TECHNICAL NOTE

RELIABILITY ANALYSIS OF A TURBOSHAFT ENGINE

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Abstract

This paper brings out estimation of Average Service Life (ASL) and Mean Life of a turboshaft engine powering a single engined helicopter. This has been carried out through reliability analysis over defect investigation, repair and overhaul data for a period of 5 years. The implication of ASL and Mean life are deliberated. Critical areas for availability improvement for different operators are also highlighted in the paper.

Abbreviations

ASL = Average Service Life
MTBF = Mean Time Between Failure
MTTF = Mean Time To Failure
TBO = Time Between Overhaul
FOD = Foreign Object Damage
PDF = Probability Density Function
DI/R = Defect Investigation/Repair

Introduction

Reliability of any aircraft or engine fleet is normally characterized by the MTBF or MTTF or in general termed as Mean life. Average Service Life (ASL) is a simple and powerful method for reliability quantification with respect to Time Between Overhaul (TBO). Hence it is widely used with service operators for evaluating the reliability of their aircraft, engines and critical lifed components besides monitoring reliability trend over a period. Mean life is the average time to failure of identical products operating in identical conditions [1].

Average Service Life and mean life estimation are carried out on a turbo shaft engine powering a military helicopter based on investigation outcome of defects and nature of the reported defects. Engine under consideration is a constant speed engine of 400 kW power class of second generation turboshaft engine. Analysis is done on the defect investigations and premature withdrawal repairs carried out for a period of 5 years. ASL is calculated for all operators combined and independently. ASL has also been quantified for incremental improvements assumed in maintenance, operational and design domains. Same exercise is repeated with Weibull model in terms of Mean Life.

Failure Data Analysis

This engine is used by four different operators and out of this operator 3 and 4 are operating in saline environment. Engines are withdrawn for different defects which are covered under 18 categories such as bearing failure, oil system related failure, abnormal noise, FOD and etc. A split up of defects based on Operators is shown in the Fig.1.

However, during defect investigation some cases could not be confirmed which is 29.6%, 19.3% and 9.5% for operator 1, 2 and 3 respectively. Only few defects were reported by operator 4 and all were confirmed. This is mainly due to improper diagnosis and rectification measures at operating unit level and to some extent due to intermittencies in components and some defects which could not be ascertained at test bench.

Following inferences are drawn from the above.

- Oil system related defects and bearing failures are generally interlinked and in many cases it has shown inadequate oil discipline.
- FOD cases are very high in Operator 2 compared to other operators, hence adequate precautionary measures to be ensured for reducing FOD cases.
- Percentage of not-confirmed defects is more for Operator 1.

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- Corrosion cases are predominant for those who are operating in saline operating environment.

Average Service Life (ASL)

Average service life is a measure of reliability of engines assuming constant failure rate and is calculated using the following equation.

$$ASL = \frac{\Sigma \text{ Hrs done of all defect Engines} + \text{No. of O/H Engines*TBO}}{\text{No. of defect Engines} + \text{No. of O/H Engines}}$$

Where,

- Hours have been calculated for each case by taking the difference of hours between the present event and the previous event hour for the same engine.
- TBO has been taken appropriately for different operators.

The ASL value considering all operators from 2006-11 is found to be 1159 hrs against a TBO of 1750hrs. The trend of ASL considering all operators is shown in the figure 2:

The ASL trend indicates improvement with years. This can happen due to either or combination of both of the two phenomena given below.

- Failures occur at comparatively higher operational hours than previous years.
- No. of engines withdrawn for defect reduces in comparison with no. of engines withdrawn for overhaul which is a healthy indication.
- Figure 3 presents the overhaul and defect trend pattern of this engine, it can be seen that more than 50% of yearly production task of this engine in the recent years were for overhaul which is an indication of the survival of the engines and thus the maturity of the engines in its life in relation with assigned TBO as per the standard normal deviation distribution patterns. As per the standard aeroengine maintenance norms, about 20% of the engines remain with repair overhaul agencies out of which up to 10% should contribute to defect investigation and repair (DI/R) cases while balance is for overhaul after completion of its assigned TBO.
- The figure indicates that engine withdrawals for defect as well as for overhaul follow a reducing trend. Effectively the total annual task also reduces with years which clearly indicate that availability of the engine for service exploitation is on increase. Progressive reduction in total production task and DI/R statistics over the years is a sign of the enormous maturity of these engines leading to increase in reliability & availability of engines for operations. ASL calculated for the period of reckoning is assigned as baseline ASL.

Table-1 shows that ASL of Operator 1 and 2 are closer while other Operators (3 and 4) are in the same order. This can be due to the similarity in the operational requirements between the operators. Higher ASL percentage for Operators 3 and 4 compared to the first two can be due to better maintenance practices adopted.

Few key defect categories where improvement is possible have been identified. Proportionate increase of ASL with the assumed improvement with respect to these defects categories is also quantified. All improvements have been assumed from the baseline ASL shown above. Operator 4 has not been considered for analysis due to smaller sample size and hence inferences may not be fruitful.

Improvement in ASL is quantified for various improvements assumed as below:

- Not-confirmed defects are generally due to improper diagnosis. If proper diagnosis is ensured, the engine would not have been withdrawn for the reported defect and the engine could have run probably till overhaul. This can be arrested with regular field workshops and in-plant training of maintenance crew for improving and sustaining their professional competency.
- FOD cases or defects are due to inadequate maintenance practices and cleanliness of hangers and runways. Further if the operations are generally closer to ground with frequent landing in unprepared helipads, then the probability of FOD increases manifold. If these

Table-1 : User Wise ASL

Operator	ASL (Hrs)	TBO (Hrs)	% ASL of TBO
Operator 1	1186	1750	67.8
Operator 2	1220	1750	69.7
Operator 3	996	1200	83
Operator 4	1054	1200	87.9

aspects were given due attention, then the engine might not have undergone FOD damage and it would have run probably till overhaul.

- Several engine withdrawals are understood to be due to improper adjustment of fuel accessories like speed governor, altitude idling device, starting solenoid valve, fuel pump, etc. With correct adjustment practices the engine would have run till overhaul.
- Turbine shaft bowing is due to incorrect engine start and shut down practices. The reported defect would not have occurred with proper start and shut down practice.
- Few oil leak cases were attributed to fuel oil seals. Re-designing of seal may enable the engine to run till overhaul.

Based on these assumptions, the hours done for the above cases were replaced with overhaul life. ASL is again estimated for each case with this data set. The improved ASL thus estimated for each case is tabulated in Table-2 and graphically shown in Fig.4.

From Table-2 and Fig.4, the following can be inferred:

If Operator 2 could have attended FOD cases (say No FOD cases), then ASL would have gone to 1310hrs (existing 1220hrs) or Operator 1 could have attended the non-confirmed defect aspects (say no unconfirmed cases), then ASL in Operator 1 would have gone up to 1371hrs (existing 1186hrs) or manufacturing overhaul agency would have looked into improving fuel oil seal design, then ASL of Operator 2 would have gone up to 1245hr (from existing 1220hrs. Improvement in defect diagnosis yields greater benefits to Operator 1 and 2. Operator 1's major problem is defect diagnosis while Operators 2's major concern is FOD.

Mean Life Calculation Using Weibull Model

Apart from the ASL values computed above, corresponding mean life has also been obtained using Weibull model for a comparative study. Mean life gives an indication of life potential of the engine. Since any TBO is the forced withdrawal for a re-conditioning by replacing the entire mandatory parts which have both operational and environmental degradation effects, Mean Life should not be linked to TBO. However Mean Life can give an indication whether an engine TBO can be increased or decreased.

Weibull analysis helps in understanding the failure rate of the system, whereas ASL assumes constant failure rate. Weibull distribution is an empirical distribution, which provides a flexible model for analysis of failure data. Weibull models have been used in many different applications to model complex data sets [2].

Since "Weibull" is a multi-shape distribution model, the shape mainly depends upon the value of shape parameter (β). Significance of this parameter is generally on the following lines:

- $\beta < 1$ indicates a decreasing hazard rate (early failure regime)
- $\beta = 1$ indicates a constant failure rate (chance failure)
- $\beta > 1$ indicates an increasing hazard rate (the wear out failure regime)

Scale parameter (η) value is given by the age at which 63.2% of equipment population is expected to fail [3].

Data used for combined ASL was used as is to Weibull model and the Mean life is found out to be 1139 hrs. The Weibull plot is shown in Fig.5.

Table-2 : ASL with the Assumed Improvements

Assumptions	ASL					
Operators	Baseline ASL (Taking all Defects)	Not Confirmed Defects as no Doubts	FOD as no Defect	Improper Adjustment as no Defect	Turbine Bowing as no Defect	Oil Seal Failure as no Defect
Operator 1	1186	1371	1202	1221	1198	1206
Operator 2	1220	1325	1210	1246	1258	1245
Operator 3	996	1023	1003	1005	1002	1017

The corresponding ASL is 1159 as discussed in 3.0. As life found out by both the methods are in close match, both the methods are mutually validated.

In the Weibull analysis, overhaul has been considered as "Survival" as it is a forced withdrawal for preventive maintenance and not as "Failures". Analysis was accordingly re-run with these changes discussed above and an increased Mean life of 3606 hours was obtained. η and β values are 2882 hrs and 0.7 hrs respectively. Beta value indicates that the failures are dominated due to quality related issues. Here quality issue means deviation in production or maintenance or operation standards or a combination of these. Wear out / ageing has a minor effect on this system. The Weibull plot for this analysis is shown in Fig.6.

Same methodology was followed for establishing baseline Mean life for various operators and further Mean lives were also obtained with the same set of improvements assumed in ASL case. The Mean lives with Weibull parameters are tabulated in Table-3.

Mean lives are considerably higher compared to their corresponding ASL values. This is due to declaration of appropriate entries as survival in the analysis. Beta values for all operators indicate quality related issues where Operator 1 being more serious followed by Operator 2. Assuming similar quality of production, quality deviation is expected in maintenance and operation in case of Operator 1.

Another striking inference is Mean life of Operator 1 is higher than Operator 2 which is opposite with respect to ASL figures. It should be noted that ASL is a function of TBO, **whereas mean life is a quantification of total life potential of the engine based on service exploitation**. Thus Mean life gives indication for probable life extension of engines. With this understanding, even though ASL is higher in Operator 2 than Operator 1, total life potential is higher in Operator 1 engines. This is dictated by the respective engine failure distribution of operators.

The above analysis also gives ample indications that FOD and non confirmed defects are alarming for Operator

Table-3 : Mean Life and Weibull Parameters for all Operators

		Operator 1	Operator 2	Operator 3
Baseline ASL	Beta	0.6216	0.7623	0.8066
	Eeta	3710	3061	5287
	Mean Life	5339	3597	5956
Nont-confirmed Defects	Beta	0.6826	0.7812	0.8935
	Eeta	5789	3954	5056
	Mean Life	7511	4559	5351
FOD	Beta	0.6214	0.7007	0.8213
	Eeta	3836	4462	5453
	Mean Life	5523	5642	6067
Improper Adjustment	Beta	0.6353	0.8045	0.8405
	Eeta	4009	3099	5254
	Mean Life	5621	3497	5756
Turbine Bowing	Beta	0.6233	0.7948	0.8039
	Eeta	3824	3200	5648
	Mean Life	5485	3642	6377
Oil Seal	Beta	0.6092	0.7576	-
	Eeta	4057	3256	-
	Mean Life	5986	3845	-

2 while for Operator 1 non confirmed defects is the point for concern, Further the mean life obtained is higher for Operator 3 while that for Operator 2 is considerably low as seen from the above analysis.

Conclusion

ASL and Mean life have been estimated and quantified for each operator with the assumed improvements. From analysis it is seen that proper diagnosis will notably improve engine availability for all operators. Military Aviation maintenance crews do get shifted from one stream to another due to service exigencies at regular intervals. Hence regular competency training of maintenance crew through field workshops and in-plant training are very essential to enhance and sustain the professional competency and this can reduce non confirmed defect cases to a greater extent. Consultation with the manufacturing agency, before back loading the engines to factory for DI/R, can also reduce the downtime of engines and greatly enhance the availability of engines for operations as seen from the recent past trend. Flying operations and ground FOD drills and associated checks requires a close scrutiny for reduction of FOD cases. Mean life figures for all operators show encouraging signs and potential for increasing engine TBO.

References

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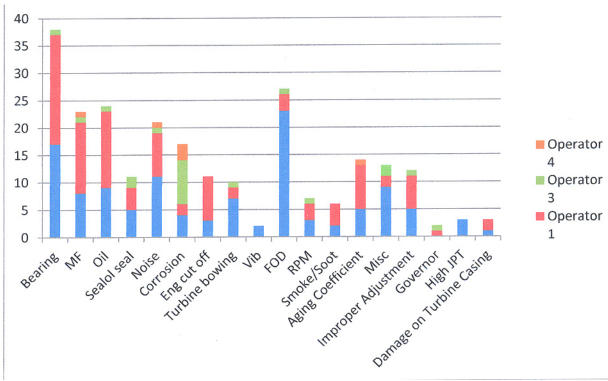

Fig.1 Categorization of Defects

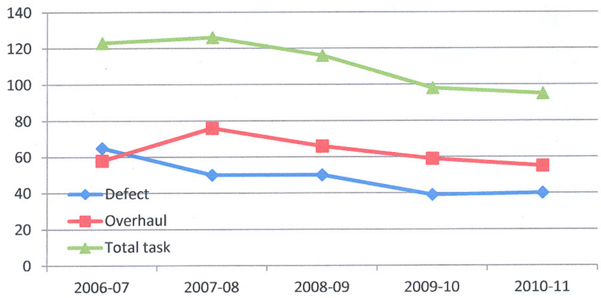

Fig.3 Engine Withdrawl Trend : Defect and Overhaul

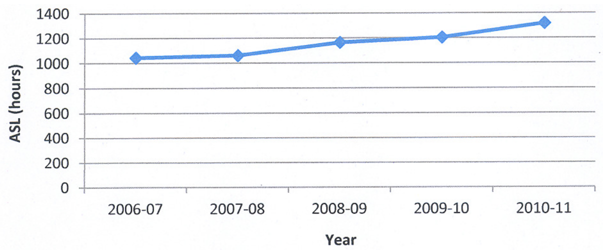

Fig.2 Combined ASL Trend

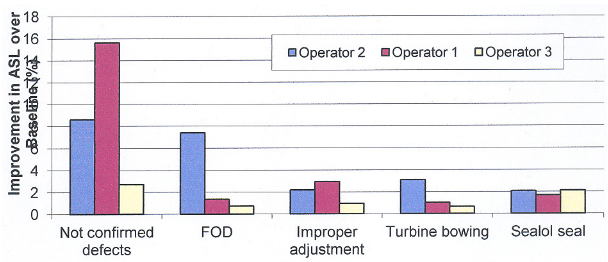

Fig.4 Increment in ASL for Improvements Assumed

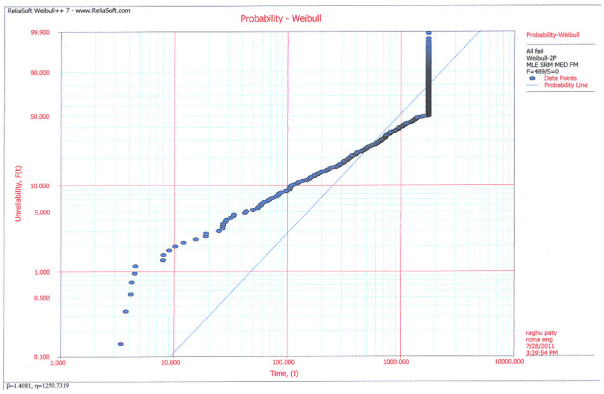

Fig.5 Weibull Plot for as is Combined ASL Data

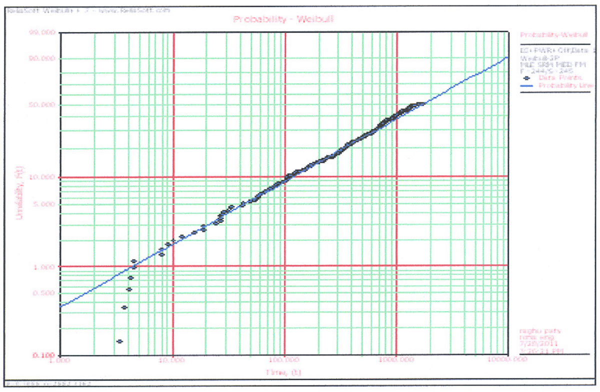

Fig.6 Weibull Plot for Combined ASL Data with Overhaul Entries as Survival