Anti-Corrosion Methods and Materials

Corrosion control assessment for Indonesian ageing aircraft

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Abstract

Many Indonesian operators generally have a tendency to keep their aircraft in service up to or even beyond their economic design goal life (EDGL). The problem that should be solved by the operators is how to operate those ageing aircraft safely and economically. The combination of fatigue and corrosion phenomena needs vigorously corrective action to meet airworthiness requirements, though it increases costs in maintenance. Since corrosion is a never-ending problem, the aviation community such as designer, manufacturer, operator and the regulatory authority has an obligation to be more concerned and proactive in ensuring continuous airworthiness of the ageing aircraft. Aims to assess issues on corrosion prevention and control activities conducted by Indonesian operators, discusses all the facts and possible corrective actions and provides recommendations to maintain and ensure safe operation of ageing aircraft by controlling and preventing corrosion as well as metal fatigue.

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The airline business is known to be a huge investment, with high risk, complex management, high technology and marginal profit. But is also known to be one of the fastest and most comfortable forms of transportation, especially for passengers and perishable goods.

Regarding the above statement, it seems reasonable for the air operators to operate ageing aircraft based on economic considerations instead of airworthiness compliance. It will be even worse when they face more tight competition, less purchasing power and lack of government support.

The primary objective of the airline management is to make a profit, and they will do whatever they can to gain that objective and sometimes it may endanger the safety by cutting the edge of airworthiness.

Buying or leasing new aircraft is not always a good way out, especially when the customers are still "price sensitive" and not "quality sensitive". This is realistic, considering we are operating ageing aircraft, i.e. with metal fatigue and metal corrosion problems, as old-design aircraft are mostly of metal structure rather than composite. But it does not mean that operating ageing aircraft is not feasible; the questions are: shall we be able to operate those ageing aircraft safely and economically, and shall we be able to determine when we have to stop operating (phase out) that particular aircraft?

In this paper we shall focus on the discussion of the corrosion problems found in Indonesian registered aircraft by considering several aspects of manufacturing, operations, maintenance, quality assurance systems and environment.

Aircraft corrosion

Corrosion which is related to exposure time and environment is the electrochemical deterioration of a metal because of its chemical reaction with the surrounding corrosive environment. The corrosion process begins early in the process of manufacturing and continues when the aircraft enters its service. Even

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protective coatings that are properly designed and installed during fabrication or maintenance become ineffective over time and allow corrosion to develop. The corrosion process will continue until an airframe structure is functionally weakened or completely destroyed, unless it is controllable.

Catastrophic corrosion events

According to FAA Advisory Circular number 43-4A (1991) corrosion is most often thought of as a slow process of material deterioration, taking place over a significant period of time (e.g. general corrosion, pitting, exfoliation).

Other forms of corrosion degradation can occur very quickly, in days or even hours, with catastrophic results. These forms (such as stress corrosion cracking, environment embrittlement, and corrosion fatigue) depend on both the chemical and mechanical aspects of the environment and can cause catastrophic structural failure without warning.

As we have all understood, in order to have a measure in controlling the corrosion, the industry has classified the conventional corrosion condition into three levels (Boeing Ageing Airplanes CPCP Guidelines, 1990) which are as follows:

Level 1 corrosion

This is damage discovered on initial inspection, or occurring between successive inspections, which is local and can be reworked/blended-out within allowable limits as defined by the manufacturer in the Structural Repair Manual (SRM), Service Bulletin, etc., and when the amount of corrosion occurring between repetitive task intervals considered to be indicative of acceptable control and prevention of corrosion.

This amount is generally within the manufacturer's blend-out limits for corrosion removal.

Level 2 corrosion

This is damage discovered on initial inspection, or occurring between successive inspections requiring rework or blend-out that exceeds the manufacturer's allowable limits, and therefore requires a repair or complete/partial replacement of a principal structural element (PSR) as defined by the original equipment manufacturer's SRM, or on a primary structural member where the manufacturer has not identified principal structural elements (PSEs). Also, when the amount of corrosion, occurring between repetitive task intervals, is considered to be indicative of a control and prevention programme, that requires a restrictive correction, such as shorter task intervals, modified prevention task, etc.

Level 3 corrosion

This is damage found during first or subsequent inspection(s) which is determined by the operator to be a potential airworthiness concern requiring expeditious action.

The manufacturer of the aeroplane will normally participate in the determination of level 3 corrosion.

The amount of corrosion found during an initial task or repetitive task gives an indication of a potentially serious airworthiness concern for aeroplanes of the same design and in similar usage.

Corrosion prevention and control aspects

Because aircraft corrosion is unavoidable, a balanced, effective and efficient corrosion prevention and control programme (CPCP) must be planned and worked out from the initial design until the aircraft is out of service. In the case of CPCP the following aspects should be taken into consideration:

(1) *Design*. The corrosion process restriction by design aspects may cover such items as:
   - material selection, where technology today provides us with so many choices of material which can fit the strength and weight requirements with good corrosion resistant criteria;
   - correct and proper corrosion protection applications especially for areas prone to corrosion;
   - sufficient and effective drainages for accumulated water, moisture and contaminants;
   - installation of sound-proofing material and heat-isolation blankets may initiate corrosion owing to trapped moisture, if not properly protected.

(2) *Manufacturing*. Manufacturing processes contribute to corrosion problem restriction, such as:
   - a good raw material incoming/receiving inspection and storage control;

- correct and proper application of sealants and protection;
- correct and proper process of coating, cladding and other corrosion-resistant processes;
- cleanliness of manufacturing process such as removal of dirt and metal debris or material debris.

(3) *Operational.* Aircraft operations do not only mean flying the aircraft but also include other activities such as:
- cargo, catering and other loading/unloading activities which, if not carefully handled, will cause some damage, liquid spillages or debris that can initiate corrosion;
- cargo and luggage packaging which might also cause corrosive liquid spillage or debris;
- cleanliness behaviour of the crews and passengers.

(4) *Maintenance.* Aircraft maintenance personnel have complex duties regarding corrosion problem solutions, covering preventing, restricting, detecting and correcting or repairing, described as follows:
- careful and proper maintenance activities/practices to prevent any damage that may initiate corrosion;
- corrosion detection by intensive inspections not only following and complying with the manufacturer's instructions, but also creating a better inspection interval and/or method based on operators' experience and reliability control;
- feedback and consultation (service difficulty reporting system) to the authority and manufacturer that will facilitate guidance for proper corrective actions; information to other operators and other necessary actions concerning corrosion problem solutions;
- additional corrosion prevention by application of anticorrosion products, aircraft cleaning and aircraft repainting or polishing;
- ensuring removal or drainage of any accumulated dirt, water and moisture periodically.

Corrosion problems of Indonesian ageing aircraft

Indonesian ageing fleet

An investigation was performed recently for six major Indonesian air carriers. Five of them are scheduled airlines, while another is non-scheduled. It permits us to cover not only fixed-wing aircraft but also helicopters which more or less may indicate the existing fleet condition. Generally, when aircraft exceed their design goal life (EDGL), limited by the manufacturer in calendar time, flight cycles or flight hours, whichever occurs first, they will be classified as ageing.

This EDGL, which is determined conventionally to guarantee the aircraft's structural integrity during its service, may vary from one type to another, especially in the limits of flight cycles and flight hours. Most of the manufacturers in the aircraft transport category agree on a period of 20 years as the EDGL of aircraft, yet the ageing process commences earlier. In fact, because of various reasons such as design, manufacturing, type of operations, maintenance compliance, quality assurance and severe environment for Indonesian aircraft, the calendar time limit is achieved first.

Table I shows all fleets in terms of aircraft type, year of manufacturer and average age in years.

Furthermore, questionnaire responses of six major air carriers provide other relevant information as seen in Table II, which indicates nature of corrosion, dominant causes, rectification, anti-corrosion products and includes airworthiness authority action.

All respondents considered aircraft corrosion to be a serious problem which needs vigorous corrective action and high-cost expenditure. Corrosive environment, cleanliness and cargo packaging or handling are the major causes of corrosion rather than design and manufacturer defects.

Reported corrosion cases

There are some corrosion cases that have been reported through service difficulty report (SDR) and questionnaire responses as shown in Table III. This report confirms the dominant causes of corrosion such as spillage of toilet liquid, contamination due to spillage or evaporation from the cargo compartment, contamination due to high humidity, corrosive environment and age.

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Table I Serviceable aircraft fleet of major air carriers

Number	Air carrier	Aircraft type	Number	Year of manufacture	Average age (years)
1	Garuda Indonesia	Boeing 747-400	3	1993-1994	3
		MD-11	6	1992-1993	3
		Airbus 300B4-622R	9	1992-1993	4
		Boeing 747-200	6	1980-1981	15
		DC-10-30	6	1976-1979	18
		Airbus 300B4-220FF	9	1981	15
		Boeing 737-300	8	1988-1990	7
		Boeing 737-400	7	1993	3
2	Merpati Nusantara	Fokker F-27 series	18	1966-1981	20
		Casa N/C –212	12	1980-1985	15
		CN-235	14	1990	6
		BAe ATP	5	1992	4
		DHC-6 Twin Otter	11	1971-1974	23
		F-28 MK.3000	5	1977-1978	19
		F-28 MK.4000	26	1980-1984	13
		Fokker 100	3	1993	3
		Boeing 737-200	3	1981-1982	14
3	Pelita Air Service	Casa N/C-212	11	1975-1982	15
		Gulfstream G-III	1	1983	13
		F-28 MK.1000	3	1973-1974	22
		F-28 MK.4000	5	1979-1982	14
		Fokker 100	1	1990	6
		Gulfstream G-I	1	1975	21
		Lockheed L-382	4	1979-1980	17
		BAe AVRO 146-RJ85	1	1993	3
		BAe 146-200	1	1986	10
		DHC Dash 7-103	5	1974-1982	18
		Transall C-160	6	1981-1987	13
		SA-330 Puma	14	1971-1981	20
		Bolkow NBO-105	26	1974-1984	13
		Sykorsky S-76A	4	1981	15
		AS-332 C Super Puma	3	1983	13
4	Sempati Air	Fokker F-27	5	1963-1969	29
		Boeing 737-200	7	1970-1981	19
		Airbus 300B4-220FF	3	1982-1983	13
		Fokker 100	6	1990-1991	5
		Fokker 70	2	1994	2
5	Bouraq Airlines	HS-748-2A,2B	11	1967-1982	14
		VC-8	3	1964	32
		Boeing 737-200	8	1972-1985	16
6	Mandala	Boeing 737-200	7	1979-1982	15

Source: DGAC Aircraft Register

For some types of aeroplanes significant reported corrosion has been found during the first ten years (first mid-economic life) of their operating service. In general, corrosion has been found in the area surrounding the cargo compartment, wing structure and landing gear.

Discussion

Technical aspects

It has been mentioned previously that the technical aspects affecting corrosion phenomena consist of design, manufacturing, operation and maintenance, which are discussed below.

During the design stage a material selection must be taken into account to comply with all requirements including safety regulations. Yet there is no material which best meets all the criteria; the designers may optimize their choice with regard to its physical and mechanical properties.

For certain principal structural elements the decision for selecting material is usually

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Table II Corrosion findings on Indonesian fleet

Number	Items	Description	Remarks
1	Significant corrosion starting	Between 10-15 years Between 10,000-30,000 FH Between 10,000-30,000 FC	Most of corrosion found
2	Type of corrosion	Exfoliation, galfanic, filiform and stress corrosion	Most of corrosions are exfoliation
3	CPCP compliances	Most of corrosion found level 1 and 2 Corrosion type and location found in accordance with CPCP Contamination due to high humidity	Moderately effective and some of CPCP very effective
4	Dominant causes of corrosion	Spillage of toilet liquid Contamination due to spillage or evaporation from cargo compartment Corrosive environment and age	Mostly found as above
5	Repair or rectification of corrosion damage	Data support and instruction provided by manufacturer	Repairable corrosion damages will reoccur after longer period of time in similar conditions
		Treatment and protection used: • Alodine, primer and paint	Quality of anti-corrosion products varies from moderately effective to good
		• In accordance with CPM and SRM Alodine 1200, primer, topcoat and corrosion protection Anti-corrosion product used: LPS-3, Dinol, BMS 3-23, Biobore	Same as above
6	Effect of aircraft cleaning and painting for prevention	Good Very good	Most of operators agree
7	Opinions regarding DGAC instructions of corrosion prevention and rectification	Instructions, advisory statements and references for CPCP	Just follow the programme prepared by manufacturer. Improve the programme based on data and information from operators.
		Surveillance of CPCP compliance and corrosion rectification	Just accept report from operators. Accept reports and conduct field surveillance. Actively seek data and information, conduct field surveillance and communicate with the manufacturer or other authorities

Source: DGAC questionnaire

based on its high fatigue resistance instead of corrosion resistance. It seems simpler to prevent corrosion by applying correct and proper protection, avoiding water traps, moisture and contaminants or installing heat isolation rather than using a material of better corrosion resistance. But the evidence shows that many corrosion cases in service are finally solved by changing the material.

It has already been discovered that an improper process during aircraft manufacturing may provoke corrosion. Each process, from raw material forming until final assembly, needs corrosion control.

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Table III Reported corrosion cases

Number	Aircraft type	Age Years	Age Flight hours/ cycles	Reporting date	Description
1	Cessna Citation III	6	2,364 H 1,750 C	June 1994	While defuelling the aircraft, approximately 20 gallons of water was drained from the sumps of fuel containment area and heavy corrosion found inside wing fuel tank in the area of: • forward spar, lower cap between RBL 21.30 and RWS 32.00 and lower cap between LBL 21.30 and LWS 32.00. • stringer 10 (P/N 6221160-7) and stringer 11 (P/N 6221160-8), both are part of the 21 skin bond assembly. It was due to excessive and prolonged water accumulation
2	Lockheed L-382G	15	16,000 H	June 1994	Corrosion was found on the left-hand (LH) and right-hand (RH) main landing gear (MLG) beam assembly due to accumulation of pollution of exhaust/outport
3	Lockheed L-382G	15	16,000 H	October 1994	Corrosion was found at lower side cover skin between frame Sta.617 up to 657, centre of lower cap and area under flapper valve rubber
4	Boeing 737-200	12	–	May 1994	During C check, inspection found level 2 corrosion on a bearing housing and heavy corrosion on stringer and fitting
5	Boeing 737-200	13	–	May 1994	During C check, inspection found a level 2 corrosion on wing inboard torque tube and on Keel beam T-chord
6	F28 MK-4000	15	–	1995	Heavy corrosion was found at aft cargo compartment lower side of belly area
7	Boeing 747-200	15	–	1995	Heavy corrosion was found on lower fairing support of Sta.980
8	Airbus A-300 B4 220 FF	12	–	April 1993	Corrosion was found during D check in the area of Sta.54 of cabin floor structure and belly area
9	Airbus A-300 B4 220 FF	14	–	October 1995	Corrosion was found on wing lower surface between Rib 1 to Rib 2 and Mid Spar to Rear spar
10	Boeing 747-200	14	–	October 1994	Corrosion was found on RH wing lower skin and lower cap of front spar
11	Douglas DC-10-30	18	58,569H	July 1995	During D check found corrosion on LH wing front spar lower cap of sta.XORS 346 to XORS 372
12	Boeing 737-200	26		January 1996	During C-01 check found corrosion on LH main landing gear support fitting
13	NC-212	4	3,600 H	September 1990	Corrosion on lower wing skin in the area behind the engine exhaust at sta.2288 to sta.2860 wing skin and inboard flap, caused by exposure to high temperature

(Continued)

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Table III

Number	Aircraft type	Age: Years	Age: Flight hours/ cycles	Reporting date	Description
14	CN-235	6	7,500 C	December 1994	1. Corrosion damage provoked the following exfoliation on several sites such as: • On rib leading edge of RH inner flap at sta.1600. • On NLG door and hinge support assy between sta.2377 and sta.4067.5. • On fuselage frame 48 of rear fuselage at sta.20122; LH and RH upper fitting of rear fuselage at frame 48; RH bracket of rear fuselage at frame 47 sta.19836 and angle of centre fuselage between sta.5136 and sta.6152 • On union of LH rear nacelle cowling between sta. X = 2345 and sta. X = 4045. • On vertical stabilizer hinge fitting at sta.186.5. • On centre wing lower skin LH between sta.3500 and sta.3900 2. Surface corrosion on centre wing upper and lower fitting LH and RH at sta.4250 and on outer wing upper and lower fitting LH and RH at sta.4250

Less susceptible alloys, preferably welded butt joints rather than lap joints, closer galvanic series of metals and inhibitors are considered to be corrective actions.

This corrosion prevention varies from one manufacturer to another. It depends on data and information collected as input from market research, including the maintenance review board (MRB), authorities and customer reports. The number of heavy corrosion cases found during the maturity period of certain aircraft types reflects the manufacturer's quality control.

Since the Aloha Boeing 737-100 accident in April 1988, some manufacturers, in co-operation with authorities and operators, have established the ageing aircraft task force which has introduced not only SIP (structure inspection programme) but also CPCP (corrosion prevention and control programme).

One of the manufacturers of large jet aeroplanes provides a CPCP, while the others try to cover this programme by issuing mandatory service bulletins (SBs) or other notices. According to Table I, there are 89 (65 per cent) jets, 87 (82 per cent) turboprops and 47 (100 per cent) helicopters passing their mid-economic life or entering the ageing process. The aircraft operators are consequently requested to conduct vigilant surveillance or inspection in line with CPCP, mandatory SBs or airworthiness directives (ADs); otherwise corrective actions cannot meet requirements. The type of operation and compliance with routine maintenance play significant roles in ensuring a successful CPCP.

The spillage of debris or liquid, damages and corrosive environment which occur during operation will intensify the corrosion process. Furthermore, it becomes worse if the operator tends to postpone the maintenance inspection schedule as observed previously (Suyitno, 1995). In this case law enforcement tends to observed shall be implemented to prevent the accumulation of damage forcing air carriers to operate an economic but non-airworthy aeroplane.

Other difficulties are also found when corrosion damage rectification is not properly carried out and does not comply with the minimum standard of quality. It will leave maintenance deviation, to some extent,

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responsible for hidden defects which will reduce structural integrity. As reported by Suyitno (1992) recently, operators may face dilemmas in operating airworthy and economic ageing aircraft.

As mentioned in Table II, all operators agree that compliance with CPCP is moderately effective to locate and rectify corrosion. There is no doubt that the CPCP will be more effective if it is backed up by a good quality management system, qualified personnel and adequate facilities, especially for non-destructive test (NDT).

Quality management system

It is not open to discussion that successful CPCP is finally rooted on the implementation of quality management systems. It will promote good quality assurance and provide a high standard of reliability for aircraft maintenance and operation.

Manufacturers and operators are committed to establishing a good quality management system which generally covers quality manual procedures, work instructions and conformance to standards and safety requirements. The initial airworthiness of manufacturing and the continuous airworthiness of operation can then be guaranteed by law enforcement. Unfortunately, the majority of corrosion problems arise during aircraft maintenance activities (see Table III).

A continuous communication loop must be maintained between design manufacturer, operator and airworthiness authority. CPCP will not be effective without guidance, instruction and assistance from the design manufacturer. Controlling compliance with CPCP among air carriers is not an easy job and it is almost impossible to achieve a 100 per cent result without strong enforcement of the authority.

Since reported corrosion occurs not only on ageing aircraft but also on relatively new ones (see Table III), it is recommended that CPCP is implemented at an earlier stage of their mid-life and more frequently.

Of course, to ensure a better quality standard an adequate number of qualified personnel is indispensable. According to the DGAC record, six Indonesian major air carriers have only 18 level-one NDT operators or authorized personnel in total. Although they may hire NDT experts from other companies, in the long term this will affect the achievement of the minimum quality standards required. The existence of a maintenance inspection delay and skilled personnel shortage as pointed out before indicates the lack of a quality management system. It also demonstrates that human factors are finally the key to maintenance quality assurance.

Finally, it should be pointed out that it is expected that we all establish a good quality management system by providing a strong commitment to ensure safety and airworthiness of continuing ageing aircraft operations.

Conclusion

The corrosion prevention and control programme or its equivalent developed by manufacturers is moderately effective in locating and rectifying corrosion damage. It will be more effective for ensuring a maintenance standard for ageing aircraft if a good quality management system is implemented and qualified personnel and facilities are available.

It is recommended that a better maintenance quality be achieved by implementing CPCP earlier and more frequently. This will bring about a safe and airworthy ageing aeroplane to be extended for longer continuing operation.

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