Failure Analysis of Engine Starter Valve CFM56-3 Engine

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ABSTRACT

Aircraft engine contributes about 48% maintenance cost to the overall aircraft maintenance costs. Therefore, the implementation of effective programs and efficient treatment is needed by each airline. In the review of failure data from ATA 71 to ATA 80, Starting System (ATA 80) had the highest failure frequency, with 23% maintenance findings of the overall findings in the pilot's report (Pireps) in 2009. In addition, the reliability report indicated that the system starting in the year 2009 had caused 18% delay from the total delay experienced by Boeing 737-300/400/500. After evaluating the failure data of the engine starting system, from SAP System and Strip Report from January 2004 until June 2010, the highest failure mode in this system is the failure of engine starter valve. This component contributes up to 10% departure delays of the overall delay during the year 2009. Data processing using Weibull analysis results in the reliability function of the parts that make up the engine starter valve. This reliability function is used also to obtain the optimum interval maintenance of actions, with respect to cost, for the engine starter valve. The evaluation results show two failure modes with the highest frequency in the engine starter valve, i.e. diaphragm fail and diaphragm dirty. The Weibull analysis indicates that diaphragm's failure has a normal distribution pattern. It means a preventive maintenance with the optimum interval, with respect to the total cost, is needed to improve the reliability of the engine starting system. While for the dirty failure mode has an exponential pattern, which means that the component's operating condition is not match with the design of the component, a modification is needed.

Keywords: *Engine starter valve, Weibull analysis, delay, preventive maintenance*

1. INTRODUCTION

The Indonesian Civil Aviation Safety Regulation (CASR) 121.373 requires "Each certificate holder shall establish and maintain a system for continuing analysis and surveillance of the performance and effectiveness of its inspection program and the program covering other maintenance, preventive maintenance, and alterations and for the correction of any deficiency in those programs, regardless of whether those programs are carried out by the certificate holder or another person".

Every aircraft engine contributes up to 48% maintenance cost of the overall aircraft maintenance costs. Therefore, the implementation of effective programs and efficient treatment is needed by each airline. From the results of analysis of the PT. GMF AeroAsia data, Starting System (ATA 80) had a failure with the highest frequency in the review from ATA 71 to ATA 80, with 94 numbers of finding or 23% of the overall finding in the pilot's report in 2009. In addition, the reliability report of PT. GMF AeroAsia indicates that the amount of delay caused by the starting system in the year 2009 had reached 18% of the total delay experienced by Boeing 737-300/400/500.

Starting system is one of all systems in the aircraft that serves initial rotation on the main engine to achieve a minimum speed to operate independently. Starting system includes: engine starter turbine, engine starter valve, starter indication, pneumatic ducting, and starter control unit.

2. ENGINE STARTER VALVE

Three Inches Diameter Starter Engine Starter Control Valve or Engine Starter Valve is a pneumatic valve manufactured by Honeywell and used on Boeing 737-300/400/500 engine [4].

Engine Starter Valve works using a pneumatic system with 3 inches diameter of Butterfly Valve as the core of the component. Engine Starter is actuated by a solenoid valve which opens and closes the orifice so that high pressure air flows through the component. Engine Starter Valve is also equipped by a torsion spring, as part of the valve closing mechanism. The position of the Engine Starter Valve is shown in Figure 1.

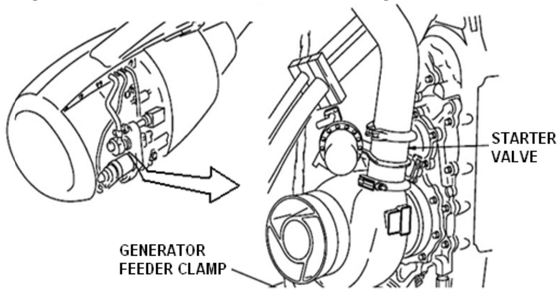

Figure 1 Engine Starter Valve Position [4]

The engine starter valve, which is also called three Inches Diameter Starter Control Valve, consists of two main components, i.e. Valve Actuator Assembly and Body Assembly. Figure 2 shows the main parts of the valve. At normal operating condition, the actuator assembly is loaded with a torsional spring so that it is always closed. This assembly consists of dual diaphragms pneumatic actuator with solenoid assembly, relief valve assembly, external position indicator and an electrical position switch operation. The two diaphragms is connected with the end of a guide which connected with a linkage to rotate the butterfly shaft in the valve assembly.

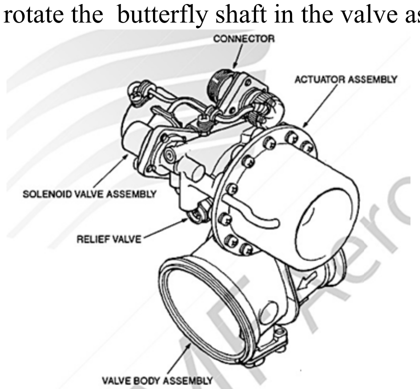

Figure 2 Engine Starter Valve [4]

3. FAILURE DATA ANALYSIS

Failure modes in starting system can be obtained with FMEA analysis. The analysis results in two dominant failure modes of the Starting System, based Pilot Reports (PIREPS), as indicated in Table 1, where the frequency is shown as well. The frequency for both failure modes is close to each other where the starter valve has 16 events and the engine starter motor has 13 events.

Table 1 Failure Mode of Starting System

Failure Mode	**PIREPS Frequency**
Starter Valve Broken	16
Starter Motor Broken	13

Analysis of failure consequences is necessary in order to assess the importance of failure. The failure of Engine Starting System Valve had led to flight delays where the contribution of each component to the flight delays, in the year 2009, is shown in Table 2. The results shown in Table 1 and Table 2 motivates to investigate further the failure characteristics of the starter valve.

Table 2 Component Cause of Delay (ATA80)

Failure Mode	**Frequency**
Start Valve	13
Starter motor	7
Other	2
Total	22

Further detailed data of the starter valve is collected from the System Application Product (SAP) information system and the Strip Report from the Component Shop of PT. GMF AeroAsia, with a range of time from January 2006 until June 2010. Table 3 shows the data obtained for the failure mode of the Starter Valve. Diaphragm fails and dirty are two failure modes with the highest frequency. The next further investigation is focused in these two failure modes.

Table 3 Failure Mode of Engine Starter Valve

Failure Mode	**Strip Report & SAP**
Diaphragm Fail	30
Dirty	27
other	8
Packing Fail	2
Solenoid Fail	14
Overtime Operation	9
Total	99

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Table 4 indicates the detailed data collected for the Diaphragm Fail failure mode of the Starter Valve. For each Serial Number (SN) the Time Since Install (TSI) until failure, in Flight Hours (FH), is shown. The failure data of Dirty failure mode is collected as well, but not shown in this paper. Further analysis is then on the development of the failure distribution for each failure mode by using the Weibull Analysis.

Table 4 Time To Failure data for Diaphragm Fail

No.	SN	TSI (FH)
1	7798	2384
2	6832	4513
3	2244GA	5717
4	2483	6525
5	2329	6623
6	1261	7829
7	3931	8064
8	2244GA	9218
9	2248	15492
10	2323	16875
11	2402	18190
12	3903	20855
13	1849	22870
14	5314	24210
15	2442	29510
16	2845GA	47188

The number of data for the Diaphragm Fail failure mode is only 16, therefore the parametric method of statistical analysis is carried out. It requires a fit test for the selected failure distribution. A Mann test is carried out, but for verification a Kolmogorov test is also conducted. Table 5 shows the calculation results of the tests and the parameters of the Weibull distribution both for the Diaphragm Fail failure mode and Dirty failure mode.

As shown in Table 5, the parameter of the Weibull distribution for the failure mode of diaphragm fail has the shape parameter (β) greater than 1, but relatively small. It indicates that this failure mode has a normal distribution with a large standard deviation or a slow increasing failure rate. It is verified with the value of standard deviation shown in Table 5 and the result of Kolmogorov test. While for the dirty failure mode, the shape parameters (β) is less than 1, which means that it has a hyper-exponential distribution or a decreasing failure rate. Figures 3 and 4 show the plot of the failure rate for each of the failure modes.

Table 5 Statistical calculation results

Parameter	Failure Mode	
	Diaphragm Fail	**Dirty**
Mann	Yes	Yes
M value	0,84	1,33
F Critical	2,33	2,05
Kolmogorov	Yes	No
Value of |Ft-Fs|	0,20	0,31
Kolmogorov value	0,33	0,28
% Kolmogorov	60,70	-
Bheta (β)	1,31	0,71
Eta (η, in FH)	17285	10809
R	0,96	0,92
SD (FH)	11746	13955
MTTF (FH)	15926	13461
Estimated Time (FH)	4180	-494

By having the value of eta (η), the value of MTTF can be determined for each failure mode, as shown in Table 5. As compared to the MTTF, the standard deviation of the distribution is very large, for both of the failure modes. The value of the standard deviation is larger than the MTTF for the Dirty failure mode, which indicates that the distribution is far from a normal distribution type.

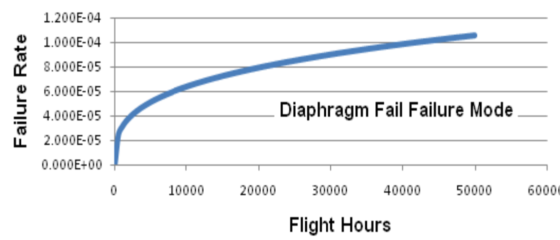

Fig. 3 Failure rate for Diaphragm Fail failure mode

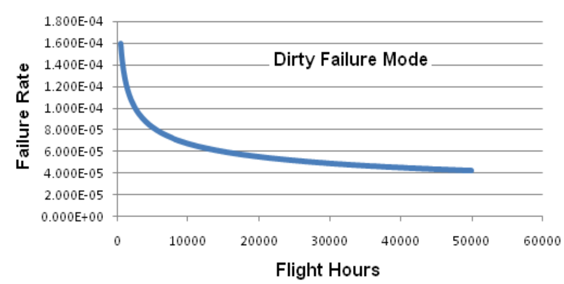

Fig. 4 Failure rate for Dirty failure mode

For the shape parameter (β) > 1, it means that the occurrence of the failure mode has a relationship with the age. Application of preventive maintenance will reduce the risk of failure of these components. However, comparison

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of the percentage of |FT-FS| to the value that Kolmogorov critical value is higher than 50%. This indicates that the failure of the diaphragm has a tendency to enter to a random pattern.

For the dirty failure mode, the shape parameter value (β) = 0.71 and therefore no preventive maintenance is applicable. A redesign is required to prevent failure. A comparison with other component for the same function concludes that an addition of a filter before controlling air enters to the component may be necessary. This failure mode occurs probably because the operating condition is beyond the initial estimate of the manufacturer.

4. FINANCIAL ANALYSIS

Table 6 lists the elements of maintenance of the valve. The annual preventive maintenance cost can be formulated as follow.

$$PM = \frac{t}{T}.(CC + MH)$$

where: PM = *Preventive Maintenance Cost*

t = maintenance interval (FH)

T = annual flight hours (3000 FH)

CC = *Cost Code*

MH =*Man Hour Cost*

Table 6 Maintenance cost elements

No	Parameter	Code	Price (USD)
1	Diaphragm set price	DA	550/service
2	Cleaning Tools	CT	100/service
3	Man Hour	MH	300/service
4	Delay Cost	DC	200/Minute
5	Total Delay Cost	DL	12000/delay

The annual corrective maintenance cost can be formulated as follow.

$$CM = CDF(CC + MH + DP.DL)$$

where: CM =Corrective maintenance cost (USD)

CDF = cumulative probability of failure

DL = Delay cost (USD)

DP = Delay probability/year

The Delay Probability (DP) is calculated by comparing the number of failures of valve which lead to flight delay to the total failures for the period being considered (year 2009). From 18 failures of the valve in the year 2009, 13 failures lead to flight delays. CDF is a function t, where the function is determined from the failure data of each failure mode.

An optimization is carried to determine the best interval of preventive for the least total cost of preventive and corrective maintenance cost (PM+CM). PM will be decreasing when the interval t is increasing. While CM will be decreasing when the interval t is increasing. Figure 5 depicts the changes of the total cost as a function of the preventive maintenance interval t for the diaphragm fail failure mode. For the dirty failure mode the financial analysis is not conducted because no preventive maintenance is applicable.

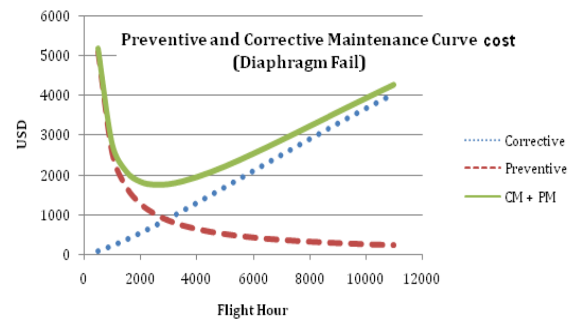

Figure 5 Preventive and Corrective Maintenance cost curve

Table 7 shows the calculation results of the financial analysis for the diaphragm fail failure mode. It is divided into two categories, i.e. the preventive maintenance cost and the corrective maintenance cost. The minimum maintenance cost will be USD.1744 for each valve for the failure mode with preventive maintenance interval 2500 Flight Hours. This interval is far below the MTTF, namely 4180 FH, and therefore it is considered safe. Because the diaphragm can be considered as non-repairable, then the preventive maintenance task will be replacement.

Table 7 Optimum Cost Summary

Failure Mode	Minimum Cost		Preventive		Corrective	
	Flight Hour	USD	USD	%	USD	%
Diaphragm Fail	2500	1744	1020	58.5	724	41.5

5. CONCLUSIONS

The conclusions can be drawn from the analysis above are following.

a. For fleet being analyzed, in the year 2009, engine starter valve was the component that caused the highest frequency of delay for starting system.
b. From failure data of the fleet, diaphragm fail and dirty were the most dominant failure mode in the engine starter valve.
c. By using Weibull analysis, the approximate failure time for diaphragm fail is 4180 FH.

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d. From cost analysis, the preventive maintenance interval time for the minimum cost is at 2500 FH, for diaphragm fail failure mode.
e. For dirty failure mode, it requires a modification to prevent failure.

6. ACKNOWLAGEMENT

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