tasks and the prediction of maintenance intervals can be one of the most important assignments concerning Continuing Airworthiness.

3.4.1 Development of MSG-3

The ATA (Air Transport Association) MSG-3 (Maintenance Steering Group - 3) logic is the most widely used methodology to determine the maintenance tasks, and to estimate the maintenance intervals before the type aircraft comes into operation.

The very first MSG document; Handbook MSG-1 was developed by representatives of various airlines in July 1968. It contained decision logic and inter-airline/manufacturer procedures for developing scheduled maintenance for the new Boeing 747 aircraft. (ATA, 2003) In 2003, the MSG-3 Revision 2003 (not the latest issued, but the highest edition available at internet) was issued by ATA.

3.4.2 Mission of MSG-3

The objective of MSG-3 is to present a means for developing the scheduled maintenance tasks and intervals which will be acceptable to the regulatory authorities, the operators, and the manufacturers, from both safety and economic point of view.

Before the processes of development, the scheduled maintenance tasks were divided into two groups; scheduled tasks (at specified intervals) and non-scheduled tasks.

In the group of scheduled tasks, it covers from the most common task, which is lubrication and servicing to the most extreme task, which is discarding. And the non-scheduled tasks take place as a subsequence of scheduled task, or a functional failure, or a series of data analysis.

And the mission of MSG-3 could be divided into 4 sections; airframe systems (including powerplant and APU's), structural components, zonal inspections, and L/HIRF. Each section can be used independently from other sections.

3.4.3 The Author's Understanding about MSG-3

The following are the author's understands of MSG-3 procedures based on his own investigation and study.

I. MSG-3 carries out a top-to-bottom logical approach to classify the functional failure of systems/sub-systems, components, and parts, and then determines the maintenance tasks due to categories.

II. The input of MSG-3 is occurrence of functional failures. The applicability of inputs is critical for the accuracy of the results.

III. Significant Items (including Maintenance Significant Items and Structural Significant Items) can be emphasised in MSG-3. Hence, the identification of significant items is significant as well.

IV. For structural maintenance, Fatigue Damage deserves more attention in type design phase.

V. For other system/sub-systems, components, and parts, which developed based on experience data, the collection and analysis of data can be important.

3.5 The Continuing Airworthiness Applied on Flying Crane Project

As described in previous sections, the methodology of author's research is MSG-3 logic. The output of this research is a proposed maintenance plan for selected airframe systems and structural components of Flying Crane, which includes maintenance tasks and intervals. And the input is the functions, function failures, failure effects, and failure causes of the objective airframe systems, and fatigue damage data of the objective structural components.

The required data can be provided by system reliability and maintainability people and particular designer of each components of the Flying Crane project. The source of author's individual research is the results of these colleagues during their group design phase.

Hence, it is necessary to clarify first that, what valuable data can be provided and selected from the group design phase.

3.5.1 Airframe System

As previously mentioned, input is critical to aircraft maintenance developed under MSG-3 logic. Without specific and adequate data generated in detailed design phase, there will be nowhere to start the analysis procedure.

In the group design phase, the systems reliability and maintainability people developed a range of analysis tools related to system functions, including FHA (Functional Hazard Assessment), FTA (Fault Tree Analysis) and PSSA (Preliminary System Safety Analysis) for the ice protection system and surveillance system, as well as the FMEA (Failure Mode and Effect Analysis) for fuel system. Among these analysis tools, FMEA provides applicable information that can be directly adopted as the basis to develop maintenance plan on. Thus, the fuel system was selected.

3.5.2 Structural Component

For structure design, fatigue analysis results are directly related to structural maintenance plan.

In the Group Design Project, structure designers chose the most widely accepted fatigue design type, Damage Tolerance Design. With this design method, the length and growth rate of fatigue crack can be calculated, and the structural inspection interval was suggested by the designer as well. The data resulted from Damage Tolerance analysis is one of the most essential inputs of MSG-3 logic.

The author had three typical structural components analyzed using MSG-3 logic. The selected structures were fuselage skin panel, fin-fuselage attachment, and wing root joint.

3.6 Research to Non-destructive Tests

Within scheduled maintenance processes, Non-destructive Test (NDT) is widely applied to discover most types of damage occurred on aircraft structures.

Literally according to the name, Non-destructive Test is a series of inspection techniques used to find out scratches or defaults of metallic material or component insides without causing any damage.

Material seams (such as fatigue scratch on significant structural items) and internal contaminants (such as entrapped water and corrosion inside the airplane skin panel) can be revealed during scheduled maintenance tasks using Non-destructive Tests, and then followed by maintenance activities against those defaults.

In this section, the author will investigate and discuss seven of the most common Non-destructive Test methods which have the possibilities to be applied to the scheduled maintenance of aircraft structures, including Visual Inspection, Radiographic Inspection, Ultrasonic Testing, Eddy Current Testing, Dye Penetrant Inspection, Magnetic Particle Inspection, and Infrared Inspection.

3.6.1 Visual Inspection

Visual Inspection is the basic and primary method among all Non-destructive Tests. It could lead to the decision that whether other NDT is applicable.

This category could be subcategorized into General Visual Inspection (GVI) and Detailed Visual Inspection (DVI). GVI means that an inspection is implemented by naked eyes without any assistant tools. Oppositely, DVI is aided by magnifiers, mirrors, and accessibility enhancement equipments such as borescopes or introscopes.

Visual Inspection is the oldest and still the most widely used method of Non-destructive Inspections because of its simplicity, quickness and economy.

Common uses:

The most common use of GVI is to find out visible fatigue scratch on external surfaces, as well as any other type of visible scratches on accessible surfaces. With optical aids such as borescopes and television camera, DVI is also used to discover damage on internal surfaces or piping insides.

In addition, other advanced NDT methods can be used according to the results from Visual Inspection.

Limitations:

The result of Visual Inspection is valid only for surfaces with good condition. Basically, cleaning is necessary before the application of Visual Inspection. Furthermore, de-painting, degreasing, and sandblasting can be needed in some certain situations.

Additionally, human factor affects the results of Visual Inspection significantly. Results can be different depending on the training level of the inspectors, the physical and mental condition of one single inspector, the accessibility of illumination, and the size of acceptable defect comparing to the whole inspection area.

3.6.2 Radiographic Inspection

Industrial Radiographic Inspection includes X-ray Inspection and Gamma-ray (ɣ-ray) Inspection. Radiography technique is used to demonstrate a shadow image of a solid item in order to discover internal defects which are invisible to direct eyesight.

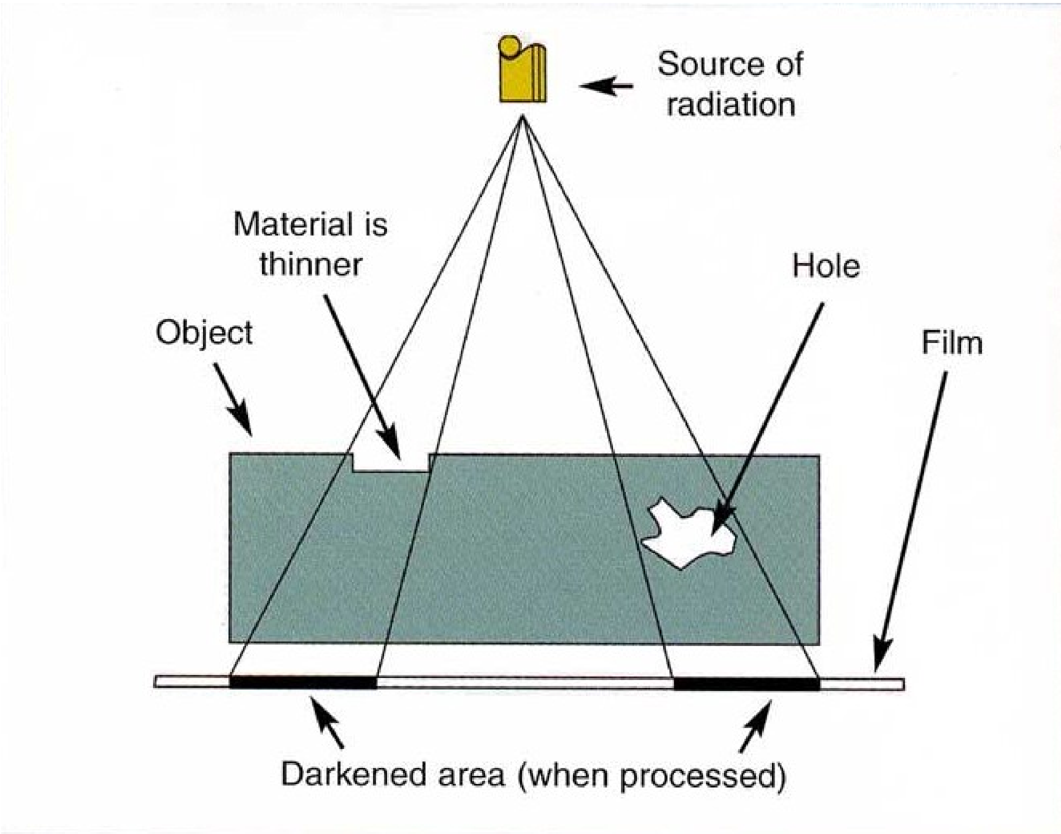

Figure 3-4 Layout of Radiographic Inspection (NDT Education Resource Center, 2011)

The general layout of Radiographic Inspection is shown in Figure 3-4. Because the penetrative rate of radiation varies according to the mass and type of objectives, the intensity of radiograph penetrated through the inspected items varies between different material intensity, style and size of internal defects, and material thickness. Thus, a distributed intensity of radiation will be receive by the film and illustrated by photosensitive material.

Common uses:

Radiographic Inspection is a very widely used type of NDT. It is used to assess a wide range of both metallic and non-metallic material thickness levels, even if the shape is complex (as long as both sides are accessible). And because of the inspection results are permanent (forty years at least), with appropriate equipments and sufficient look angles, real-time radiographic images can be realized.

Limitations:

Both sides of the objective have to be accessible. The probability of inspection will be reduced severely when cracks are not oriented parallel to the X-ray beam. Radiographed marginal discontinuities require much more careful recognization by qualified personnel comparing with gross flaws. Both X-ray and Gamma-ray harm human-beings' health. And the process is expensive, and takes a lot of time.

3.6.3 Ultrasonic Testing

Ultrasonic is referred to as sound waves at frequency above 20,000 Hz. And the range of frequencies used in Ultrasonic Testing is from less than 0.1 to larger than 15 MHz.

Because sound wave can be reflected by the boundary of different mediums, the ultrasonic wave will be reflected in different period and amount of energy. This difference can be analyzed to determine the presence of internal flaw or change on thickness.

The layout of Ultrasonic Testing is shown in Figure 3-5.

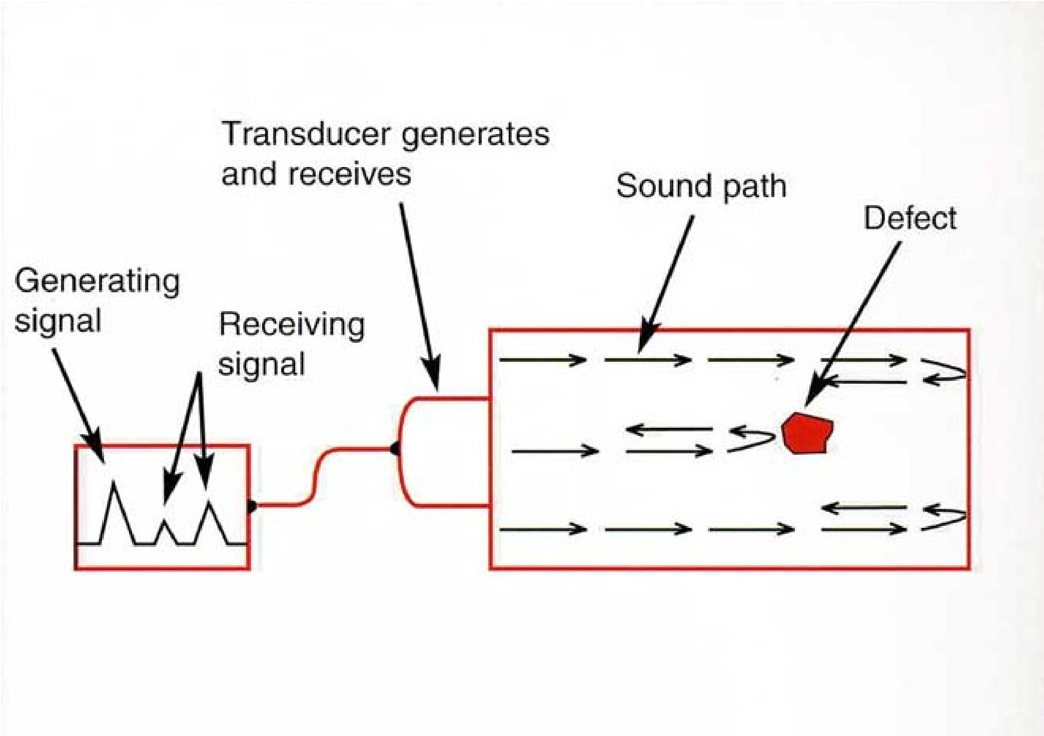

Figure 3-5 Layout of Ultrasonic Testing (NDT Education Resource Center, 2011)

Common uses:

Being applicable for inspecting internal defects, Ultrasonic Testing is frequently compared with Radiographic Inspection.

Because Radiographic Inspection is good with finding out defects parallel with radiation beams, and Ultrasonic Testing is good with inspecting defects vertical to sound wave beams, they are significant supplementary method to each other.

With different angles of incidence and correspondent calculations, the depth and size of internal defects can be accurately measured.

In addition, since the accessibility of only one single side needed, no harm to human-being health, and much less expensive (no film needed), Ultrasonic Testing is more recommended in conditions that Radiographic Inspection is also applicable, although it does have its own shortages.

Limitations:

Comparing with Radiographic Inspection, Ultrasonic Testing is suitable for thicker surfaces and defects vertical to sound beams. Higher surface condition is required in order to avoid interfere to inspection. Operators need to be trained more extensively than other NDT methods.

3.6.4 Eddy Current Testing

Electric current flowing in a coil generates magnetic field. When the electric current varies, the generated magnetic field varies accordingly. When the coil is placed near a conductive material, the changing magnetic field causes current flows in the conductive material. These currents are called Eddy Currents.

Thus, for conductive materials, the conductivity, permeability, and defects on/near surface can be measured inspected by measuring the magnetic field generated by eddy currents itself. This is how Eddy Current Testing works. (As shown in Figure 3-6)

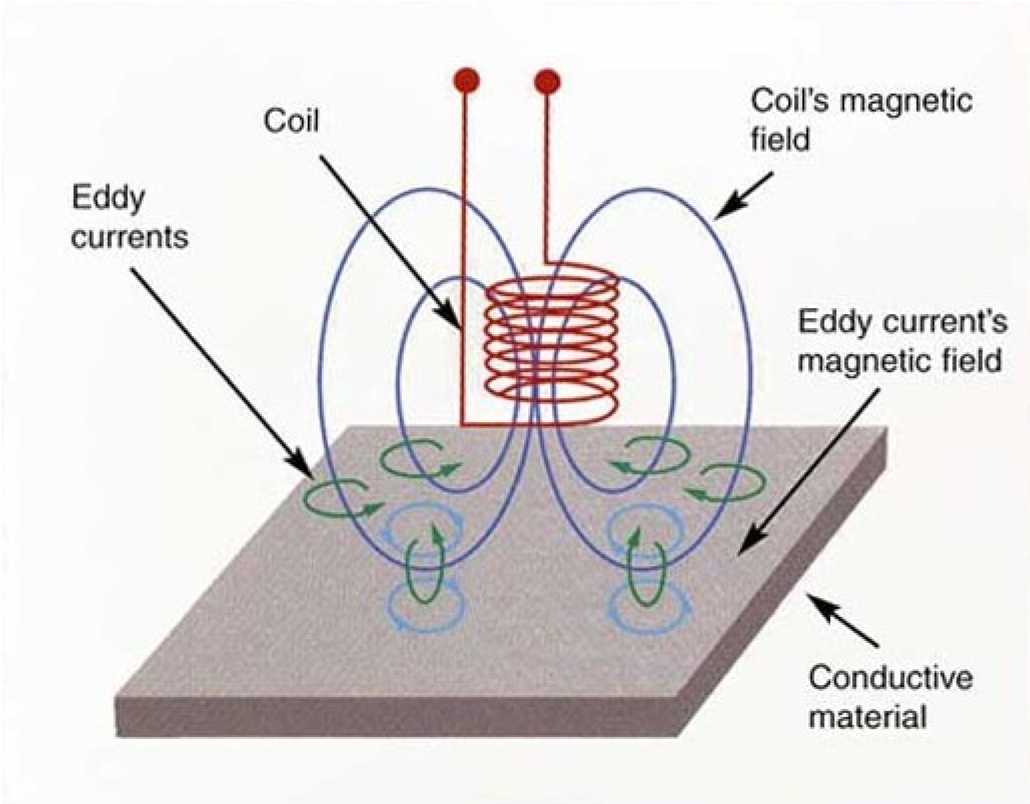

Figure 3-6 Layout of Eddy Current Testing (NDT Education Resource Center, 2011)

Common uses:

According to the principle of Eddy Current Testing, its main usage is to inspect properties related to conductivity changing, e.g. electrical conductivity, coating thickness, metal sorting, and surface condition (corrosion, heat damage, hardness).

Because the probe is not needed to touch the objective surface, Eddy Current Testing can be used to discover surface damage in some conditions as well.

Limitations:

Obviously, Eddy Current Testing is only applicable for conductive material such as metal. And Ferromagnetic materials require special treatment to address magnetic permeability.

Because of the characteristic of magnetic field, defects lying parallel to coil winding direction can be undetected.

The training requirements are comparatively higher.

3.6.5 Dye Penetrant Inspection

Dye Penetrant Inspection (DPI) is probably the most extensively used one among all NDT methods.

The primary principle of DPI is CAPILLARITY phenomenon. Capillarity happens when a penetrant material bath is applied on a clean surface of an objective. Removing excess penetrant material, the material that already penetrated into surfaces cracks will be pulled out and dyed by the application of Developer in the next step. Then, it is easy to detect any surface flaws under a certain level of illumination.

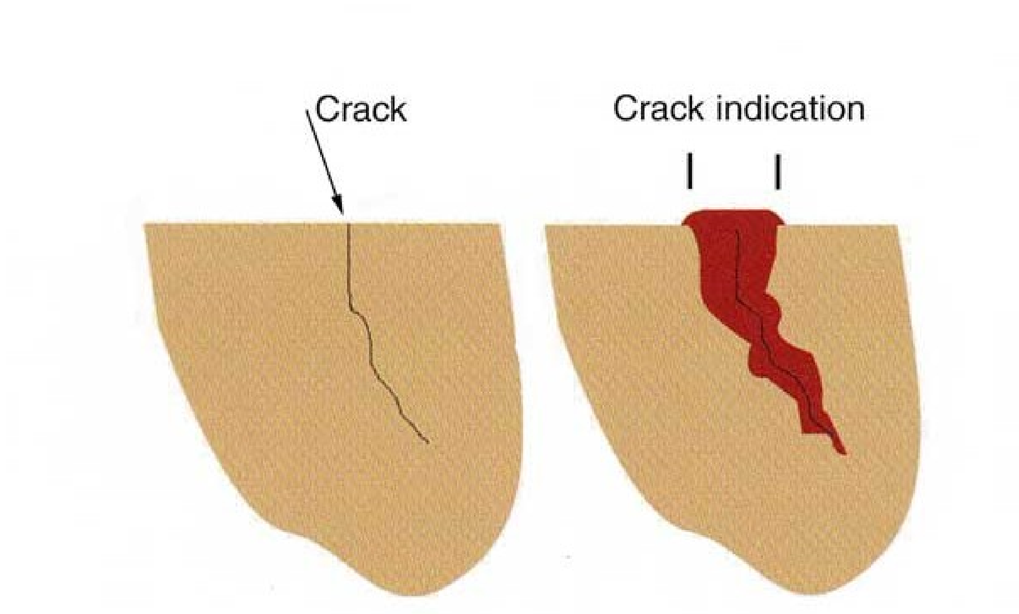

Figure 3-7 "Capillarity Phenomenon" during Dye Penetrant Inspection (NDT Education Resource Center, 2011)

Common uses:

Because of its effectiveness and convenience, Dye Penetrant Inspection is widely used to locate surface cracks, especially for large areas and complex surfaces which could be difficult for other NDT methods.

Limitations:

Only surface defects can be detected by Dye Penetrant Inspection.

The inspected surface needs to be cleaned thoroughly. In some conditions, special cleaning processes are necessary, such as vapour de-grease and sandblast.

Penetrant material is inflammable and harmful to human-being heath.

3.6.6 Magnetic Particle Inspection

The purpose of Magnetic Particle Inspection (MPI) is quite similar with Dye Penetrant Inspection. The major difference is that, MPI is only applicable to ferromagnetic materials.

In MPI, detection of cracks depends on the magnetic leakage fields, which are known as the disturbed, resembled magnetic lines caused by surface flaw of ferromagnetic objectives.

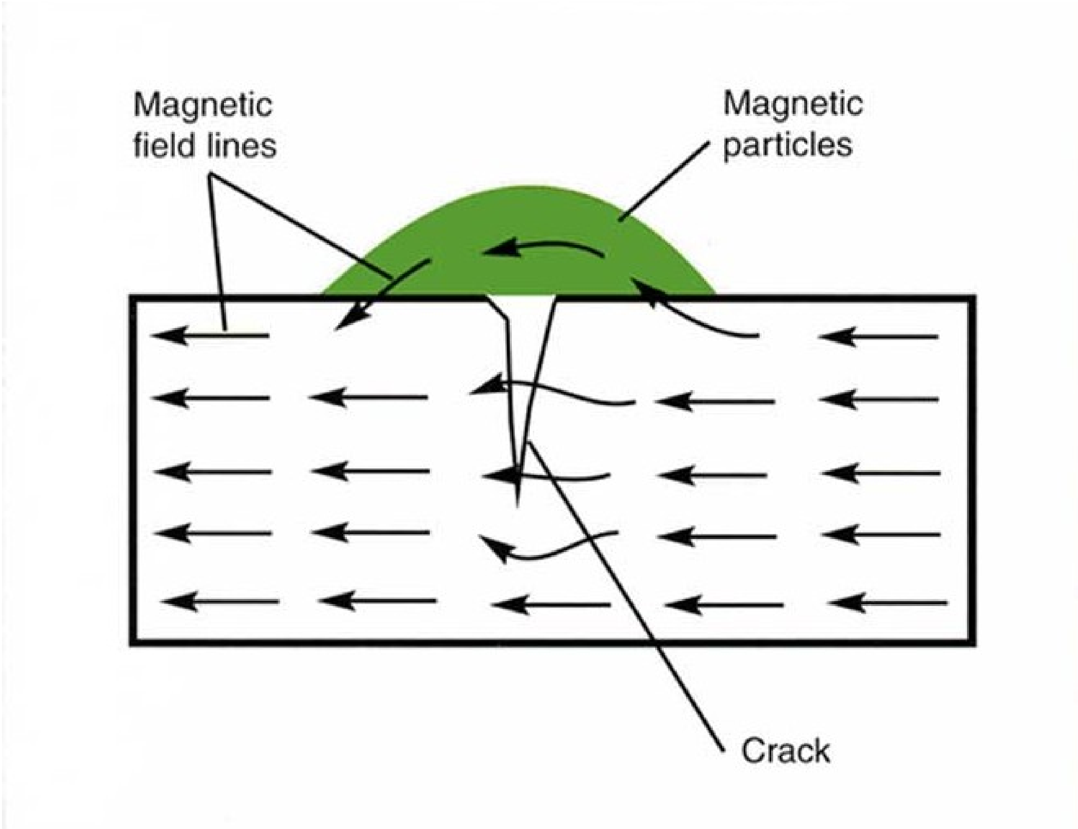

Figure 3-8 Layout of Magnetic Particle Inspection (NDT Education Resource Center, 2011)

Common uses:

Magnetic Particle Inspection could be considered as an alternative of Dye Penetrant Inspection for ferromagnetic material. However, MPI has one more advantage, which is that defects not deep under surfaces can be discovered by MPI.

Limitations:

There is one single limitation different than DPI, which is that the MPI is only applicable for ferromagnetic materials.

3.6.7 Infrared Inspection

Infrared Inspection is one means of Thermal Inspections.

Within this type of inspection, the objective is heated by infrared radiation, whilst its resulting temperature and/or thermal gradient is recorded and displayed. Correlating the results with pre-settled standards, the defects can be identified.

This mushrooming technique was firstly introduced to aviation industry in 90s of 20th century. It has been more and more widely utilized because of obtaining relatively extensive application, rapid procedure, large inspection area, and visualized result.

In addition, there is no contact between infrared generator and inspected item, and the heating can be easily controlled by adjusting the intensity of infrared radiation.

Common uses:

Internal damage caused by external impact (especially on composite material), fatigue scratch, corrosion (especially on internal surface), entrapped water in the honeycomb structure or foam material of fuselage.

Limitations:

The accuracy of results can be affected by surface emissivities because of surfaces with different materials. Surface emission has to be known before the inspection processes. Infrared sensors with high response need cooling with liquid nitrogen to reduce internal noise. The cost of sensors and instrumentation is relatively high.

3.6.8 Comparison of Non-destructive Testing Methods

A comparison of the characteristics of different NDT methods presented above is shown in the following Table 3-1.

Table 3-1 Comparison of NDT Methods

NDT Method	Instruments	Applicable Material Types	Applicable Location	Inspection Objective	Other Limitations
Visual Inspection	Naked Eyes or magnifiers, mirrors, borescopes, Close Circuit Television, etc.	All material types	Any visible, accessible and clean area	Visible fatigue scratch on external surfaces and any other visible damages	Accessibility of illumination, high training requirements
Radiographic Inspection	X-ray or Gamma-ray generator, films	Metallic and non-metallic	Both side accessibility required	Material thickness (thinner), internal defects (parallel with radiation beams)	harmful to health
Ultrasonic Testing	Ultrasonic instrument (Pulse or Continuous-Wave)	Metallic and non-metallic	Single side accessibility required	Material thickness (thicker), internal defects (vertical to soundwave beams), measurement of internal defects	high training requirements
Eddy Current Testing	Different types of coils, Display	Conductive material only	Surfaces not complex	electrical conductivity, coating thickness,	defects parallel to coil undetected, high training requirements

NDT Method	Instruments	Applicable Material Types	Applicable Location	Inspection Objective	Other Limitations
				corrosion, heat damage, hardness	
Dye Penetrant Inspection	Surface cleaning instrument, penetrant material, developer	Metallic and non-metallic	Large areas and complex surfaces (cleaning required)	surface cracks only	harmful to health, inflammable
Magnetic Particle Inspection	Magnetic particle instrument	Ferromagnetic material only	Large areas and complex surfaces (cleaning required)	surface and not deep defects only	ferromagnetic material only
Infrared Inspection	Infrared generator, heat sensor, display	Material without emissive coating	Areas without emissive coating	internal damage of composite, corrosion on internal surface, entrapped water inside fuselage	high costs, cooling needed

3.7 Summary

In this chapter, the author described the concept of airworthiness, Continuing Airworthiness, as well as the main regulatory authorities in the world, together with the regulations they issued. Meanwhile, the regulation to comply with and the methodology of this research were selected. And initial analysis to MSG-3 logic was presented as well. Then, the author reviewed the data related to Continuing Airworthiness and identified those were required by this research. In the end, a research to common Non-destructive Testing, which would be taken as scheduled maintenance tasks, was presented.

4 Scheduled Maintenance Development Based On MSG-3 Logic

In this chapter, the author applied the previously introduced MSG-3 (Maintenance Steering Group - 3) logic on the results from the Detailed Design Phase of Flying Crane project (the Group Design Project) to propose scheduled maintenance tasks and intervals for selected structures and airframe system.

4.1 Obligations of Type Certificate Holders

Type Certificate Holder (TCH) is an organization that has applied and obtained a Type Certificate of an aeronautical product. Normally, the prime manufacturer of an aircraft, or engine, or airborne equipment is considered as a Type Certificate Holder.

In this study, the author's role can be considered similar to a Type Certificate Holder's.

Generally, from the perspective of Continuing Airworthiness, a TCH has three fundamental obligations in the whole design and service life of an aircraft Type.

- To generate Continuing Airworthiness instructions, which are the basis and guideline for operators to build aircraft maintenance programmes. These instructions are supposed to consist of specifications for operation and maintenance, interface information between main components, and manuals for airborne equipments.
- To collect and analyze feedback from operators and directives from regulatory authority, in order to keep improving the design and

maintenance programme of the aircraft, as well as revising the defects and problems detected during the aircraft's operation.

- To provide technical support to the operators for service difficulties and mandatory corrective activities.

Scheduled maintenance is contained in Continuing Airworthiness instructions. This work should be accomplished during the type design phase, and submitted to the regulatory authority as one of the main supportive documents for Type certification.

4.2 Scheduled Maintenance for Selected Structures

According to ATA MSG-3 logic, damages to aircraft structures could be caused by three damage sources, Accidental Damage (AD), Environmental Deterioration (ED), and Fatigue Damage (FD). Damages caused by different damage sources should be analyzed separately using different methods and logics.

The input of this analysis was the results from detail design phase of Flying Crane in Group Design Project. The results included design detail, selected material, damage tolerance data, etc. And the input included the A check and C check intervals provided by maintainability designer in Group Design Project as well.

4.2.1 Introduction to Selected Structural Items

In this part of research, the author selected three structural items, which had been designed according to damage-tolerance type during GDP phase. These items are fuselage skin panel, fin-fuselage attachment, and wing root joint, which were designed respectively by aft fuselage, fin, and inner wing structure designers.

i. Fuselage skin panel

According to the results of detail design, the skin thickness was 2.0mm between station 19.92m and 23.5m, 1.6mm between 23.5m and 28.5m, and 1.2mm after 28.05m. The chosen material was 2024-T3 (aluminium alloy with copper and magnesium, tempered to ultimate tensile strength of 400-427 MPa).

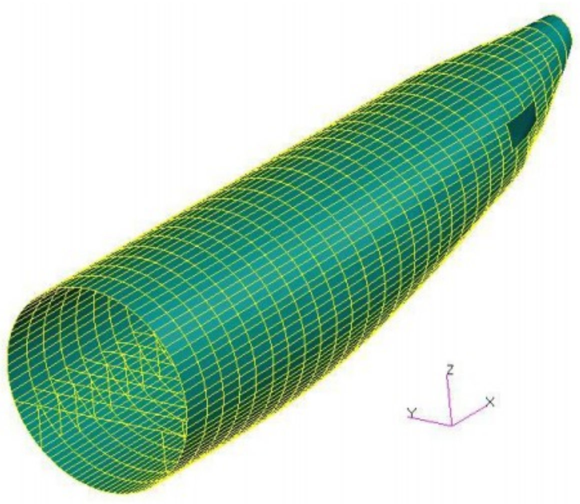

Figure 4-1 Aft Fuselage Skin of Flying Crane

(Jinglin Liu, Cranfield University Group Design Report, 2010)

ii. Fin-fuselage attachment

The fin was designed removable to increase the maintainability and inspectability. To satisfy the removability, the designer chose to use two bolts to fasten the double edge lugs and at spar flanges and one bolt to fasten the middle lug (see Figure 4-2).

The material was Ti-6Al-4V (alpha-beta titanium alloy).

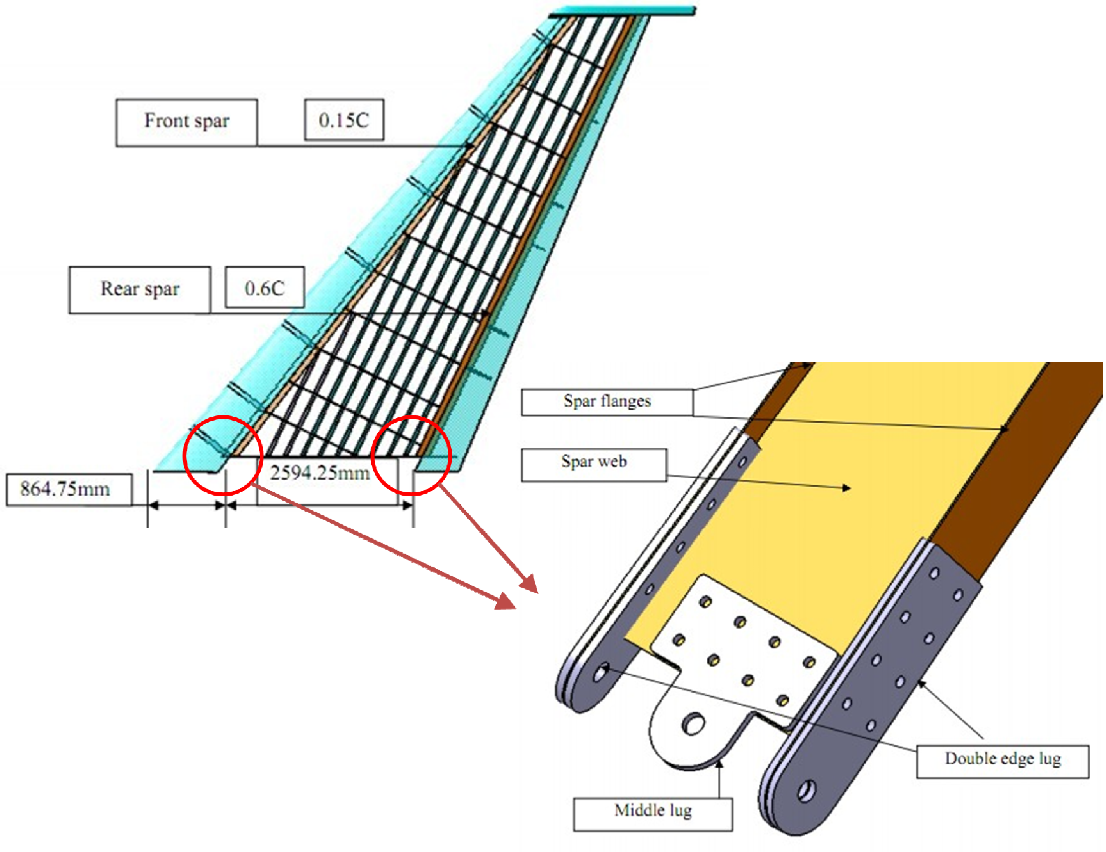

Figure 4-2 Fin-Fuselage Attachment of Flying Crane

(Jinfeng Lv, Cranfield University Group Design Report, 2010)

iii. Wing root joint

Wing root joint is considered as one of the most important structural areas, especially from the perspective of Continuing Airworthiness.

The designer chose spliced plates to attach the central and inner wing because of its light weight, reliability and inherent fail-safe feature (see Figure 4-3).

The material was Ti-6Al-4V (alpha-beta titanium alloy).

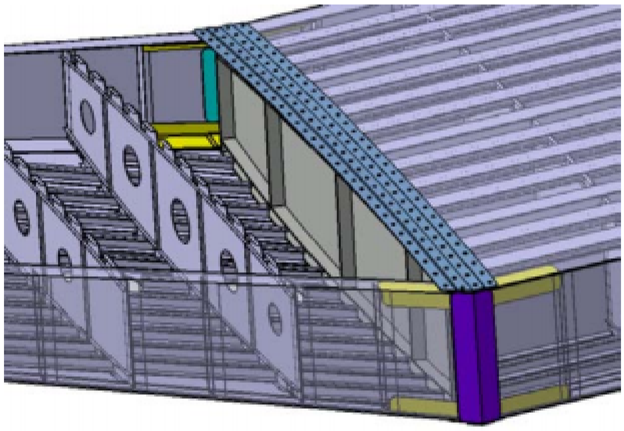

Figure 4-3 Wing root joint

(Yifei Liu, Cranfield University Group Design Report, 2010)

4.2.2 Scheduled Structural Maintenance Development Procedure

Flying Crane was developed under the philosophy of reliability centred maintenance. Therefore, in accordance with EASA Part-M, the maintenance instructions for operators should be developed under MSG-3 (Maintenance Steering Group) logic.

In this section, the author will take the three selected structure as examples to explain the scheduled structural maintenance development procedure in detail with MSG-3 logic (see Figure 4-4).

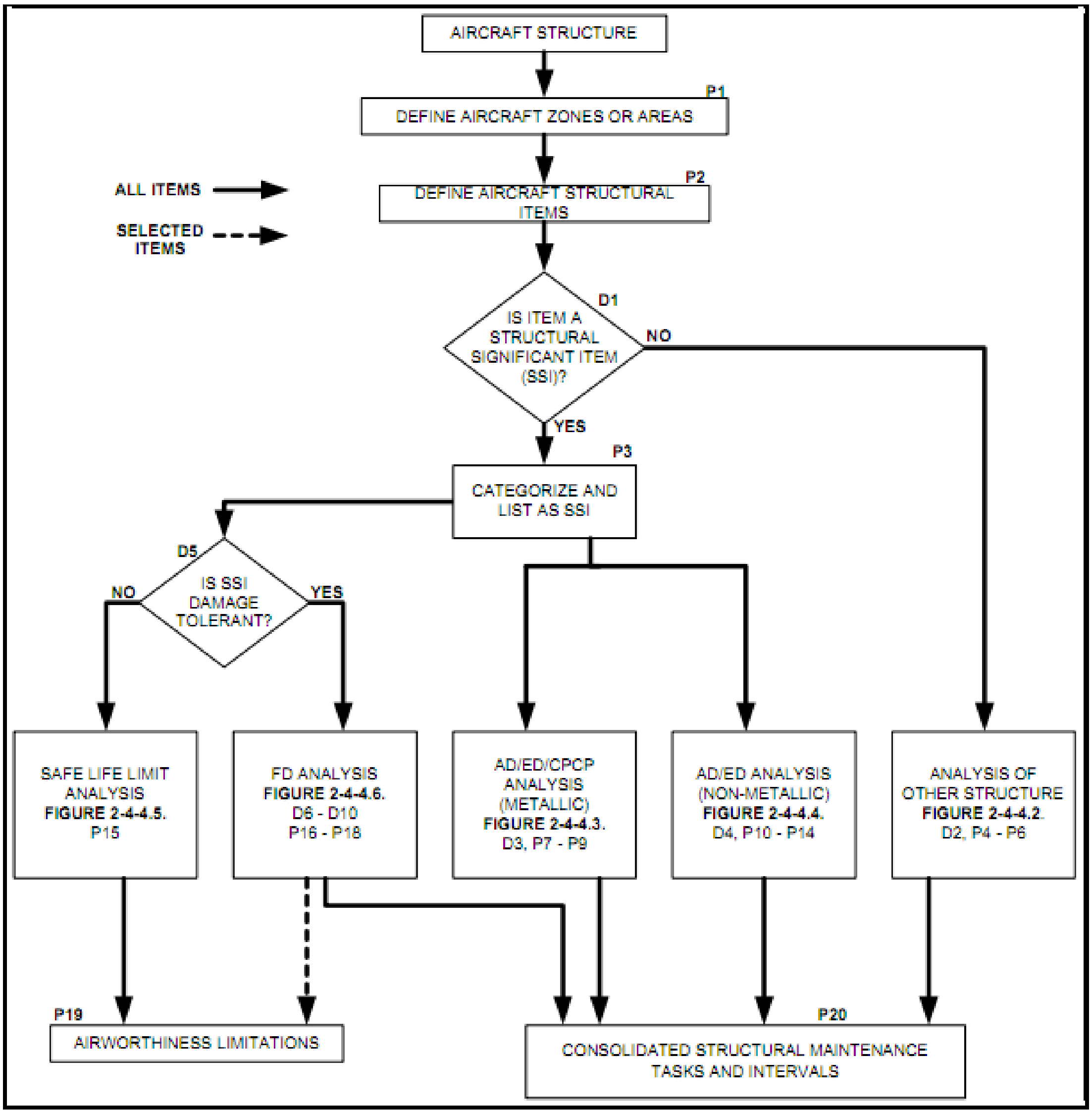

Figure 4-4 MSG-3 logic diagram for structures (ATA, 2003, MSG-3 Logic)

4.2.3 Define aircraft zones or areas (P1) and define aircraft structural items (P2)

As mentioned before, the Author selected three representative structural parts from the group design phase of Flying Crane project. They are aft fuselage detail design (provided by the designer Ms. Jinglin Liu), fin detail design (provided by the designer Mr. Jinfeng Lv), and inner wing detail design (provided by the designer Mr. Yifei Liu).

The fatigue analysis data and results of these three structures were all available.

4.2.4 Identifying Structural Significant Items (D1)

First, it's necessary to identify that, a Structural Significant Item (SSI) is any detail, element or assembly, which contributes significantly to carrying flight, ground, pressure or control loads, and whose failure could affect the structural integrity necessary for the safety of the aircraft. (ATA MSG-3, 2003)

Fuselage skin panel is one of the most significant elements of an aircraft. With its failure, the aerodynamic performance will be totally reversed, and the internal components will be easily corroded and contaminated. It has significant affect for flight safety. Thus, the fuselage skin panel is considered as a Structural Significant Item.

The fin-fuselage attachments of Flying Crane were identified as structural significant item for the following two reasons:

1) The fin-fuselage attachments need to undertake fore-aft, vertical, and shear loads apply on the vertical stabilizer.
2) The fin of Flying Crane was designed removable to ensure the maintainability and detectability.

With the failure of the attachments, the fin can be totally off the fuselage.

Wing root joint was also identified as structural significant item, because that, without this joint, the wings can be broke and the aeroplane can be out of control completely.

As the selected structures are all structural significant items, the next step should be P3, Categorize and list SSI's.

4.2.5 Generating Structural Significant Items List (P3)

All the three selected structural items were identified as Structural Significant Items. The SSI's list in this research, which can be considered as a segment of the SSI's list of Flying Crane aeroplane, is as follow (Table 4-1).

Table 4-1 Structural Significant Item List

Item ID	SSI Name	Zone	Material Category
01	Fuselage Skin Panel	Aft Fuselage	Metallic
02	Fin-fuselage Attachment	Fin	Metallic
03	Wing Root Joint	Inner Wing	Metallic

4.2.6 AD/ED/CPCP Analysis for Metallic Structures (P7 – P9)

As all selected structures are metallic, the next procedure should be P7 – P9, AD/ED/CPCP Analysis (see Figure 4-5).

In accordance with MSG-3 logic, in this stage, a rating system should be utilized to rate each structural significant item in terms of susceptibility and detectability due to each damage source. This rating system is supposed to be applicable for the assessment of each structural significant item. And rating of Accidental Damage, Environmental Deterioration, and Fatigue Damage should all be included.

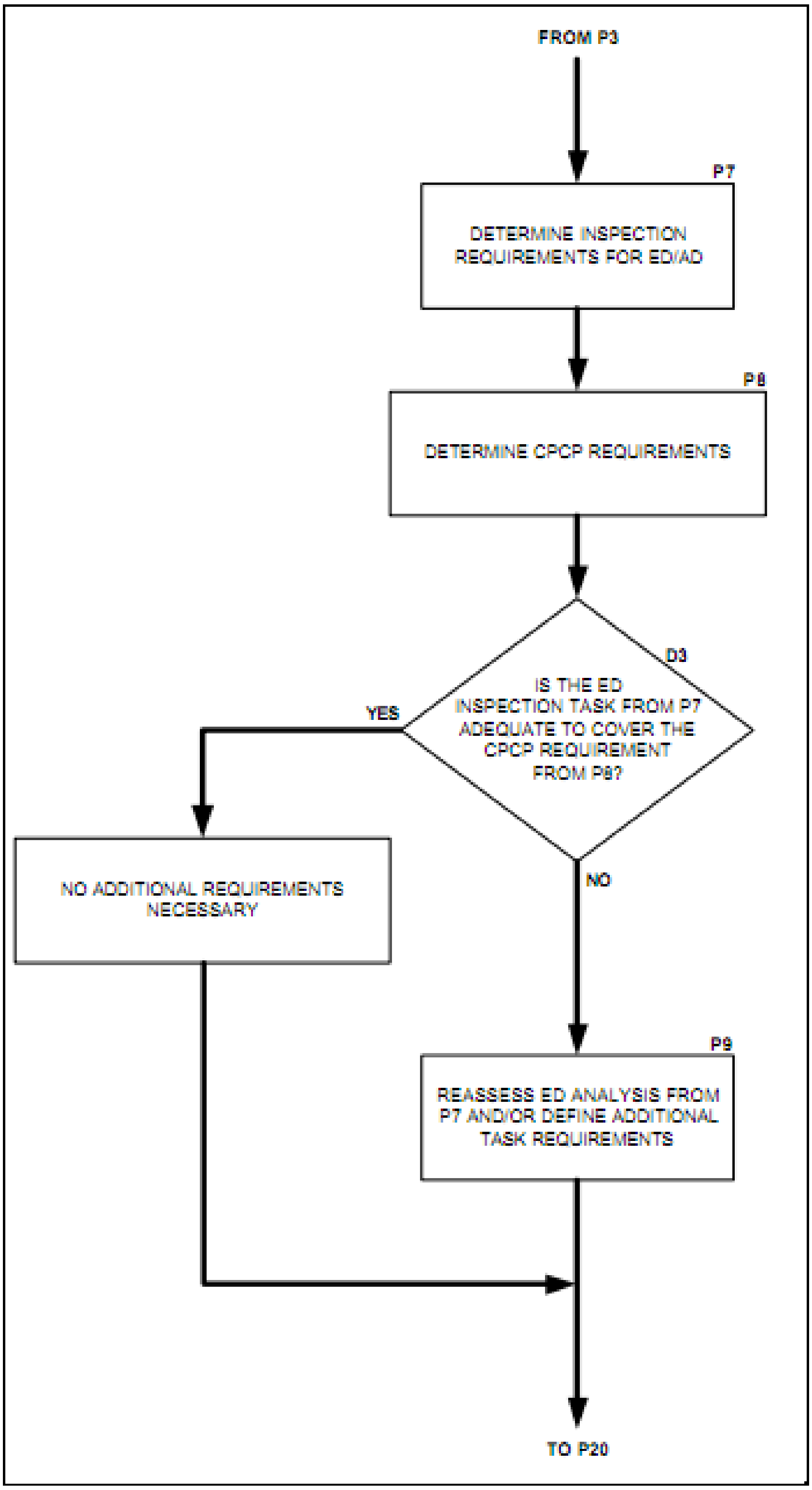

Figure 4-5 MSG-3 AD/ED logic diagram - metallic

(ATA, 2003, MSG-3 Logic)

To establish an SSI rating system is a great amount of work by both manufacturers and airline operators based on their experience.

Because of time limitation, and lack of relevant experience data, in this study, the author just analyzed the selected structures and listed the AD/ED requirements to them.

Talking about Accidental Damage and Environmental Deterioration, these types of damage sources could be understood as damage sources other than fatigue damage during airliners' service life. The main means of damage for the selected structures are list in Table 4-2 below.

Table 4-2 Main Accidental Damage and Environmental Deterioration of selected structures

Fuselage skin panel	Foreign impact, e.g. hail, debris, and birds
	Corrosion, especially corrosion on internal surface
	Failed structures, e.g. fasteners, sealant
	Entrapped water
Wing root joint	Loose bolts
	Corrosion
Fin-fuselage attachment	Loose bolts
	Corrosion

For the fuselage skin panel, physical damage caused by impact could be detected by visual check. The check frequency, which should be established based on experience data, could vary according to season, climate, air quality, etc. Basically, visual checks on skin panel should be taken every A check at least.

Corrosion on structures is a common problem for each item. For corrosion on external surfaces, visual check is applicable. Corrosion on internal surface or structures can be found with Non-Destructive Tests such as Infrared Inspection and X-ray Inspection. The visual check for corrosion should be taken every A check. The inspections where Non-Destructive Tests needed are recommended to be taken every four A checks (4A check).

Rivets and sealant on skin panel can be checked visually. Welds should be inspected with NDT. And internal bolts on fin-fuselage attachment and wing root joint should be inspected with NDT as well. It is compatible with corrosion checks that, visual check should be taken every A check. The inspections where NDT needed will be taken every C check. Table 4-3 provides a summary of the checks.

Table 4-3 AD/ED requirements for selected structures

Structural Item	Damage Source	Check Method	Check Frequency
Fuselage skin panel	Foreign impact, e.g. hail, debris, and birds	Visual check	A check
	Corrosion, especially corrosion on internal surface	Visual check (external); Eddy current test (internal)	A check 4A check
	Failed structures, e.g. fasteners, sealant	Visual check (rivets, sealant)	A check C check
	Entrapped water	Infrared Inspection	4A check
Wing root joint	Loose bolts	Visual Check	C check
	Corrosion	Eddy current test	4A check
Fin-fuselage attachment	Loose bolts	Visual Check	C check
	Corrosion	Eddy current test	4A check

Therefore, the maintenance tasks and intervals for selected structures due to Accidental Damage and Environmental Deterioration are shown in Table 4-4 below.

Table 4-4 Structural maintenance tasks and intervals due to AD/ED

Task ID	Task Description	Task Method	Task Area	Task Interval
01.a.001	Check for physical damage on skin panel	Visual Check	Fuselage skin panel	A check
01.a.002	Check for corrosion on external surface of skin panel	Visual Check	Fuselage skin panel	A check
01.a.003	Check for failed rivets and sealant on skin panel	Visual Check	Fuselage skin panel	A check
01.4a.001	Check for corrosion on internal surface of skin panel	Eddy Current Test	Fuselage skin panel	4A check
01.4a.002	Check for entrapped water inside skin panel	Infrared Inspection	Fuselage skin panel	4A check
03.4a.001	Check for corrosion on wing root joint	Eddy Current Test	Wing root joint	4A check
02.4a.001	Check for corrosion on fin-fuselage attachment	Eddy Current Test	Fin-fuselage attachment	4A check
03.c.001	Check for loose bolts on wing root	Visual Check	Wing root joint	C check

	plates			
02.c.001	Check for loose bolts on fin-fuselage attachments	Visual Check	Fin-fuselage attachment	C check

4.2.7 To Determine Damage Tolerant or Safe Life

In this research, all selected structural items were designed under the philosophy of damage tolerant.

Damage tolerant structures need to be inspected due to possible fatigue damage at a certain frequency in accordance with Continuing Airworthiness instructions suggested by the manufacturer (refer to Table 4-5).

For safe life category, the manufacturer will generate safe-life limit which is included in the aircraft Airworthiness Limitations. And this field will not be contained in this research.

Table 4-5 Category as damage tolerant or safe-life

Structure	Design suggested interval	Aircraft service life	Category
Fuselage skin panel	17,872 flights	50,000 flights	Damage tolerant
Fin-fuselage attachment	53,511 flight hours	90,000 flight hours	Damage tolerant
Wing root joint	92,248 flight hours	90,000 flight hours	Damage tolerance

4.2.8 Fatigue Damage Analysis

All fatigue analysis results from structural detail design phase of Flying Crane project were based on damage tolerance philosophy. Visible crack length was applied. Thus, the author selected visual check as the method to detect fatigue damage (refer to Figure 4-6).

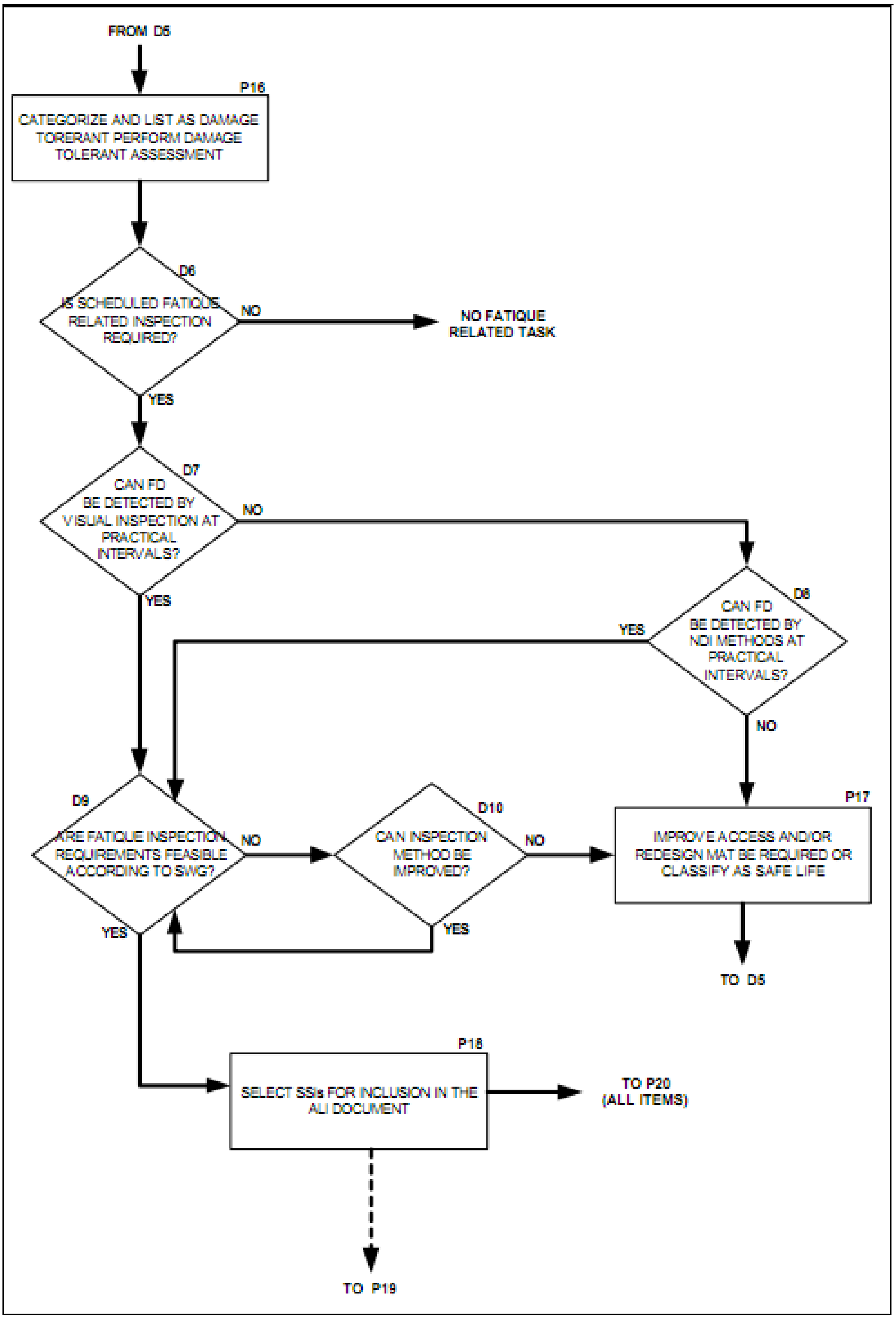

Figure 4-6 MSG-3 Fatigue Damage logic diagram (ATA, 2003, MSG-3 Logic)

For fuselage skin panel, the designer suggested inspection interval was 4,468 flights. Because Flying Crane aircraft is designed aimed at Chinese domestic market, the author assumed the average operating duration per flight is three hours, which is compatible to the airline between Beijing and Guangzhou, two of the biggest cities in domestic China (Official website of Civil Aviation Administration of China, 2010).

Thus, to convert flights to flight hours, the suggested inspection interval of fuselage skin panel equals to 4,468 flights multiple 3 hours per flight equals to 13,404 flight hours. Since the C check interval of Flying Crane is 6,000 flight hours, the inspection to fatigue damage on fuselage skin panel should be taken every two C checks during operation.

For the fin-fuselage attachment, the designer suggested inspection interval was 17,837 flight hours. Because a safety factor of 4 was applied in the detail design phase, it is acceptable to extend the inspection interval to 18,000 flight hours, which equals to three C check intervals.

For the wing root joint, the inspection interval was 92,248 flight hours, which already exceeded the length of aircraft service life. So in this research, there was no maintenance task related to fatigue damage for wing root joint. Table 4-6 provides a summary of the maintenance tasks and intervals due to fatigue damage.

Table 4-6 Structural maintenance tasks and intervals due to Fatigue Damage

Task ID	Task Description	Task Method	Task Area	Task Interval
01.2c.001	Check for fatigue crack on skin panel	Visual Check	Fuselage skin panel	2C check
02.3c.001	Check for fatigue crack on fin-fuselage attachment	Visual Check	Fin-fuselage attachment	3C check

4.2.9 Generating Preliminary Scheduled Structural Maintenance

So far, a preliminary maintenance schedule, which contains structural maintenance tasks and intervals, can be generated (Table 4-7).

It is necessary to clarify that,

- This preliminary scheduled structural maintenance should be submitted to and selected by Structures Working Group (SWG) and proved by Industry Steering Committee (ISC), and then included in the Maintenance Review Board (MRB) report proposal.
- It is supposed to be more detail information such as inspection instructions, required qualification, etc. This range of information should be provided by

design department, maintenance department, and quality department of the manufacturer in the real life.

Table 4-7 Scheduled Maintenance for Selected Structures

Task ID	Task Description	Task Method	Task Area	Task Interval
01.a.001	Check for physical damage on skin panel	Visual Check	Fuselage skin panel	A check
01.a.002	Check for corrosion on external surface of skin panel	Visual Check	Fuselage skin panel	A check
01.a.003	Check for failed rivets and sealant on skin panel	Visual Check	Fuselage skin panel	A check
01.4a.001	Check for corrosion on internal surface of skin panel	Eddy Current Test	Fuselage skin panel	4A check
01.4a.002	Check for entrapped water inside skin panel	Infrared Inspection	Fuselage skin panel	4A check
03.4a.001	Check for corrosion on wing root	Eddy Current Test	Wing root joint	4A check

	joint			
02.4a.001	Check for corrosion on fin-fuselage attachment	Eddy Current Test	Fin-fuselage attachment	4A check
03.c.001	Check for loose bolts on wing root plates	Visual Check	Wing root joint	C check
02.c.001	Check for loose bolts on fin-fuselage attachments	Visual Check	Fin-fuselage attachment	C check
01.2c.001	Check for fatigue crack on skin panel	Visual Check	Fuselage skin panel	2C check
02.3c.001	Check for fatigue crack on fin-fuselage attachment	Visual Check	Fin-fuselage attachment	3C check

4.3 Scheduled Maintenance for Selected System

In MSG-3 logic, airframe system analysis needs more supportive data from system designers and reliability department than structures.

For each item under analysis, the following must be identified in advance: functions, functional failures, failure effects, and failure causes.

For this reason, in this study, the author selected fuel system as the example to implement MSG-3 system analysis because of the availability of such necessary data.

4.3.1 Introduction to Fuel System

The fuel system of Flying Crane was developed by Mr Zhaoang Meng during the detail design phase. It has four main sub-systems, which are engine/APU feed system, refuel/defuel system, vent/scavenge system, and fuel management system.

Inside each wing, there are three fuel tanks, which are inner tank, outer tank and surge tank. Among them, inner tanks and outer tanks are fuel tanks providing fuel directly to the engine and APU. And surge tanks are pressurization tanks, which is used to keep balance of the aircraft. (Zhaoang Meng, Cranfield University Group Design Report, 2010)

The necessary input of this section, functions, functional failures, failure effects, and failure causes, was delivered in the means of Failure Mode and Effects Analysis (FMEA), which was developed with the assist from maintainability designer, Mr Wangfeng Yang (seen in Figure 4-7).

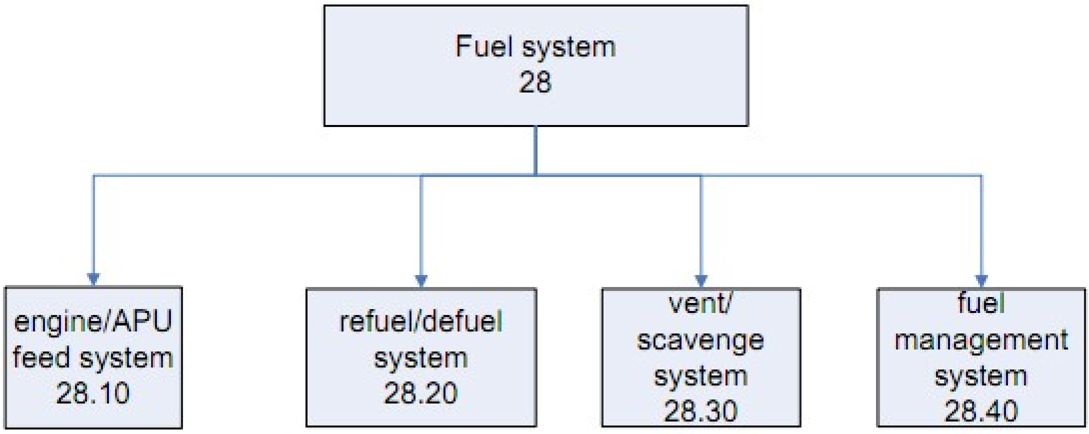

Figure 4-7 Flying Crane fuel system structure

(Wangfeng Yang, Cranfield University Group Design Report, 2010)

Due to the limitation on space, the author took partial of the FMEA analysis form as example to explain the system maintenance development procedure.

Table 4-8 A Section of FMEA Analysis Form (Wangfeng Yang, Cranfield University Group Design Report, 2010)

Failure Mode and Effects Analysis - Flying Crane												
System : fuel system（28） Subsystem: engine/APU feed system（28.10）							Date source: Analyst: WY and Z M		Date: 21-6-2010			
Item Number	Item Description	Function description	Failure Mode ID	Failure Mode	Failure cause	Local Effect	Next Higher Effects	End Effects	Sev.	Detection Method	Compensating Provisions	Remarks
28.10.01	AC boost pump	supply engine with fuel from tank under the specific pressure and flow	FM-01	Loss function of delivering fuel	motor failure	Other pumps workload increase	fail to provide fuel to engine	Loss thrust	II	Sensor	Warning	Backup
					Jam because of contamination	Other pumps workload increase	fail to provide fuel to engine	Loss thrust	II	Sensor	Warning	measure fuel pollution Regularly
			FM-02	provide fuel with low pressure and/or flow	wear or corrosion	Other pumps workload increase	provide un sufficient fuel to engine	the thrust decreased	II	NO	Warning	Preventive inspection
28.10.02	DC APU pump	supply fuel to APU under the specific pressure and flow	FM-01	fail to deliver fuel	motor failure	Other pumps workload increase	APU fails to work(on ground)	Fail to star engine	V	Sensor	Use the ground electrical power unit	Backup
							APU fails to work(in flight)	failed to provide electrical power to	I	Sensor	Warning	measure fuel pollution Regularly

Failure Mode and Effects Analysis - Flying Crane

System : fuel system（28） Subsystem: engine/APU feed system（28.10）	Date source: Analyst: WY and Z M Date: 21-6-2010

Item Number	Item Description	Function description	Failure Mode ID	Failure Mode	Failure cause	Local Effect	Next Higher Effects	End Effects	Sev.	Detection Method	Compensating Provisions	Remarks
								aircraft				
					Jam because of contamination	Other pumps workload increase	APU fails to work(on ground)	Fail to star engine	Ⅴ	Sensor	Use the ground electrical power unit	Backup
						N/A	APU fails to work(in flight)	failed to provide electrical power to aircraft	Ⅰ	Sensor	Warning	measure fuel pollution Regularly
	the Main Generation Assembly check valve Permits fluid flow through the		FM-02	provide fuel with low pressure	wear or corrosion	N/A	provide insufficient fuel to APU (on ground)	Fail to star engine	Ⅴ	Sensor	Use the ground electrical power unit	Backup
						N/A	provide insufficient fuel to APU (in flight)	APU function descend/no enough electrical power	Ⅰ	Sensor	Warning/decrease the power load	measure fuel pollution Regularly

4.3.2 Maintenance Significant Items Selection

Before the MSG-3 logic applied on system items, Maintenance Significant Items (MSI) should be identified.

To select maintenance significant items, the whole aircraft, as well as each system and sub-system, should be divided into major functional areas, until all replaceable items identified.

And then, those items would be judged from four aspects, which are detectability, safety affect, operational impact, and economic impact. Because fuel system is an airframe system closely related to flight safety and economy, all listed items were identified as Maintenance Significant Items.

At last, the candidate MSI list needs to be submitted to and get approval from Industry Steering Committee in the real industry.

This part of work was done in GDP phase and partly shown in table 4-9

Table 4-9 Failure Effect Category of Selected Maintenance Significant Items

Maintenance Significant Item	Functional failure	Failure effect category
AC boost pump	Loss function of delivering fuel	5
AC boost pump	provide fuel with low pressure and/or flow	5
DC APU pump	fail to deliver fuel (on ground)	6
DC APU pump	fail to deliver fuel (in flight)	5
DC APU pump	provide fuel with low pressure (on ground)	6
DC APU pump	provide fuel with low pressure (in flight)	5

4.3.3 Analysis Procedure

To prepare for the actual analysis procedure, for each Maintenance Significant Item, the functions, functional failures, failure effects, and failure causes should be identified clearly.

Generally, this range of information can be delivered within Failure Mode and Effects Analysis (FMEA).

Table 4-8 was a really practical style of FMEA. It listed every potential functional failure for each function, and clearly identified each functional failure's effects on three levels, which will be quite helpful and convenient in the analysis procedure.

The analysis itself has two levels. Level 1 is to categorize each functional failure by their failure effects. And level 2 is to determine what task applicable for each functional failure.

4.3.4 Category of Failure Effects (First Level)

In the following paragraphs, the author will analyse each item in table 4-8 through MSG-3 logic (see Figure 4-8 and Figure 4-9).

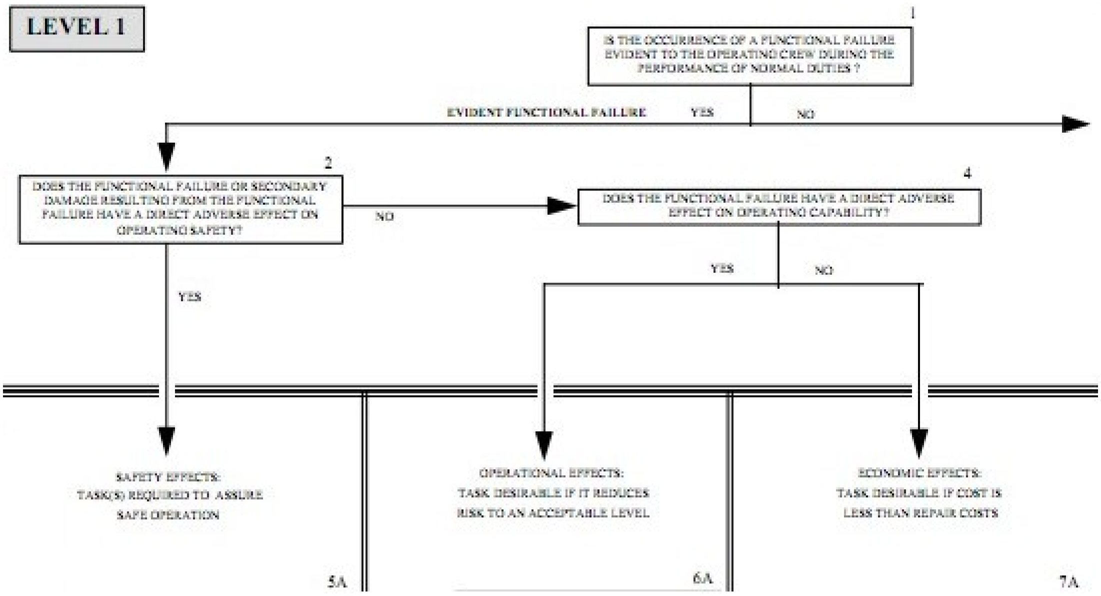

Figure 4-8 Level 1 System Logic - Part 1 of 2 (ATA, 2003, MSG-3 Logic)

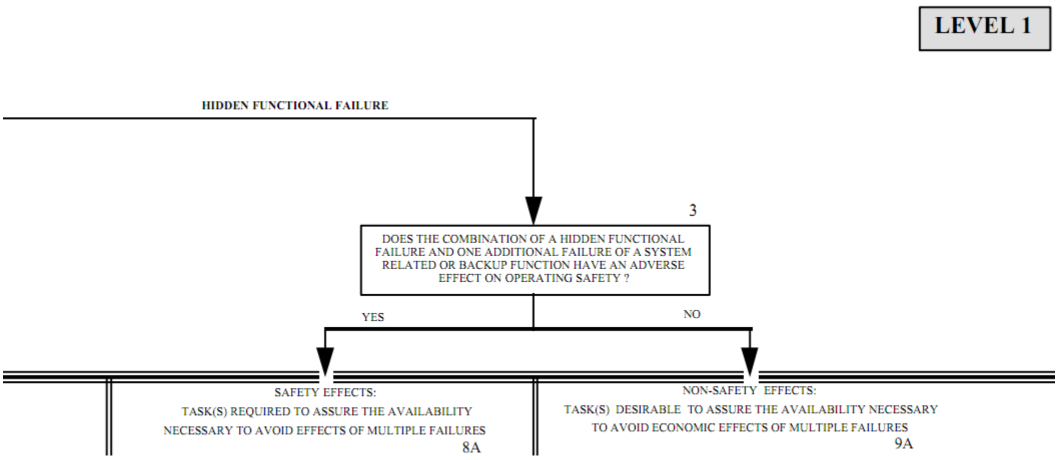

Figure 4-9 Level 1 System Logic - Part 2 of 2 (ATA, 2003, MSG-3 Logic)

Maintenance Significant Item: 28.10.01, AC boost pump

Functional failure: FM-01, Loss function of delivering fuel

The answer to question 1 is YES. Because there will be indicators to warn the crew when this functional failure happens. Now turn to question 2.

The answer to question 2 is YES. Loss of fuel delivery will lead to loss of engine thrust. And the severity of this functional failure is II, hazardous, which means large adverse effects will be committed.

Thus, the functional failure, “loss function of delivering fuel”, was categorized as Category 5, “Safety Effects”.

Functional failure: FM-02, provide fuel with low pressure and/or flow

With the same analysis routine, this functional failure was categorized as Category 5, “Safety Effects”.

Maintenance Significant Item: 28.10.02, DC APU pump

Functional failure: FM-01, fail to deliver fuel

When this failure happens on ground, it is evident to the crew. It has no adverse effect on safety, but adverse effect on operating capability. So it is categorized as Category 6, “Operational Effects”.

Quite differently, when this failure happens in flight, although it is still evident to the crew, it has great adverse effects on safety because of lacking electrical power provided. So it is categorized as Category 5, “Safety Effects”.

Functional failure: FM-02, provide fuel with low pressure

Compatible with FM-01, two situations should be considered.

When this failure happens on ground, it is evident to the crew. And it has no adverse effect on safety, but adverse effect on operating capability. So it is categorized as Category 6, “Operational Effects”.

When this failure happens in flight, although it is still evident to the crew, it has great adverse effects on safety because of lacking electrical power provided. So it is categorized as Category 5, “Safety Effects”.

4.3.5 Tasks Development (Category 5, Second Level)

The category 5 is functional failures which have evident safety effects. For those functional failures related to safety, all questions should be asked.

The functional failure of loss function of delivering fuel, AC boost pump was taken as example.

This functional failure has two possible causes, which are motor failure and contamination jam.

Refer to Figure 4-10, Question 5A: YES. For motor failure, scheduled lubrication and servicing would be helpful to maintain the motor at a good working condition. For contamination jam, a clearance for all related fuel tubing will help reduce the risk of this functional failure.

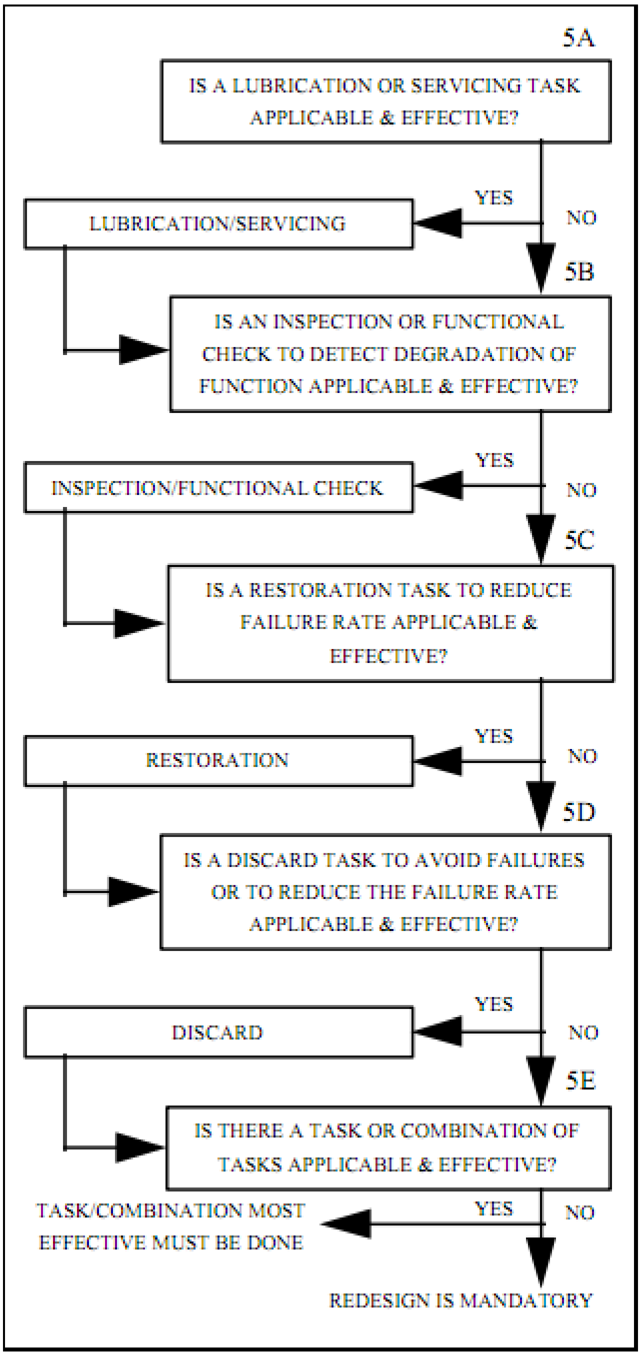

Figure 4-10 Functional Failures Categorized as Evident Safety Effects (ATA, 2003, MSG-3 Logic)

Proposed tasks:

i. Pump motor servicing

ii. Fuel tubing cleaning

Question 5B: YES. Figure 4-11, which is called P-F curve, demonstrates what happens in an item's service life. It is a widely accepted concept in reliability-centred maintenance. As shown in P-F curve, a functional failure happens at point F, and it had been detectable since point P. So in the period between point P and F, the potential failure can be found out by an inspection or functional check.

Proposed tasks:

iii. Functional check the AC boost pump

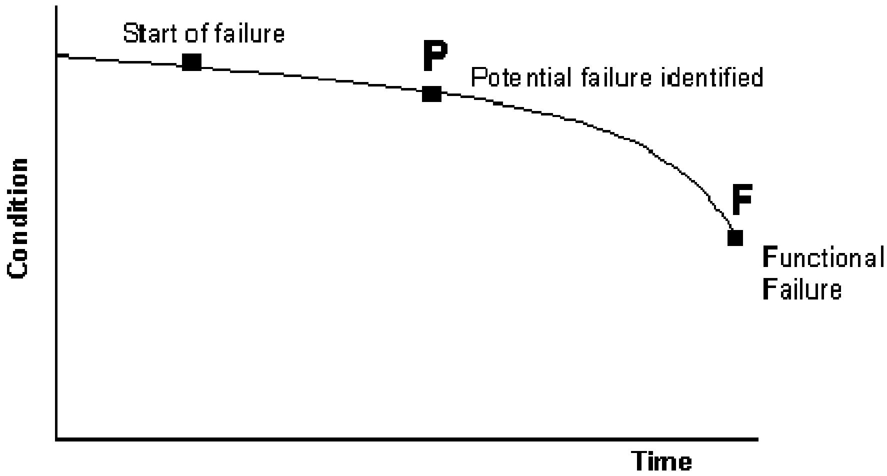

Figure 4-11 The P-F curve (John Moubray, 1997)

Question 5C: YES. For finished products such as AC boost pump, it is necessary to uninstall them after a certain period of usage and send them back to the work shop to restore them into a high working condition.

Proposed tasks:

iv. Alternate AC boost pumps for restoration

Question 5D: YES. After a long period of usage, there will be unrecoverable internal wear within the pump. So in this condition, a discard is needed.

Proposed tasks:

v. Discard the AC boost pump

Question 5E: YES. In this step, as this is a category related to safety, every task should be taken unless it is totally covered by another, or several of them can be combined into one with all original purpose. Among the tasks proposed above, the fifth task, discard the AC boost pump, can be combined with the forth task, alternate AC boost pumps for restoration. Because when the pumps back to the work shop, the supplier would determine its availability. If a discard is needed, it will happen together with restoration works. So there’s no need to discard the pump when maintaining the system.

The same procedure was applied on the other three functional failures which categorized as evident safety effects. Table 4-10 shows the proposed maintenance tasks.

Table 4-10 Proposed Maintenance Tasks for Category 5 Functional Failures

Maintenance Significant Item	Task Description	System
AC boost pump	Servicing AC boost pump motor	Fuel system
AC boost pump	Cleaning tubing connected to AC boost pump	Fuel system
AC boost pump	Test AC boost pump fuel supply pressure	Fuel system
AC boost pump	Functional check the AC boost pump	Fuel system
AC boost pump	Alternate AC boost pumps for restoration	Fuel system
DC APU pump	Servicing DC APU pump motor	Fuel system
DC APU pump	Cleaning tubing connected to DC APU pump	Fuel system
DC APU pump	Test DC APU pump fuel supply pressure	Fuel system
DC APU pump	Functional check the DC APU pump	Fuel system
DC APU pump	Alternate DC APU pump for restoration	Fuel system

4.3.6 Tasks Development (Category 6, Second Level)

The category 6 is functional failures which have evident operational effects. The author took the failure of fail to deliver fuel (on ground), DC APU pump as example to implement the level two analysis procedure for Category 6 system items. Because this procedure was quite similar with Category 5, the author described the part which is different than the Evident Safety Effect category (see Figure 4-12).

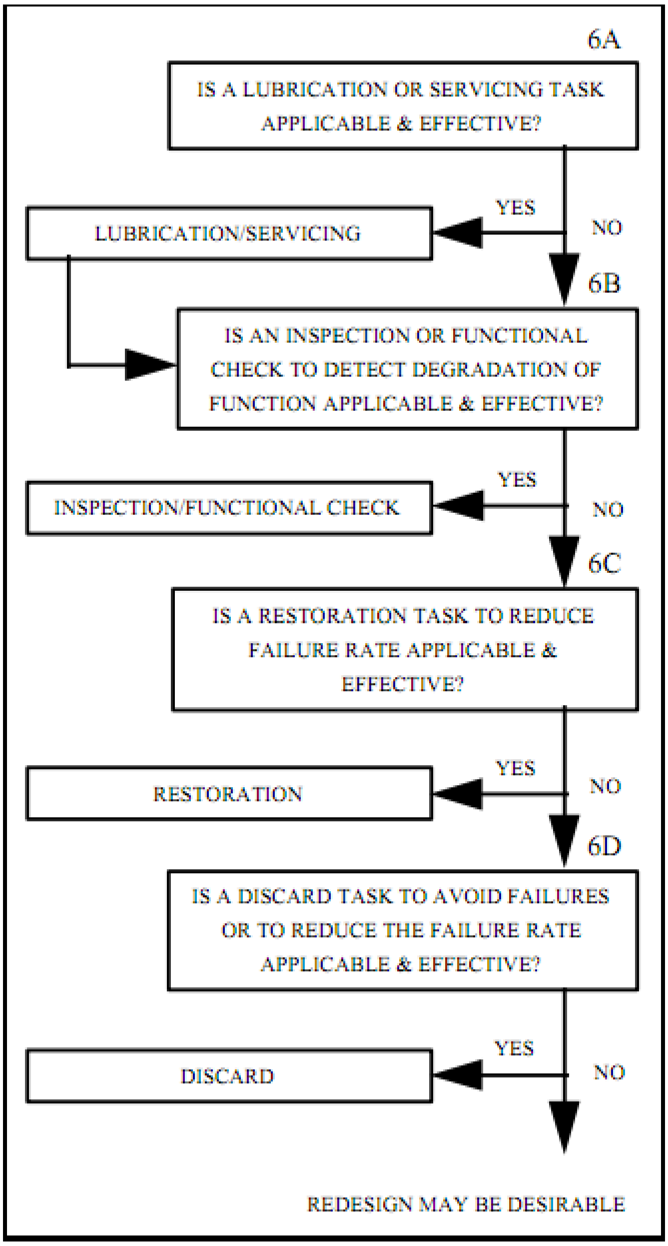

Figure 4-12 Functional Failures Categorized as Evident Operational Effects (ATA, 2003, MSG-3 Logic)

There are two possible causes of this functional failure, which are motor failure and contamination jam.

The most significant different between the analysis procedures of Evident Operational Effects category and Evident Safety Effects category is that, in Category 6, it is not necessary to go through the whole procedure every time.

For example, for the functional failure of “fail to deliver fuel (on ground)”, the answer to question 6B is YES. Then it comes to “inspection or functional check”, which is the end of this procedure.

It is because that, these kind of functional failures has no relationship with flight safety. From airworthiness point of view, it is acceptable to take Condition-based Maintain, which means maintenance performed after their occurrence.

Thus, the proposed tasks for this failure are shown in Table 4-11.

Table 4-11 Proposed Maintenance Tasks for Category 6 Functional Failures

Maintenance Significant Item	Task Description	System
DC APU pump	Servicing DC APU pump motor	Fuel system
DC APU pump	Cleaning tubing connected to DC APU pump	Fuel system
DC APU pump	Test DC APU pump fuel supply pressure	Fuel system
DC APU pump	Functional check the DC APU pump	Fuel system

4.3.7 System Maintenance Task Intervals Development

In the realistic industry, for a new designed aircraft, it is almost impossible to establish the “right” interval for maintenance tasks, because of the lack of specific data of functional failure rates and characteristics.

Basically, in the type design and certificate phase, intervals for system maintenance tasks are developed based on service experiences data collected from comparative systems, components, and aircrafts.

From Continuing Airworthiness' perspective, for the consideration of flight safety, the recommendation of "shorten the initial interval, then extend it gradually" will be given to the manufacturers and maintenance organizations, especially relevant experience data is inaccessible.

There are three main methods to determine maintenance task intervals in nowadays aviation industry.

For finished products such as pumps and valves in fuel system, the suggested Mean Time Between Failure (MTBF) should be provided by product suppliers to help determine maintenance task intervals.

Another method to determine maintenance interval is manufacturer's experiment and engineering analysis. And relative record and data should be submitted to the competent authority together with the results.

The third method is make development based on experience data from similar aircraft types in service. But, even for one single aircraft, the maintenance programme could vary dramatically from different periods in its service life. For one single type, different airlines could have quite different maintenance plans due to different maintenance ability and operational circumstances.

For the reasons described above, the author did not make the predictive maintenance intervals for airframe systems. The author hopes in the future research in this field, there could be an individual research topic, which is to determine system maintenance intervals with reliability-centred maintenance theory.

4.4 Continuing Airworthiness Instructions

The scheduled maintenance tasks and intervals for systems and structures is contained in the Maintenance Review Board Report (MRBR). MRBR is one of the documents related to Continuing Airworthiness, submitted by type design organizations and proved by regulatory authorities like EASA.

Other than MRBR, these documents include Aircraft Flight Manual (AFM), Airworthiness Limitation Items (ALI), Certification Maintenance Requirement (CMR), and Main Minimum Equipment List (MMEL).

This collection of documents is defined as Continuing Airworthiness Instructions for type certification.

4.4.1 Organizations of Continuing Airworthiness instructions Development

In the realistic industry, any of Continuing Airworthiness instructions is not developed or determined by any single organization. They can be checked and revised times and times by different types of organizations assembled to control and support the development procedure.

Taking the maintenance schedule as example, all maintenance tasks and intervals should be developed in associate with the Industry Steering Committee (ISC) and Maintenance Working Group (MWG).

The members of ISC include representative from manufacturer and operators. This organization is considered as the leader or guide for maintenance development procedure. It accounts for work related to policy, management, plan, final approval, and contact with regulatory authority.

On the other hand, the MWG's, which consists of specialist representatives from operators, manufacture, and regulatory authority, are much more like supportive organizations providing supportive information such as technical data, experiential recommendations, engineering analysis, which shall be contained into the final report presented to regulatory authority.

4.4.2 Proposed Continuing Airworthiness Instructions of Flying Crane

As an initial form of a part of Continuing Airworthiness instructions, the scheduled maintenance developed by the author includes proposed predictive maintenance tasks and intervals for three structural items (fuselage skin panel, fin-fuselage attachment, and wing root joint) and one airframe system (propulsion and fuel system) based on design data of Flying Crane project, which is the Group Design Project of Aircraft Design Programme in academic year 2010 (see Table 4-12).

Due to the limitation on time and space, lack of experiential data sources, and limited results from detailed design phase, the author were not able to make this research into a very specific level. Therefore, in the sixth chapter, the author gave his own suggestion to future study.

Table 4-12 Proposed Maintenance Schedule for Structures and Systems of Flying Crane

Task ID	Task Description	Task Method	Task Area	Task Interval
01.a.001	Check for physical damage on skin panel	Visual Check	Fuselage skin panel	A check
01.a.002	Check for corrosion on external surface of skin panel	Visual Check	Fuselage skin panel	A check
01.a.003	Check for failed rivets and sealant on skin panel	Visual Check	Fuselage skin panel	A check
01.4a.001	Check for corrosion on internal surface of skin panel	Eddy Current Test	Fuselage skin panel	4A check
01.4a.002	Check for entrapped water inside skin panel	Infrared Inspection	Fuselage skin panel	4A check
03.4a.001	Check for corrosion on	Eddy Current Test	Wing root joint	4A check

	wing root joint			
02.4a.001	Check for corrosion on fin-fuselage attachment	Eddy Current Test	Fin-fuselage attachment	4A check
03.c.001	Check for loose bolts on wing root plates	Visual Check	Wing root joint	C check
02.c.001	Check for loose bolts on fin-fuselage attachments	Visual Check	Fin-fuselage attachment	C check
01.2c.001	Check for fatigue crack on skin panel	Visual Check	Fuselage skin panel	2C check
02.3c.001	Check for fatigue crack on fin-fuselage attachment	Visual Check	Fin-fuselage attachment	3C check
28.10.001	Servicing AC boost pump motor	Lubrication/ Serving	Fuel System	TBD

28.10.002	Cleaning tubing connected to AC boost pump	Lubrication/ Serving	Fuel System	TBD
28.10.003	Test AC boost pump fuel supply pressure	Inspection/ Functional Check	Fuel system	TBD
28.10.004	Functional check the AC boost pump	Inspection/ Functional Check	Fuel system	TBD
28.10.005	Alternate AC boost pumps for restoration	Restoration	Fuel system	TBD
28.10.006	Servicing DC APU pump motor	Lubrication/ Serving	Fuel system	TBD
28.10.007	Cleaning tubing connected to DC APU pump	Lubrication/ Serving	Fuel system	TBD
28.10.008	Test DC APU pump fuel supply pressure	Inspection/ Functional Check	Fuel system	TBD

28.10.009	Functional check the DC APU pump	Inspection/ Functional Check	Fuel system	TBD
28.10.010	Alternate DC APU pump for restoration	Restoration	Fuel system	TBD

Notes: A check = 600 Flight Hours

C check = 20 Months or 6,000 Flight Hours

5 Selection of Chinese Maintenance Organizations

As the target market of Flying Crane aircraft is Mainland China, the Flying Crane was supposed to be operated by Chinese domestic airline companies. And the Continuing Airworthiness of Flying Crane was supposed to be maintained by qualified Chinese domestic aircraft maintenance organizations as well.

In this chapter, the author introduced the responsibilities of maintenance organizations, and the criteria to select maintenance organizations for Flying Crane aircraft.

5.1 The Role of Maintenance Organizations

A qualified and certified Maintenance Organization is supposed to have adequate capability and correct qualification to maintain aircrafts and aircraft components in accordance with Continuing Airworthiness instructions from the manufacturer.

The business scope of maintenance organizations includes inspection, repair, modification, overhaul, line maintenance, and other maintenance tasks required by operators and authorized by competent authority (see Figure 5-1).

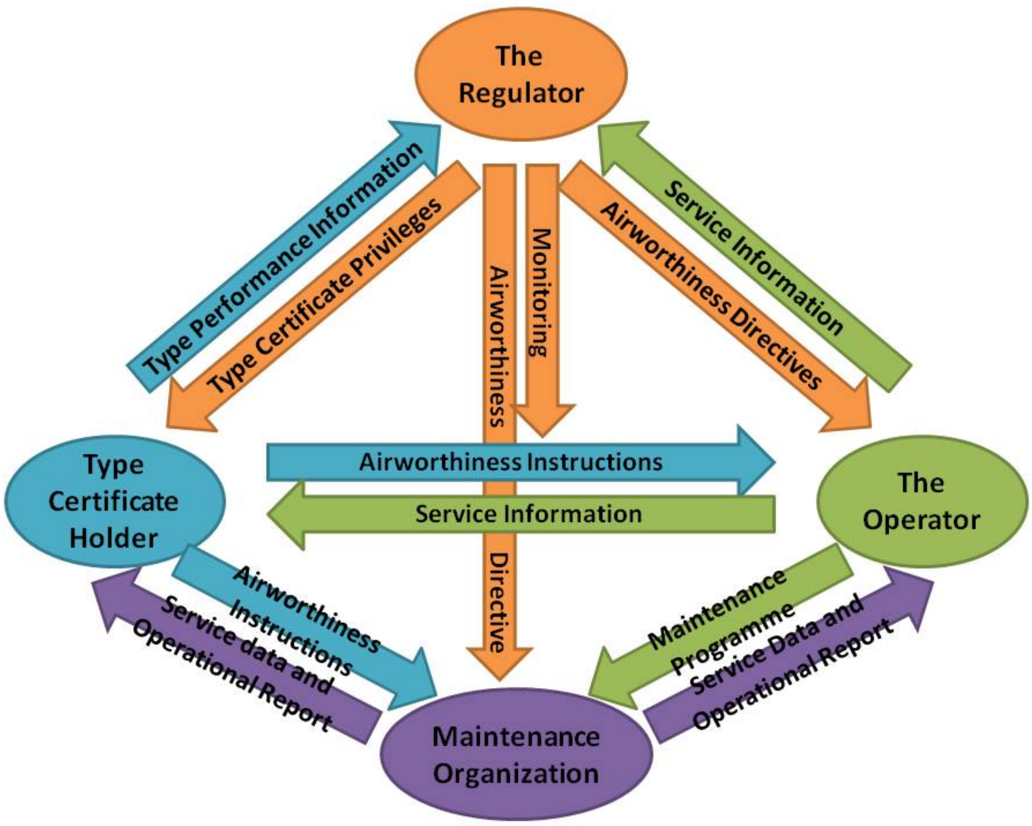

Figure 5-1 the Role of Maintenance Organization in Continuing Airworthiness

Other than the three basic roles, the Regulator, the TC Holder, and the Operator, Maintenance Organization is not legally indispensible in the world of Continuing Airworthiness.

However, in the realistic civil aviation industry, it is neither economic nor technically feasible for airline companies to undertake all maintenance work during aircraft operation life. Thus, for most civil aircraft operators, to cooperate with specific aircraft maintenance enterprise is the solution.

Basically, from the perspective of airworthiness management, maintenance organization is a unit sharing tasks related to maintenance with aircraft operator. And it has the same responsibility of implementing airworthiness directives from Regulatory Authority and exchanging information with manufacturer as well.

The responsibilities of maintenance organization include:

- To strictly follow every certified maintenance programme issued by operator and manufacturer;
- To implement every airworthiness directive issued by Regulatory Authority;
- To record any inaccuracy, deficiency, and redundancy of maintenance programme discovered during practical operations, and give feedback to the operator and manufacturer;

5.2 Selection Criteria

5.2.1 Maintenance Approval Class and Rating

According to Part-145, the scope of organization's work is defined and classified by the approval classes and ratings granted by competent authority. The scope declines from Category A to Category D. Meanwhile, Category A is partitioned into Base and Line maintenance.

For instance, the 4C check for fuselage and engine overhaul have to be undertaken in maintenance organizations with Category A classes and ratings. But for A check, a Category C is applicable.

5.2.2 Hangar Capacity

Larger hangar capacity assures higher efficiency during parallel processing.

But the demand of large hangar capacity depends on the fleet size of the specific operator.

5.2.3 Market Performance and Experience

Market is a good tool to measure the capability of an enterprise. So it is significant to choose maintenance organizations with comparatively higher market share.

In addition, different types of aircrafts have different structure characteristic, system layout, and engine size. So the experience of maintaining aircrafts on the comparative level with Flying Crane (e.g. Boeing 737 and Airbus A320) is another important factor.

5.2.4 Technical Requirements

In the maintenance plan proposed in Chapter 4, the scheduled maintenance had contained A check, 4A check, C check, 2C check, and 3C check. Due to different maintenance intervals, the according maintenance tasks had different technical requirements. From economic and operational perspective, maintenance organizations with different technical level should be selected for different maintenance tasks.

5.2.5 Accessibility

For shorter interval checks, such as A Checks, the location of the selected maintenance organization should not be far from most often used airport.

5.3 Selecting Maintenance Organizations in China

Even during 2007 and 2008, in which the global financial crisis went the most seriously, a rapid increase was remained in civil aviation market of China. Along with the development of civil aviation, the aviation maintenance industry is experiencing a fast growth as well.

In Chapter 4, the author developed a series of scheduled maintenance tasks in different check intervals. In the following paragraphs, the author would recommend one Chinese maintenance organization for each maintenance type, based on the scheduled maintenance (Table 5-1), and in accordance with the criteria set in Section 5.2.

Table 5-1 Technical Requirements for Maintenance tasks at Different Interval

Interval	Task
A Check	Visual Check for corrosion and physical damage
4A or C Check	Eddy Current Test; Infrared Inspection; X-ray Inspection
2C or 3C Check (overhauls)	Visual Check (de-painting required); Visual Check (large component removal required)

Within the author's investigate to aircraft maintenance companies in Mainland China, the top four of them were taken under consideration.

According to the selection criteria established in section 5.2, the candidate companies were analyzed and rated in the following Table 5-2.

Table 5-2 Maintenance Organization Selection Matrix

	TAECO Taikoo (Xiamen) Aircraft Engineering Company, Limited		**GAMECO** Guangzhou Aircraft Maintenance Engineering Co. Ltd		**AMECO** Aircraft Maintenance and Engineering Corporation		**STAECO** Shandong Taikoo Aircraft Engineering Company, Limited	
	Score	**Description**	**Score**	**Description**	**Score**	**Description**	**Score**	**Description**
Maintenance Approval Class and Rating	7	Category A overhaul for Boeing 737/747/757/767, Airbus A330/340; Modification, Avionics Update, and Fuselage De-painting for Boeing 747-200/300/400 and MD11	9	Category A. A/B/C/D Check for Boeing 737/747/757/767/777, Airbus A319/320/321/300/330, and EMB145	8	up to Category A check of Boeing 737/747/757/767 and Airbus A320/330/340	8	Boeing 737 Classic A, C, D check; Boeing 737 Next Generation all check; Airbus A319/A320/A321 up to C check; Bombardier CRJ200/700 all check
Hangar Capacity	10	10 wide-body airliners and 5 narrow-body airliners	6	4 wide-body airliners or 12 narrow-body airliners	6	12 narrow-body airliners	4	10 narrow-body airliners

	TAECO Taikoo (Xiamen) Aircraft Engineering Company, Limited		**GAMECO** Guangzhou Aircraft Maintenance Engineering Co. Ltd		**AMECO** Aircraft Maintenance and Engineering Corporation		**STAECO** Shandong Taikoo Aircraft Engineering Company, Limited	
	Score	**Description**	**Score**	**Description**	**Score**	**Description**	**Score**	**Description**
Market Performance and Experience	7	focused on large airliner maintenance, relatively lack of experience about narrow body aircraft maintenance	7	experienced in maintaining narrow-body airliners	9	experienced in maintaining narrow-body airliners	5	experience in maintaining narrow-body airliners only
Technical Requirements	10	All requirements satisfied	10	All requirements satisfied	10	All requirements satisfied	10	All requirements satisfied
Accessibility	7	Located in Xiamen City, Fujian Province, which is on the coast of Southeast China	10	Located in Guangzhou City, Guangdong Province, South China	10	Located in Beijing, the Capital of China	5	Located in Jinan, Shandong, Mid-east China

	TAECO Taikoo (Xiamen) Aircraft Engineering Company, Limited		GAMECO Guangzhou Aircraft Maintenance Engineering Co. Ltd		AMECO Aircraft Maintenance and Engineering Corporation		STAECO Shandong Taikoo Aircraft Engineering Company, Limited	
	Score	**Description**	**Score**	**Description**	**Score**	**Description**	**Score**	**Description**
Overall	**41**		**42**		**43**		**32**	

Refer to the overall ratings, STAECO got the lowest score 32, which suggested that it did not obtain enough advantages compared with other candidate companies within this assessment rules.

The other three companies got almost the same score, which indicated that they all satisfied the maintenance demands of Flying Crane.

Based on their own advantages, they were designated respectively as maintenance organizations for overhauls, mid-term maintenance and short-term maintenance for the following reasons.

- For maintenance organization for overhauls, large hangar capacity is necessary to ensure parallel working in order to keep process delay and time costs at a relatively low level.
- For maintenance organization for short-term maintenance, quickness and efficiency are priorities to be concerned. So the company located at the position with the highest accessibility was selected.
- For mid-term maintenance, both of above two points have to be considered, and the choice of the company with the richest experience with narrow-body airline maintenance ensured that potential significant failures could be discovered at a relatively high possibility.

The following is further information concerning the selected maintenance organizations.

i. Maintenance Organization for Overhauls

Organization: Taikoo Aircraft Engineering Company, Limited (TAECO)

Organization Introduction: Taikoo Aircraft Engineering Co. Ltd (TAECO), which is located in Xiamen City, Fujian Province (Southeast China), was initially launched in 1993. It has become one of the largest and most professional aircraft maintenance centre in the world.

Approval Class and Rating: Category A overhaul for Boeing 737/747/757/767, Airbus A330/340; Modification, Avionics Update, and Fuselage De-painting for Boeing 747-200/300/400 and MD11.

Hangar Capacity: simultaneously 10 wide-body airliners and 5 narrow-body airliners

(TAECO, 2010)

Advantages: the largest hangar capacity in China; high technical level.

Disadvantages: comparatively lack of experienced in narrow-body aircraft maintenance,

ii. Maintenance Organization for Mid-term Maintenance

Organization: Guangzhou Aircraft Maintenance Engineering Co. Ltd (GAMECO)

Organization Introduction: GAMECO is located in Guangzhou City, Guangdong Province (South China), firstly launched in 1989. Its main customer, China Southern Airline, is the biggest airline company in China

Approval Class and Rating: Category A. A/B/C/D Check for Boeing 737/747/757/767/777, Airbus A319/320/321/300/330, and EMB145

Hangar Capacity: simultaneously 4 wide-body airliners or 12 narrow-body airliners

(GAMECO, 2010)

Advantages: Largest Hangar other than TAECO; experienced in maintaining narrow-body airliners;

iii. Maintenance Organization for Short-term Maintenance

Organization: Aircraft Maintenance and Engineering Corporation (AMECO)

Organization Introduction: AMECO is located in Beijing, China, firstly launched in 1989, based on the Capital International Airfield of Beijing.

Approval class and rating: up to Category A check of Boeing 737/747/757/767 and Airbus A320/330/340

Hangar Capacity: simultaneously 12 narrow-body airliners

(AMECO, 2010)

Advantages: experienced in maintaining narrow-body airliners

6 Conclusion and Further Work

This is a research into Continuing Airworthiness from the perspective of a TC Holder (manufacturer), based on the detailed design of Flying Crane aircrafts.

6.1 Research Findings

In this research, two aspects of Continuing Airworthiness were investigated, including maintenance programme and maintenance organization.

For maintenance programme, the author selected the MSG-3 logic, which is the most accepted and widely used method to plan scheduled maintenance during aircraft Type design phase.

With MSG-3 logic, the author developed the maintenance plan for three structural components (fuselage skin panel, wing root joint, and fin-fuselage attachment) and one airframe system (fuel system) based on results from the Group Design Project in academic year 2010-2011.

For maintenance organization, the author investigated the Chinese domestic aircraft maintenance market, and selected applicable maintenance organizations technically and economically.

Within the research, the following findings have been achieved:

- In MSG-3 logic, the ultimate aim is to ensure flight safety, whilst both technology and economy are under consideration. And the key to Continuing Airworthiness is to balance the technology and economy as well.

- The technical basis of MSG-3 analysis is Reliability-centred Maintenance and Damage Tolerance, which related to airframe system maintenance and structure maintenance respectively.

- Experience, including design experience, operational experience, maintenance experience, plays a role no less importance than calculation and analysis. Because the preliminary maintenance plan is proposed on the basis of service experience, and approved by ISC (Industry Steering Committee), which consists of a group of experienced specialist from manufacturers, operators, and Regulatory Authority.

- MSG-3 logic is mainly focused on components with high level of importance. As in both system and structure analysis, to identify Maintenance/Structural Significant Items is the very first step.

- Maintenance programmes vary from operator to operator, fleet to fleet, aircraft to aircraft. Even one single aircraft could have different maintenance programme due to different service years. Thus, the maintenance plan developed by manufacture is just a proposal. The specific operators should build their own maintenance programmes due to the one proposed by manufacturers.

- Compared with other types of system safety analysis, FMEA (Failure Mode and Effect Analysis) is the most applicable as the input of MSG-3 system analysis. Because it contains all of the Function, Functional Failure, Failure Cause, and Failure Effect of a system or sub-system.

- The interval of maintenance task against functional failure can be resulted from MTBF (Mean Time Between Failures). In addition, the inherent MTBF of a system could be calculated by designer, and MTBF for procured products should be provided by the supplier.

- For a new type of aircraft, the initially proposed intervals of maintenance tasks are recommended to be comparatively shorter. The interval could be extended along with the increased service period.

6.2 Aim and Objectives Achieved

As set at the beginning of this research, the aim of research was to prove one means of compliance to satisfy the EASA requirements related to Continuing Airworthiness by applying the airworthiness requirements and the methodology of MSG-3 logic on Flying Crane.

The author believes the aim of research has been achieved by the achievement of the objectives as following:

- Objective: To investigate current Continuing Airworthiness regulations, including EASA airworthiness requirements (as the main regulation to comply with) and Chinese CCAR airworthiness regulations (as an important reference and supplement to the research)

✓ Achievement: Achieved. The author did investigate EASA requirements and CCAR regulations related to Continuing Airworthiness, and made comparison between those regulations. In addition, EASA requirements were applied along the whole research process.

- Objective: To investigate the main analysis methodology of reliability and maintainability, including Damage Tolerance and Failure Mode and Effect Analysis (FMEA);

✓ Achievement: Achieved. With the procedure of structure and system maintenance development, the results of both Damage Tolerance and FMEA were applied to MSG-3 logic.

- Objective: To analyze the data resulted from Group Design Project using MSG-3 logic to produce a set of Continuing Airworthiness instructions, for the operator and maintenance organization of the aircraft, from the design organization’s perspective;

- ✓ Achievement: Mostly Achieved. At the beginning of this research, three airframe systems and three structural items were planned to be analyzed with MSG-3 logic and resulted in Continuing Airworthiness instructions. But at present, there is only one system analyzed. The reason was that, the author was not able to realize the practical differences between different types of reliability tools such as Faulty Tree Assessment and FMEA. During the process of research, only FMEA delivered sufficient information for MSG-3 analysis. And due to the time limitation, only the fuel system, which contained a complete FMEA analysis form, was analyzed.

- Objective: To develop Continuing Airworthiness instructions for operator to compose maintenance programme for Flying Crane aircraft, including maintenance tasks and intervals for the selected airframe systems and structural components;

- ✓ Achievement: Mostly Achieved. But for the same reason with the previous objective, the proposed maintenance programme was not as much as initially supposed.

- To identify applicable maintenance organizations in China mainland for Flying Crane aircraft in accordance with both EASA and CCAR requirements.

- ✓ Achievement: Achieved. Three of Chinese domestic aircraft maintenance organizations were identified due to different maintenance types.

6.3 Limitation of MSG-3 Logic

As previously mentioned, experience, including design experience, operational experience, maintenance experience, plays an extremely important role during the MSG-3 logic.

In the reality of industrial applications, the preliminary maintenance plan is approved by ISC based on their industrial experience, and certified by specialist employed by competent authority based on their experience as well. That means the maintenance plan is largely proposed from experience, approved from experience, and certified from experience.

Indeed, this is actually reasonable because of the unpredictability of failure and damage. However, in this situation, it is really impracticable for theoretical research.

6.4 Recommendation for Further Work

6.4.1 Required Data to Implement MSG-3 Logic

Thanks to the effects of GDP teams, in this research, most of the required data for MSG-3 logic was available by the end of GDP phase. The available data includes:

- FMEA (Failure Mode and Effect Analysis) of selected system;
- Damage Tolerance analysis results of selected structures (Design life and suggested inspection intervals); and
- Intervals of A Check and C Check

In addition, in the future research related to Continuing Airworthiness and scheduled maintenance, it will be really helpful with the provision of the following data:

- MTBF (Mean Time Between Failure) of the same system with FMEA available; and
- Statistical data of Accidental Damage and Environmental Deterioration on selected structures.

6.4.2 Further Research Related to MSG-3

As previously discussed, due to limitation of theoretical research, further research focused on MSG-3 logic itself might be impracticable or meaningless.

However, inspirited from this research, the author recommended two areas of further research related to MSG-3:

i. The Rating System for Structures

During MSG-3 structure analysis, to identify the maintenance tasks and intervals due to Accidental Damage and Environmental Deterioration, it is necessary to rate the possibility of damage and detectability.

ii. Service Data Collection System

According to airworthiness regulation, aircraft operator and maintenance organization both have the responsibility to record service and maintenance data as the feedback to manufacturers. The output of such system could be the input of MSG-3 for improving scheduled maintenance plan.

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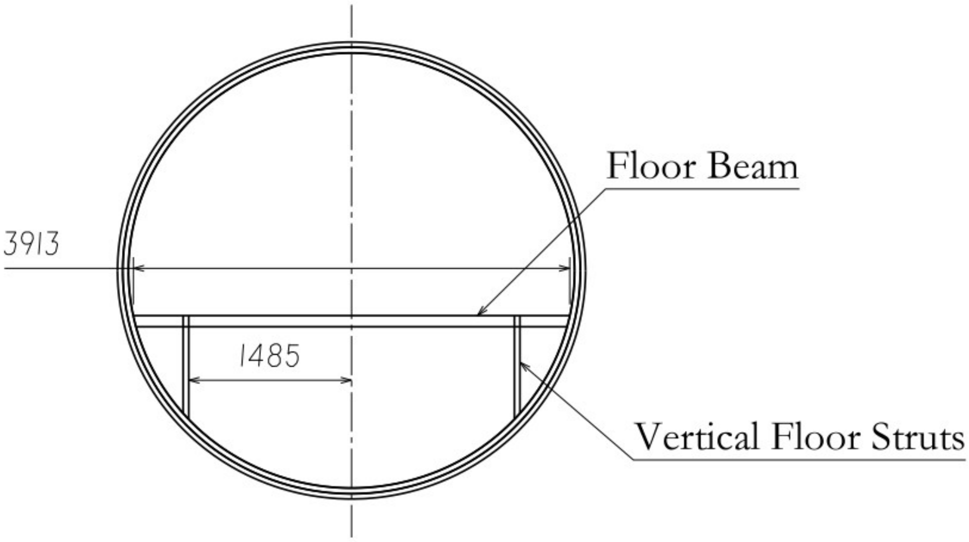
APPENDICES

Appendix A Floor Structural Calculation



A.1 Floor Beam

A.1.1 Alternation of Material

Aluminum alloy 7075-T7351 was chosen as the floor beam material by the designer in the Preliminary Design Phase. Meanwhile, there are two other types of aluminium alloy can be used for floor structures, which are 7075-T6 and 2024-T351. The author compared these three types of aluminium alloy and made a decision in his personal point of view.

Alloy	7075	7075	2024
Temper	T7351	T6	T351
Formability	Low	Low	Medium
Machinability	B	B	B
General Corrosion Resistance	C	C	D

Weldability	D	D	C
Brazeability	D	D	D
Anodizing Response	B	B	C
Stress Corrosion Cracking	B	C	C

According to the comparison, 7075-T7351 and 7075-T6 shows very similar characteristics. But 7075-T7351 performs better on Stress Corrosion Cracking. So 7075-T6 is out of consideration, and the final decision will be made between 7075-T7351 and 2024-T351.

Aluminium alloys 2024-T3 and 7075-T7351 are widely used for structural parts in high performance aircraft components because of their high strength/weight ratio. They also have other favourable characteristics obtained through specific heat treatments. T3 treatment consists of solubility heating at a temperature of 493℃, followed by a quench, cold work and natural ageing (ageing at room temperature). 2024-T3 alloys have an acceptable level of toughness. T7351 treatment consists of solubility heating, followed by a quench, artificial ageing and stress relieving treatment. 7075-T7351 alloy has a high strength but low stress corrosion cracking characteristics in all stress directions.

In conclusion, the aluminium alloy 2024-T351 was finally chosen for all these advantages.

The material properties were found in the ESDU Metallic Material Data Handbook.

t1 = 259 Mpa, t2 = 265 Mpa, E = 70 Gpa, v = 0.33, ρ = 2700 kg/m3

With the equations 4.1 and 4.2 from the ESDU 76016, m and f_n could be calculated as followed:

$$m = \frac{\log\left(\frac{\varepsilon_r}{\varepsilon'_r}\right)}{\log\left(\frac{f_R}{f'_R}\right)} = \frac{\log\left(\frac{0.001}{0.002}\right)}{\log\left(\frac{259}{265}\right)} = 30.3$$

$$fn = f_R \times \left[\frac{m \times \varepsilon_r \times E}{f_R}\right]^{\frac{-1}{m-1}} = 241\,\frac{N}{mm^2}$$

A.1.2 Verification on Previous Design of Floor Beam

The floor beam used to be design in the preliminary design phase. Because of the changing on material, the author re-calculated the floor beam to check whether the original style can work well with the new material.

In accordance with CCAR 25.561, the ultimate inertia force which the floor beams have to withstand is 6g downwards. This force is provided by passengers and seats. According to CCAR 25.562, the estimated mass of a passenger is 77kg, and the estimated mass of a seat is 11kg (2^{nd} cohort). The floor beam was calculated as followed.

Load from a 3-seat-assembly: 3 * (11 + 77) * 6 * 9.8 = 15523 N

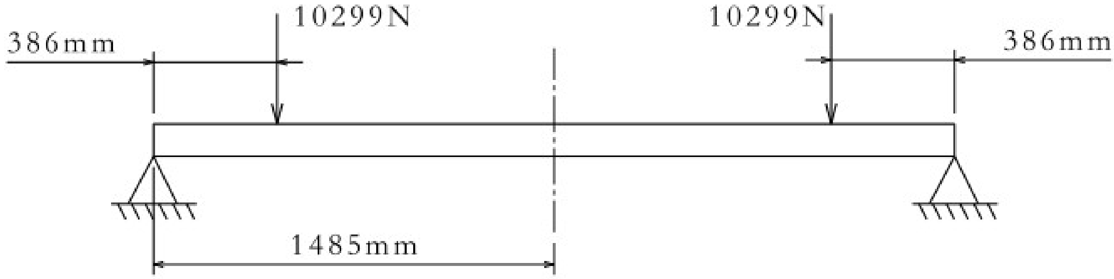
A safety factor of 1.5 was taken.

The author took the single-class configuration with 136 economy seats under consideration. And there are 23 rows of seats and 52 floor beams underneath.

So the load generated by 3-seat-assembly on each floor beam is:

15523 * 23 * 1.5 / 52 = 10299 N

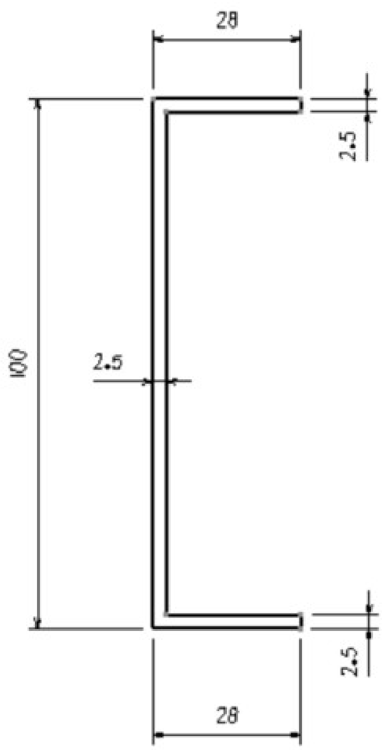
Because there are 2 struts supporting each floor beam on both sides, and the following loading case was taken:



According to the Aircraft Design Handbook,

M_{max} = P * a = 10299 N * 0.386 m = 3975 N*m

The beam section and relavant datas defined in preliminary phase is followed:



I_{xx} = 511411 mm^4

y = 50 mm

Then, σ = M_{max} * y / I_{xx} = 3975 N*m * 50mm / 511411 mm^4 = 389 MPa

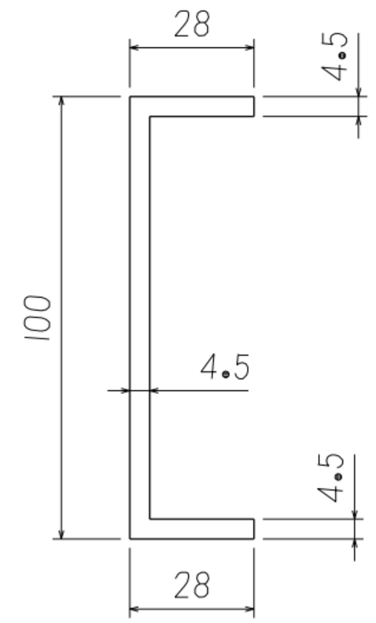
RF = f_n / σ = 241 / 389 = 0.62 < 1

Therefore, the original floor beam designed in the preliminary phase is not appropriate anymore due to the change of material. The author will explain his modification on floor beam in the following chapter.

A.1.3 Modification on Floor Beam Design

(I_{NA} needs to be more than 864130)

The author modified the web thickness of the floor beam section from 2.5 mm to 4.5 mm (shown in the following figure), then re-calculate the strength.



In accordance with the Aircraft Design Handbook

I_{xx} = [ah^3 – (a – t_1)b^3] / 12 = [28 * 100^3 – (28 – 4.5) * 95^3] / 12

= 857590 mm^4

Then, σ = M_{max} * y / I_{xx} = 3975 N*m * 50mm / 857590 mm^4 = 232 MPa

Thus, **RF = f_n / σ = 241 / 232 = 1.04 > 1**

Maximum deflection:

$Fa\ (3l^2 - 4a^2)\ /\ 24EI_{xx} = 73$ mm

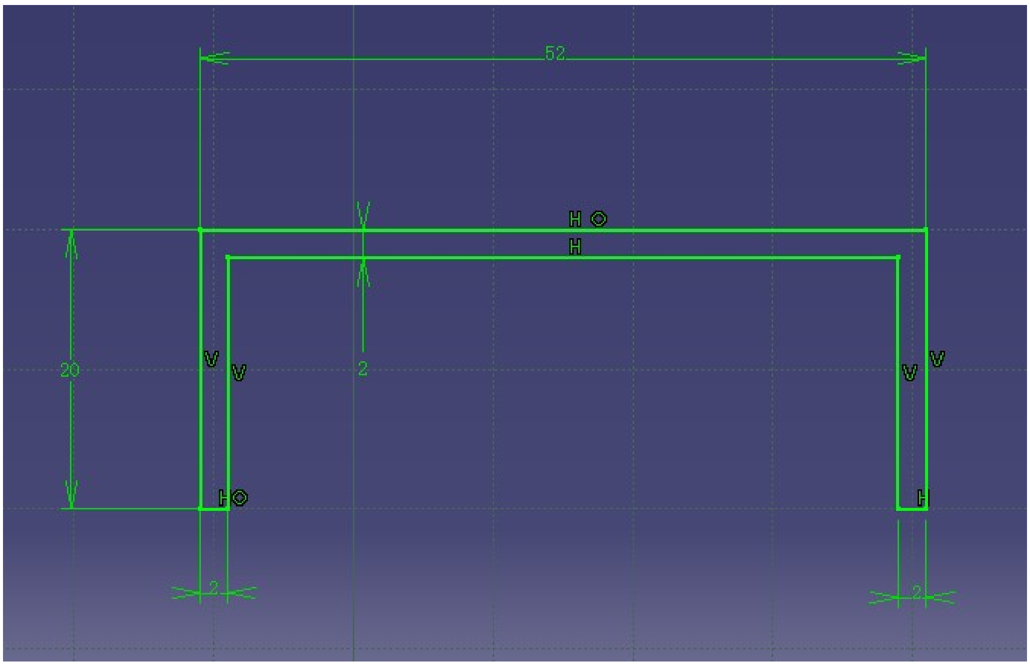
As it is an ultimate case, this deflection is acceptable.

A.2 Floor Vertical Struts Calculation

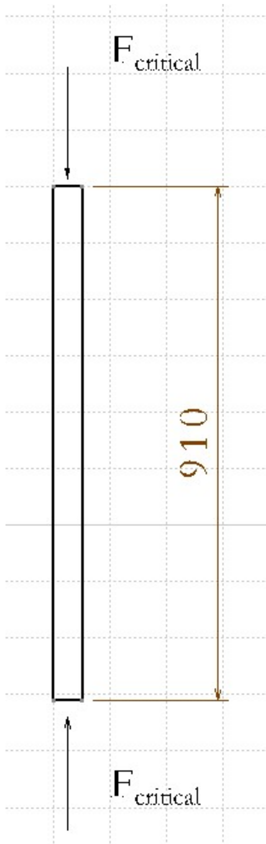
Vertical struts of floor beam were not mentioned in any report of preliminary design phase. But actually there are floor vertical struts in the CATIA model delivered by the 2nd cohort, without any information concerning material selections and strength calculations. In this situation, the author decided to verify the previous design using the new material firstly, and then made his own judgement and, probably, modifications.

According to the result calculated in the last chapter, the load generated by 3-seat-assembly on each floor beam is 10299 N. Additionally, the load from the two 3-seat assemblies in one row is equally carried by the vertical struts on both sides. So the load acting on each vertical struts, F_{column} = 10299 N.

A.2.1 Verification of Previous Floor Vertical Struts



Cross section of floor vertical struts



Floor vertical struts

$\sigma = F_{critical} / A_{column} = \pi^2 E / \lambda^2$

$\lambda = l / i$

$i = (I_{min} / A_{column})^{1/2}$

Because, $I_x = [\ ah^3 – (a – t_1)\ b^3\ ] / 12 = 68458.67\ mm^4$

And, $I_y = [\ h\overline{x}^3 – b(\overline{x} - t_1)^3 + at_2\ (a - \overline{x})^3\ ] = 91486.33\ mm^4$

Hence, $I_{min} = I_x = 68458.67\ mm^4$

$A_{column} = 52 * 20 – 48 * 18 = 176\ mm^2$

$i = (68458.67 / 176)^{1/2} = 19.7$

$\lambda = 910 / 19.7 = 46.2$

$\sigma_{critical} = 3.14^2 * 70 * 10^9 / 46.2^2 = 323$ MPa

Meanwhile, $\sigma = F_{column} / A = 10299 / 176e^{-6} = 54$ MPa

$\sigma < \sigma_{critical}$

Thus, the previous floor vertical struts can be used.

Appendix B Airworthiness Management in Group Design Project

B.1 Tasks of Airworthiness Management

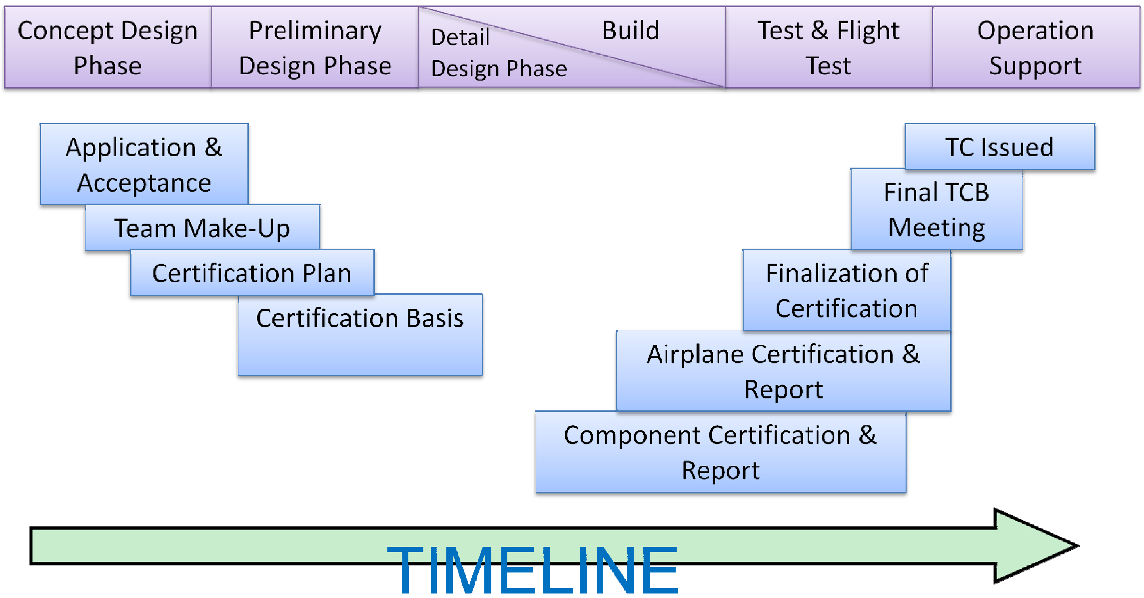


Figure B-1 General Procedure of Civil Aircraft Type Certification

During Detail Design Phase of a civil aircraft design, the tasks of airworthiness is to establish appropriate Certification Basis according to Certification Plan built in Conceptual Design Phase and Preliminary Design Phase, and to start to prepare for documents required by Type Certification.

Certification Basis includes:

- Applicable Regulations
- Special Conditions
- Equivalent Safety Findings
- Exemptions

Being in charge of airworthiness management for structure design group within Detailed Design Phase of Flying Crane Aircraft, the author’s work was focused on the selection and adjustment of relevant airworthiness regulations, and collaboration with specific designers to fully implement those regulations into design philosophy and results. And the author’s work was based on the results from preliminary design phase. The tasks of airworthiness within detailed design phase include:

- To help designers deeply understand the related items in the regulation combined with their mission.
- To assist designers to choose items into designing as well as adjust the choice
- To assist designers to optimize the means of compliance of chosen items
- To ensure there are relevant materials to witness the means of appliance to chosen item
- To make sure the fulfilment of compliance to the regulation during the whole course
- To continuously improve the Airworthiness Compliance Matrix and check the reasonability of the material to witness the means of appliance.
- To make sure there is reasonable explanation to the suitability of every item.
- To make sure there is no contradiction in the applying of relevant items.

B.2 Certification Basis Establishment

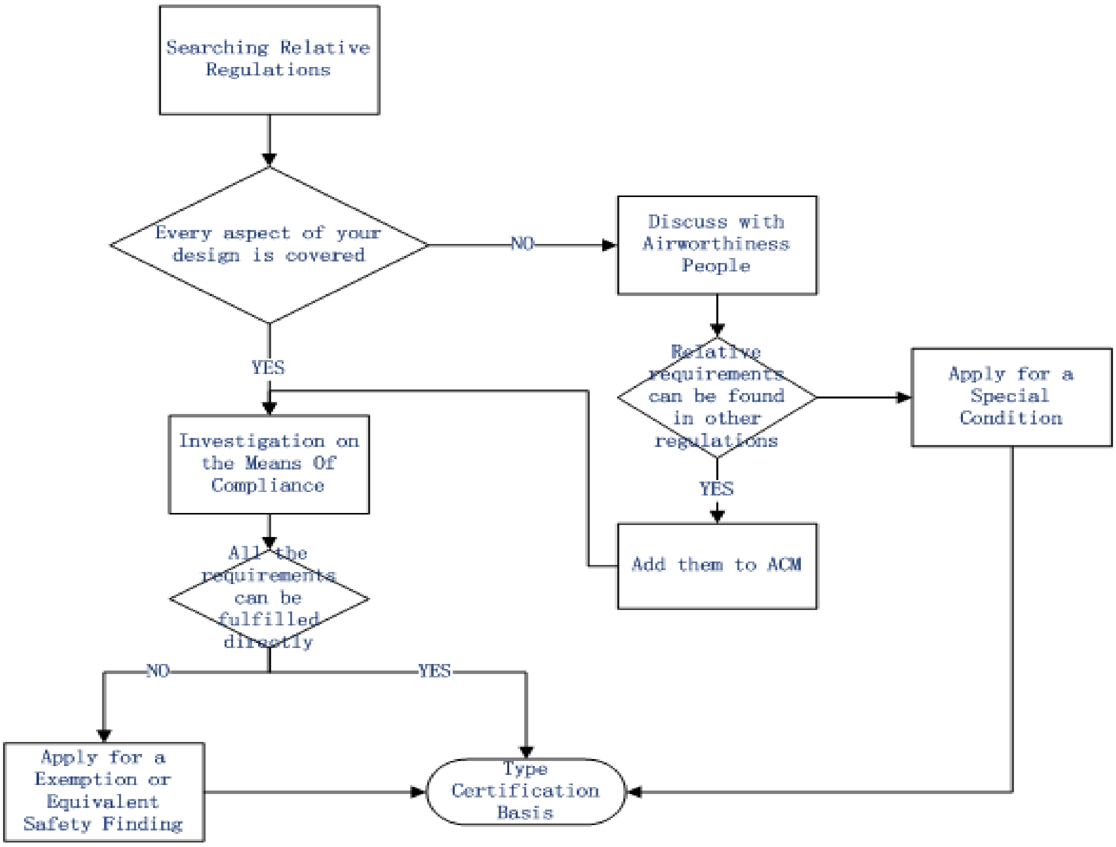


Figure B-2 Workflow of Certification Basis Establishment

As previously mentioned, among the four sections of certification basis, the applicable regulations were taken in this study, and CCAR (China Civil Aviation Regulation) was selected as the regulation system to comply with by Flying Crane.

The workflow of establishing certification basis and selecting applicable regulations was shown in Figure B-2. And the Certification Basis was interpreted in the means of ACM (Airworthiness Compliance Matrix).

This matrix is an integrated description and index to airworthiness items. And its update is also an important way to execute the mission of airworthiness management. Explanation to airworthiness compliance matrix is shown in

Table B-1 and B-2. And the ACM of Flying Crane cabin layout is shown in Table 5-3.

Table B-1 Explanation to MOC code and compliance status

MEANS OF COMPLIANCE (MOC) CODE	COMPLIANCE STATUS
0- Definition	A- Proposal
1-Drawings and Description or Report	B- Applied (Company agreed)
2-Calculation and Analysis	
3-Safety Analysis	C- NAA Agreed
4-Lab/Rig Test	
5-Aircraft ground test	D- Compliance Demonstrated
6-Aircraft flight test	
7-Inspection/Survey	X- Not Applicable
8-Simulator Test	
9-Equipment Qualification	

Table B-2 Explanation to Airworthiness Compliance Matrix

Item description	CCAR 25 REFERENCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
Applying description	Number of the item in the CCAR-25	Describe the status of each mean of compliance chosen for this item.	Requirement of the item, or the main meaning.	Describe how the means are used to be compliant to the item, give out the exact material	Means chosen to use for applying the item
Flight and navigation instruments Installation	25.1303(a)	1 B,5A,6A	The following flight and navigation instruments must be installed so that the instrument is visible from each pilot station.	Drawing (CATIA MODEL --cockpit)	1,5,6
Note : the third line is an example of the second line which explains columns in the matrix.					

Table B-3 Airworthiness Compliance Matrix for Cabin Layout

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
cabin layout	Passenger cabin door	25.783(a)	1B	Each cabin must have at least one easily accessible external door.	CATIA model	1
		25.783(b)	1A	There must be a means to lock and safeguard each external door against opening in flight		1
		25.783(c)	1A,4A	Each external door must be reasonably free from jamming as a result of fuselage deformation in a minor crash.		1,4
		25.783(d)	1A	Each external door must be located where person using them will not be endangered by the propellers when appropriate operating procedures are used.		1
		25.783(e)	1A	There must be a provision for direct visual inspection		1
		25.783(f)	1A	External doors must have provisions to prevent the initiation of pressurization of the airplane to an unsafe level if the door is not fully closed and locked. In addition, it must be shown by safety analysis that inadvertent opening is extremely improbable.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.783(h)	1B	Each passenger entry door in the side of the fuselage must meet the applicable requirements of §25.807 through §25.813 for a Type II or larger passenger emergency exit.	CATIA model	1
		25.783(j)	1A,4A	All lavatory doors must be capable of being unlocked from the outside without the aid of special tools.		1,4
	Seats, berths, safety belts, and harnesses.	25.785(a)	1B	A seat (or berth for a non-ambulant person) must be provided for each occupant who has reached his or her second birthday.	CATIA model and report	1
		25.785(b)	1A,4A	Each seat, berth, safety belt, harness, and adjacent part of the airplane at each station designated will not suffer serious injury in an emergency landing		1,4
		25.785(c)	1A	Each seat or berth must be approved.		1
		25.785(e)	1A	Demand to berth design		1
		25.785(f)	1A,4A	Load demand to seat or berth, and its supporting structure, and each safety belt or harness and its anchorage		1,4
		25.785(f)(1)	1A,4A	The structural analysis and testing of the seats, berths, and their supporting structures may be determined by assuming that the critical load in the forward, sideward,		1,4

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
				downward, upward, and rearward directions.		
		25.785(f)(2)	1A,4A	Each pilot seat must be designed for the reactions resulting from the application of the pilot forces prescribed in §25.395.		1,4
		25.785(f)(3)	1A,4A	The inertia forces specified in §25.561 must be multiplied by a factor of 1.33 (instead of the fitting factor prescribed in §25.625) in determining the strength of the attachment of each seat to the structure and each belt or harness to the seat or structure.		1,4
		25.785(h)(1)	1B	Demand to flight attendant seats	CATIA model	1
		25.785(h)(3)	1B	Positioned so that the seat will not interfere with the use of a passageway or exit when the seat is not in use.	CATIA model	1
		25.785(h)(4)	1A	Either forward or rearward facing with an energy absorbing rest that is designed to support the arms, shoulders, head, and spine.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.785(h)(5)	1A	Equipped with a restraint system consisting of a combined safety belt and shoulder harness unit with a single point release. There must be means to secure each restraint system when not in use to prevent interference with rapid egress in an emergency		1
		25.785(i)	1A	Each safety belt must be equipped with a metal to metal latching device.		1
		25.785(k)	1A	Each projecting object that would injure persons seated or moving about the airplane in normal flight must be padded.		1
	Stowage compartments	25.787(a)	1A,4A	Demand to compartment for the stowage of cargo, baggage, carry-on articles, and equipment (such as life rafts), and any other stowage compartment		1,4
		25.787(b)	1A	Demand for means to prevent the contents in the compartments from becoming a hazard by shifting, under the loads specified in paragraph		1
		25.787(c)	1A	If cargo compartment lamps are installed, each lamp must be installed so as to prevent contact between lamp bulb and cargo.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
	Retention of items of mass in passenger and crew compartments and galleys.	25.789(a)	1A	Demand for preventing each item of mass (that is part of the airplane type design) in a passenger or crew compartment or galley from becoming a hazard.		1
		25.789(b)	1A,4A	Each interphone restraint system must be designed so that when subjected to the load factors specified in §25.561(b)(3), the interphone will remain in its stowed position		1,4
	Passenger information signs and placards.	25.791(a)	1A	Demand about smoking-related design		1
		25.791(b)	1A	Demand for signs that notify when seat belts should be fastened and that are installed to comply with the operating rules of this chapter must be operable by a member of the flightcrew and, when illuminated, must be legible under all probable conditions of cabin illumination to each person seated in the cabin.		1
		25.791(c)	1A	A placard must be located on or adjacent to the door of each receptacle used for the disposal of flammable waste materials to indicate that use of the receptacle for disposal of cigarettes, etc., is prohibited.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.791(d)	1A	Lavatories must have "No Smoking" or "No Smoking in Lavatory" placards conspicuously located on or adjacent to each side of the entry door.		1
	Floor surfaces	25.793	1A,4A	The floor surface of all areas must have slip resistant properties (may be wet in servicing).		1,4
	Emergency exits.	25.807（a)(3)	1B	Configuration of Type III.	CATIA model	1
		25.807（a)(8)	1B	Configuration of Type B.	CATIA model	1
		25.807（f)(1)	1B	Each required passenger emergency exit must be accessible to the passengers and located where it will afford the most effective means of passenger evacuation.	CATIA model	1
		25.807（f)(4)	1B	Demand to emergency exit for an airplane that is required to have more than one passenger emergency exit	CATIA model	1
		25.807（g)(6)	1B	For a passenger seating configuration of more than 110 seats, the emergency exits in each side of the fuselage must include at least two Type I or larger exits	CATIA model	1
		25.807（g)(8)	1B	If a Type A, Type B, or Type C exit is installed, there must be at least two Type C or larger exits in each side of the fuselage.	CATIA model	1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
	Emergency exits arrangement	25.809(a)	1A	Each emergency exit, including a flight crew emergency exit, must be a movable door or hatch in the external walls of the fuselage, allowing unobstructed opening to the outside.		1
		25.809(b)	1A	Each emergency exit must be openable from the inside and the outside except that sliding window emergency exits in the flight crew area need not be openable from the outside if other approved exits are convenient and readily accessible to the flight crew area. Each emergency exit must be capable of being opened		1
		25.809(e)	1A,4A	Each emergency exit must be shown by tests, or by a combination of analysis and tests, to meet the requirements of paragraphs (b) and (c) of this section		1,4
		25.809(f)	1A	Demand of means to lock each emergency exit and to safeguard against its opening in flight		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
	Emergency egress assist means and escape routes	25.810(a)	1A,4A	Each non over-wing Type A, Type B or Type C exit, and any other non over-wing landplane emergency exit more than 1.83m (6 feet) from the ground with the airplane on the ground and the landing gear extended, must have an approved means to assist the occupants in descending to the ground.		1,4
	Emergency exit marking	25.811(a)	1A	Each passenger emergency exit, its means of access, and its means of opening must be conspicuously marked.		1
		25.811(b)	1A	The identity and location of each passenger emergency exit must be recognizable from a distance equal to the width of the cabin.		1
		25.811(c)	1A	Means must be provided to assist the occupants in locating the exits in conditions of dense smoke.		1
		25.811(d)	1A	The location of each passenger emergency exit must be indicated by a sign visible to occupants approaching along the main passenger aisle (or aisles)		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.811(d)(1)	1A	A passenger emergency exit locator sign above the aisle (or aisles) near each passenger emergency exit, or at another overhead location if it is more practical because of low headroom, except that one sign may serve more than one exit if each exit can be seen readily from the sign;		1
		25.811(d)(2)	1A	A passenger emergency exit marking sign next to each passenger emergency exit, except that one sign may serve two such exits if they both can be seen readily from the sign		1
		25.811(d)(3)	1A	A sign on each bulkhead or divider that prevents fore and aft vision along the passenger cabin to indicate emergency exits beyond and obscured by the bulkhead or divider, except that if this is not possible the sign may be placed at another appropriate location.		1
		25.811(e)(1)	1A	Each passenger emergency exit must have, on or near the exit, a marking that is readable from a distance of 30 inches.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.811(e)(2)	1A	Each Type A, Type B, Type C or Type I passenger emergency exit operating handle must-- (ⅰ)Be self-illuminated with an initial brightness of at least 160 micro—lamberts; or (ii) Be conspicuously located and well illuminated by the emergency lighting even in conditions of occupant crowding at the exit.		1
		25.811(f)	1A	Each emergency exit that is required to be openable from the outside, and its means of opening, must be marked on the outside of the airplane. In addition, the following apply		1
		25.811(f)(1)	1A	The outside marking for each passenger emergency exit in the side of the fuselage must include a 50mm (2-inch) colored band outlining the exit.		1
		25.811(f)(2)	1A	Demand to outside marking including the band		1
	Emergency lighting	25.812(a)	1A,4A	An emergency lighting system, independent of the main lighting system, must be installed. However, the sources of general cabin illumination may be common to both the emergency and the main lighting systems if the power supply to the emergency lighting		1,4

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
				system is independent of the power supply to the main lighting system		
	Emergency exit access	25.813	1A	Each required emergency exit must be accessible to the passengers and located where it will afford an effective means of evacuation.		1
		25.813(a)	1B	Demand for passageway leading from the nearest main aisle to each Type A, Type B, Type C, Type I, or Type II emergency exit and between individual passenger areas.	CATIA model	1
		25.813(a)(1)	1A	A cross-aisle which leads directly to each passageway between the nearest main aisle and a Type A or B exit; and		1
		25.813(a)(2)	1A	A cross-aisle which leads to the immediate vicinity of each passageway between the nearest main aisle and a Type 1, Type II, or Type III exit; except that when two Type III exits are located within three passenger rows of each other, a single cross-aisle may be		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
				used if it leads to the vicinity between the passageways from the nearest main aisle to each exit		
		25.813(b)	1A	Adequate space to allow crewmember(s) to assist in the evacuation of passengers must be provided as follows		1
		25.813(b)(1)	1A	The assist space must not reduce the unobstructed width of the passageway below that required for the exit		1
		25.813(b)(2)	1B	For each Type A or Type B exit, assist space must be provided at each side of the exit regardless of whether a means is required by §25.810(a) to assist passengers in descending to the ground from that exit.	CATIA model	1
		25.813(e)	1B	No door may be installed in any partition between passenger compartments	CATIA model	1
	Width of aisle	25.815	1B	The passenger aisle width at any point between seats must equal or exceed the values sepicified	CATIA model	1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
	Maximum number of seats abreast	25.817	1B	On airplanes having only one passenger aisle, no more than three seats abreast may be placed on each side of the aisle in any one row.	CATIA model	1
	Pressurized cabins	25.841	1A,4A	Pressurized cabins and compartments to be occupied must be equipped to provide a cabin pressure altitude of not more than 2400m (8,000 feet) at the maximum operating altitude of the airplane under normal operating conditions.		1 4
	Tests for pressurized cabins.	25.843	4A	Strength testand functional tests of pressure cabin must be done.		4
	safety equipment	25.1411(a)	1A	Accessibility. Required safety equipment to be used by the crew in an emergency must be readily accessible.		1
		25.1411(b)	1A	Demand to Stowage provisions.		1
		25.1411(c)	1A	(c) Emergency exit descent device. The stowage provisions for the emergency exit descent device required by §25.809(f) must be at the exits for which they are intended.		1

	ITEM DESCRIPTION	CCAR25 REFERNCE	COMPLIANCE STATUS	REQUIREMENT	MEANS OF COMPLIANCE	MOC CODE
		25.1411(d)(1)	1B	(1) The stowage provisions for the liferafts described in §25.1415 must accommodate enough rafts for the maximum number of occupants for which certification for ditching is requested.		1
		25.1411(d)(2)	1B	(2) Liferafts must be stowed near exits through which the rafts can be launched during an unplanned ditching.		1
		25.1411(d)(3)	1A	(3) Rafts automatically or remotely released outside the airplane must be attached to the airplane by means of the static line prescribed in §25.1415.		1
		25.1411(d)(4)	1A	The stowage provisions for each portable liferaft must allow rapid detachment and removal of the raft for use at other than the intended exits.		1
		25.851	1A	Fire Extinguishers	CATIA Model and Report	1
	Floor	25,793	1A	Floor Surface	CATIA Model and Report	1
		25.561(3)(iv)	1A	The occupant experiences the following ultimate inertia forces acting separately relative to the surrounding structure: downward, 6.0g	CATIA Model and Report	1