

Proactive maintenance philosophy for aging aircraft through corrosion induced risk assessment: An analysis on Herbin Y-12 aircraft fleet of Sri Lanka Air Force

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Abstract— Corrosion of the aging aircraft structures is a serious problem with long term effects. Corrosion takes place, due to the tendency to getting stabilized by reducing latent energy in thermodynamical aspect, on the metal structures and degrades the metal. Different types of corruptions can be identified on the aircraft structures. However, the primary corrosion methods are: Surface, Pitting, Galvanic, Filiform, and Exploitation corruptions. If corrosion is not detected before it reaches the critical stages, it may lead to instantaneous failures. Due to the possibility of strength losses caused by the pits, cavities or grain degradations developed inside the metal, it could also cause catastrophic events depending on the nature of the part failed. To prevent such events from happening this research was carried out to find a solution for the aging aircraft performance falling problem. When an aircraft gradually reaches its service life the output such aircraft delivers will be decreased compared to the previous years. It is understood that a new maintenance philosophy should be introduced to address this problem arising all over the world. To address this problem, the first step is to identify the factors which effects the failures of an aging aircraft. It has been found out that the corrosion and fatigue will play a major role in problems which were arise in aging aircraft. From those two factors corrosion can be regarded as the main factor which increases the downtime of an aging aircraft. Hence the newly developing maintenance philosophy was deployed on the corrosion factors. With the aid of a risk matrix which categorizes high, moderate and low risk areas with respect to corrosion failure it was possible to find the high risk areas from those corrosion prone areas. Generating a statistical formulation is one part. And this study is restricted to the area of corrosion, but many fields are to be studied regards the aging aircraft, such as fatigue. The continuations of this research will result more effective, efficient and more subjective.

Keywords— *aging aircraft, corrosion, maintenance philosophy, risk matrix, high risk*

I. INTRODUCTION

Aging of aircraft is a major concern because the continuation of airworthiness is challenged. (Gebman, 2009) When an aircraft is reaching its chronological age, unserviceability factor increases drastically. The intention of an operator is reduced down time but the down time of particular aircraft will be high with aging which eventually makes a loss for the airliner. If the airline has more than one aircraft which are on the verge of age the loss will be more severe. (Dr. Dan M. Ghiocel, Dr. Letian Wang, 2004)

The chronological age of an aircraft can be calculated concerning Flying Hours, Calendar Years or the Flight Cycles an aircraft and which exceeds one of these is considered as aged. After the completion of manufacturer defined lifespan the aircraft will be more prone to failure. The operator can either replace or treat for the aging and obviously replacements incur high costs. (Anon., 2007) Corrosion, fatigue and deterioration are the factors that need to be treated under maintenance and special three factors that attribute to failure and need to be maintained. (Roberge, 1999) The effect of the corrosion and prevention philosophy is studied in this research.

The corrosion takes place when certain four factors are presented. The presence of anode and the cathode, electrolyte and the electrical connectivity between the anode and cathode are in brief. To prevent or control the corrosion, need to avoid the combination of these factors. (W. Wallace, D.W. Hoepfner, P.V. Kandachar, 1985) And otherwise immediate actions to be taken. For an efficient service, corrosion related maintenances should be done in a proactive manner by the possible corrosion damage is assessed previously and ensuring the appropriate prevention methods are implemented.

Sri Lanka Air Force is operating a certain number of aging aircraft and with the consideration of these conditions to develop a proactive maintenance philosophy for the fleet is the objective of this research. And the method should comply with the safety management system perspective to ensure the safety.

II. METHODOLOGY

This research was focused on developing a maintenance philosophy correlation with Sri Lanka air force and the Sri Lanka national flag carrier airliner. Hence the collection of data was done for both expertise opinions and maintenance records which in the ways of quantitative, qualitative and literature surveying. Technical manuals, logs, are used as primary data and structured interviews and questionnaires are used as secondary data gathering. And the selection of sample should be considered about following factors.

- Comply with the aging stage
- Availability of data and information
- Availability of access to investigate the structural Conditions.

To achieve the objective following procedure has be followed. It was observed that high corrosion damages are regularly reported from some particular areas. Those areas has to be identified. After the identification of most corrosion prone areas, divided into three divisions according to the risk level of the corrosion failure. Low risk, medium risk and high risk are the areas that categorizing into. This classification is done with corresponding to the severity of the accident occurred by failing the part and the frequency of corrosion.

A. Risk Assessment Principle

$$Risk = Likelihood(probability) \times Consequence (severity)$$

Risk likelihood is a one aspect which will be used to calculate the risk and there are five categories of the risk likelihood. These categories were obtained from the safety management system (SMS) manual. The other aspect to calculate risk is risk severity. There are five categories of risk severity also and those five categories were derived by using qualitative analysis method.

Table I Definitions of the Likelihood

	Operation : Expected Occurrence Rate (Calendar-Based)
Frequent A	Equal to or more than once per week
Probable B	Less than once per week and more than once per three months
Remote C	Less than once per three months and equal to or more than once per three years
Extremely Remote D	Less than once per three years and equal to or more than once per 30 years
Extremely Improbable E	Less than once per 30 years

B. Corrosion risk analysis procedure

The risk is taken by the product of the probability and the severity. By using the risk assessment matrix the level of risk can be identified.

Table II. Risk Assessment Matrix

Risk Likelihood	Risk Severity				
	Catastrophic A	Hazardous B	Maj or C	Min or D	Negligible E
Frequent	5A	5B	5C	5D	5E
Occasional	4A	4B	4C	4D	4E
Remote	3A	3B	3C	3D	3E
Improbable	2A	2B	2C	2D	2E
Extremely Improbable	1A	1B	1C	1D	1E

(Source: Safety Management Systems Manual, Version 4.0)

C. Risk Index Categorization

The table below shows the risk threshold for low risk, medium risk and high risk varied. When there are sufficient data available a quantitative risk assessment can be done in order to calculate the risk index. As well as a qualitative risk index calculation can be done, if the data available are not enough to go for quantitative approach.

Table III. Risk Index Categorization

Risk index	Description	Recommended action
5A 5B 5C 4A 4B 4C 3A 3B 2A 1A	High risk (Intolerable region)	Cease the operation immediately. Develop risk mitigation procedures, actions, additional preventive controls in order to bring the risk index down to the moderate or low range.
5D 4D 3C 3D 2B 2C 1A 1B	Moderate risk (Tolerable region)	To bring down the risk to low level schedule safety assessments.
5E 4E 3E 2D 2E 1C 1D 1E	Low risk (Acceptable region)	No further risk mitigation is required. Work according to the existing program.

(Source: Safety Management Systems Manual, Version 4.0)

D. Maintenance Procedure

The obtained risk index gives the safety criticality of the parts to fail under the corrosion damage and assists the development of maintenance philosophy for the corrosion prevention. This leads to risk based maintenance procedure.

Risk based maintenance is highly effective when compared with the conventional maintenance. Low risk areas are eligible to continue with same maintenance procedure followed and moderate corrosion also tolerable. The high

risk areas need to follow up by special material based procedures and moreover to be conducted special material analysis and the material based actions are recommended.

III. ANALYSIS ON HERBIN Y – 12 AIRCRAFT FLEET

Harbin Y 12 aircraft of the Sri Lanka Air Force is one of the aging aircraft type which operating under the no 08 squadron from Ratmalana Air Force Base. Due to the aged condition and easy access the Y 12 fleet was selected as the sample for this study.

The sample fleet have grounded two aircraft due to extended corrosion damage and the maintenance were under proceed. The analysis done based on the reported corrosion findings and the issues encountered. The data gathering was done in both primary and secondary methods. Referring relevant maintenance manuals and analysing technical data, was done and conducted structured interviews with aircraft maintenance engineers and senior technicians. To get conformation of the data, questioners are being used.

Questioner no. 01 is developed for the identification of most impacting problem of Y 12 with the aging. 30 competent technicians were selected and got their feedback. 72% stated and confirmed that the main problem which faced by the aircraft is corrosion. Their general idea was wings, flight controls, and fuselage are more prone to corrosion. By inspecting the aircraft and with the literature 16 areas susceptible corrosion are observed.

1. Landing gear cowling area.
2. Wing bottom section.
3. Wing mount.
4. Control Surfaces (rudder and elevator shroud area, ailerons)
5. Undercarriage area.
6. Drain hole areas.
7. Wing Rear spars.
8. Freight doors and hinges.
9. Leading edges, trailing edges.
10. Galley Areas (due to spillage of juices and foods).
11. Passenger and cargo doors (due to exposure to rain water and condensate)
12. Exhaust gases path.
13. Integral fuel tank (especially inside due to water condensate)
14. Lavatory areas (due to soapy water/ human waste)
15. Battery compartment area (due to spillage of battery electrolyte)
16. Control Surfaces Hinges

The Questioner no 02 was done on 50 competent technicians and it was detailed document with the

susceptible areas to corrosion. The likelihood and severity was taken on the particular area.

The following information obtained on the likelihood and the severity from the sample fleet by questioner no. 02.

A. Likelihood of corrosion

Table IV. Obtained Likelihood

Area suspected	Result
Landing gear cowling area	Improbable
Wing bottom section.	Occasional
Wing mount	Remote
Control Surfaces (rudder and elevator shroud area, Aileron	Frequent
Undercarriage area	Remote
Drain hole areas	Frequent
Wing Rear spars	Occasional
Freight doors and hinges	Improbable
Leading edges, trailing edges	Occasional
Galley Areas (due to spillage of juices and foods)	Frequent
Passenger and cargo doors (due to exposure to rain water and condensate)	Occasional
Exhaust gases path	Remote
Integral fuel tank (especially inside due to water condensate)	Occasional
Lavatory areas (due to soapy water and human waste)	Occasional
Battery compartment area (due to spillage of battery electrolyte)	Remote
Control Surfaces Hinges	Remote

B. Severity of corrosion

Table V. Obtained Severity

Existing method	Advanced method	Based materials
1. Corrosion control program is held every 90 days	Corrosion control program is advanced up to 45 days	Corrosion map
2. Additional maintenance activities are done for the visible areas after seen.	Risk based Inspection are implemented for the high risk areas.	Corrosion Risk
3. Corrective maintenance	Preventive maintenance	Assessment Matrix
4. Material Analysis	Silicon dioxide corrosion resistive coating	Material Analysis

C. Risk Level of the Parts

With the information obtained from the Y-12 fleet following risk assessment matrix was developed.

Table VI. Risk Matrix Developed for Harbin Y 12 Fleet

Risk Likelihood	Risk Severity				
	A	B	C	D	E
5	Control Surfaces	--	--	Drain hole areas	Galley areas
4	Wing Bottom Section/ Wing rear spars	Leading Edges and trailing edges	Integral fuel tanks	Passenger and cargo doors	Lavatory areas
3	Wing Mount	Control surface hinges	Exhaust gas path	Under carriage areas/ battery compartment areas	--
2	--	Landing gear cowling area	--	Freight doors and hinges	--
1	--	--	--	--	--

The identified high risk areas are investigated for the major types of corrosion that can be seen.

Table VII. Major Corrosion Types on Identified Areas

Area	Material	Corrosion type (s)
Wing bottom section	Aluminum alloys	Surface corrosion, pitting corrosion
Wing mount	Aluminum alloys	Surface corrosion, pitting corrosion
Control surfaces	Aluminum alloys	Surface corrosion, exfoliation corrosion
Wing rear spars	Aluminum alloys	Surface corrosion (heavy)
Leading edges and trailing edges	Aluminum alloys	Localized surface corrosion
Control surface hinges	Aluminum alloys	Galvanic corrosion, Pitting corrosion, surface corrosion
Integral fuel tanks	Aluminum alloys	Microbiological corrosion, General corrosion

D. Recommendation of Non Destructive Inspections

Table VIII. Advanced NDI

NDI Method	Type of Corrosion Detected or Evaluated
Boroscope	1, 2, 3, 4, 5, 10, 11, 12
Depth Gauge	4,5
Optical Micrometer	1, 2, 4, 5, 6, 7, 8, 10,11
Fluorescent Penetrant	3, 4, 8, 9
Eddy Current	1, 2,3, 4, 6, 8, 9
Ultrasonic	3, 4, 6, 8, 9
Radiography(X ray)	6, 8, 9

(Source: USAF Technical Manual, TO 1-1-691)

- 1 - Uniform surface corrosion
- 2 - Galvanic or dissimilar metal corrosion
- 3 - Intergranular attack (general)
- 4 - Intergranular attack (exfoliation)
- 5 - Pitting
- 6 - Crevice/concentration cell corrosion
- 7 - Fretting corrosion
- 8 - Stress corrosion cracking
- 9 - Corrosion fatigue
- 10 - Filiform corrosion
- 11 - Microbiologically induced corrosion

The inspection frequencies of these parts should be advanced. All are recommended 100 flying hours/ 90 days

Area suspected	Result
Landing gear cowling area	Hazardous
Wing bottom section.	Catastrophic
Wing mount	Catastrophic
Control Surfaces (rudder and elevator shroud area, Aileron	Catastrophic
Undercarriage area	Minor
Drain hole areas	Minor
Wing Rear spars	Catastrophic
Freight doors and hinges	Minor
Leading edges, trailing edges	Hazardous
Galley Areas (due to spillage of juices and foods)	Negligible
Passenger and cargo doors (due to exposure to rain water and condensate)	Minor
Exhaust gases path	Major
Integral fuel tank (especially inside due to water condensate)	Major
Lavatory areas (due to soapy water and human waste)	Negligible
Battery compartment area (due to spillage of battery electrolyte)	Minor
Control Surfaces Hinges	Hazardous

inspection by the Squadron corrosion prevention control program (CPCP).

Sri Lanka is an island nation as well as a tropical country. And the Ratmalana airport also located closely to the coast. The marine atmosphere is very corrosion supportive. The relatively high temperatures increases the corrosive effect. FAA corrosion severity maps also categorized Sri Lanka in moderate zone.

The Inspection advancement is recommended according to the corrosion rate. The metal composition of this parts are not defined and considered as 2024-T3 alloy due to the large area of applications of aviation. The corrosion rate of aluminium alloy (The metal removing rate) 0.06 mg/cm²/day for high corrosive environments. This is relatively high and value and with the consideration of moderate zone inspection interval which is mentioned as 45 days, the visual inspections must be advanced to 45 calendar days due to the high risk level areas of corrosion. Moderate and low risk components can be allowed to conventional time periods.

Following inspection procedures are recommended.

1. Wing bottom section - Detail visual inspection in every 45 days or 100 hours
2. Wing mount - Detailed visual inspection in every 45 days or 100 hours followed by Eddy current inspection
3. Control surfaces - Detailed visual inspection in every 45 days or 100 hours followed by Fluorescent Penetrant inspection. Eddy current inspection (Eddy current may be appropriate because wing mounts also need to inspect with eddy current)
4. Wing rear spars - Boroscope Inspect in every 45 Days or 100 hours.
5. Leading edge and trailing edge of the wing detailed visual inspection in every 45 days or 100 hours
6. Control surface hinges - Detailed visual inspection in every 45 days or 100 hours followed by Eddy current inspection

Table IX. Comparison of Existing and Proposed Methods

With the actual composition of the material it can be decided that the most suitable unique compound for the protective layer. In here, all the structures are done by aluminium alloys with different compositions. But the type is not given by the manufacturer and by considering the metal is 2024-T3 the procedures were recommended. Recommending the remedial action is also divided according to the level of risk. The corrosion removing part must be done properly by using appropriate method according to the corrosion type and the state which spread. Mechanical powered, non-powered or chemical corrosion

removal system can be occupied. After removing, low risk components and parts are allowable to apply usual surface coatings.

According to corrosion map where corrosion variation of all the areas in the world are shown, Sri Lanka is categorized under moderate corrosion region. FAA has recommended corrosion program according to these regions.

- Mild - 90 days
- Moderate - 45 days
- Severe - 15 days

Hence through this research it has been advanced the existing corrosion program of SLAF which was conducted every 90 days to 45 days with the basis of the corrosion map.

In SLAF it has been found that maintenance personnel are carrying out manufacturer's recommended inspections even though the aircraft is reaching its design age. In addition to that several errors of the maintenance crew have been found by conducting structured interviews with maintenance personnel. Those are as follows;

- Corrosion control program is held every 90 days and main concerns were not given to corrosion prone areas that we've found
- Corrosion control procedures were only limited to areas where maintenance personnel could easily be accessed.
- When some of the corrosion repairs were beyond organizational limits to repair they were outsourced. In that case until the required resources become available, severe corrosion damages were left unchecked for longer time periods.
- 90-day inspection impacted the availability of the aircraft.
- Current corrosion prevention procedure is mainly concerned about corrective maintenance rather than preventive maintenance.

With the proposed maintenance philosophy the above mentioned issues have been addressed and made the 90-day corrosion control program in to an effective and proactive 45-day corrosion control program.

The moderate and high risk areas are not allowed to use general sealants. And special surface treatments must be formed. Applying MIL-DTL-81706/MIL-DTL-5541, Class 1A chromate treatment are suggested and it acts as an advanced protective layer. But due to the toxins the user must be careful when working with them. In this case MIL-PRF-23377 and MIL-PRF-85582 can be used as primers for the parts. (Anon., 1990) After chromating, appropriate top coating should be applied. In further, the organic coatings are recommended for the top coatings. Usage of polyurethane resin such as MIL-PRF-85285 enhances the chemical resistance and durability. It increases the toughness. The topcoats are MIL-PRF-85285, (Anon., 2009)

Type I are suggested. This called advanced performance coating (APC) and Extended life topcoat (ELT) and the use with Polyol resins are enhances the durability.

IV. DISCUSSION AND CONCLUSION

This study have done for develop a maintenance philosophy which based on the risk assessment and in proactive manner. In this research the attention was paid to the corrosion which effect severely on the serviceability of the aircraft. The characteristics of corrosion is differ on many factors. The operating atmospheric conditions directly effects on the growth of corrosion and high humidity and temperature induces it.

The factors effecting corrosion and the relationship between local island factors are considered as well. In the Sri Lanka case, the country belongs to the moderate corrosion risk zone due to the tropical environment with conjunction of marine atmosphere. Corrosion supportiveness relatively high due to these factors. 45 days regular inspections are recommended but with the observations it is not required. But with the safety risk of corrosion critical areas 45 days inspections can be recommended.

Few limitations are found in this research. The nature of the data and the maintenance recordings basically in generic manner. For personalization of this model the rate of growth need to be analyzed. Maintenance records not given a solid answer. And due to Lack of operational equipment and security reasons is wasn't possible to conducting an experiment on that. The literal values are used. Also some data and records such as SSID (Secondary structural inspection document), technical logs and form 700 are disclosure from the outsiders due to above reasons. Those data had to be used according to the literature. With the real data the findings may more effective.

Another limitation is some required metal analyzing facilities are not available in Sri Lanka.

The model developed can be occupied for any aged aircraft or any aircraft fleet around the world. The risk assessment system is adopted to the aging aircraft components with the literature exposure and before utilize for an aircraft, should be personalized for the particular aircraft. The reliability is increasing with the preciseness of the maintenance records. After identifying the most corrosion prone areas according to the severity of an aircraft the risk can be identified.

When considering the engineering aspect this study will enhance the reliability of maintenance activities which the organization intend to use this model. It will be helpful in avoiding the corrosion related failures by identifying them before it occurs. Hence a sudden failure of such aircraft can be avoided and the outcome can be gained from the aged aircraft will be more or less equal to the outcome which it delivered when it was new. It will increases of the reliability of the aircraft.

V. RECOMMENDATIONS

Basic three recommendations can be given according to the risk level.

- The corrosion inspection frequency should be Advanced with the consideration of corrosion rate and risk level of corrosion failure. Low risk areas are allowed to follow conventional inspection rates but the moderate and high risk zones need to have a special inspection advancements.
- Advanced inspections should be allocated which Specially targeted to the types of corrosion susceptible to occur. The allocation should be done with the scope of NDI and the frequency of utilization must be decided on the corrosion rates.
- Advanced treatment methods should be implemented. Application of protective layers, utilization of electrical insulations are the basic treatments that conduct for the corrosion. By using high grade coatings which developed specially for certain material and certain types of corrosion is more effective.

VI. FUTURE WORK

1. Development of a statistical formula for analysing the likelihood of corrosion on aging aircraft with respective to the operational conditions, environmental and material characteristics.
2. The development of proactive safety specified maintenance philosophy for fatigue.

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