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Differential Degradation Assessment of Helicopter Engines Operated in Marine Environment

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ABSTRACT

The helicopters used for marine operations encounter harsh environment laden with salt mist, sand and dust which could accelerate the deterioration of components. Assessment of the effect of operational environment on component degradation of such helicopter engines is crucial in scheduling their maintenance and ensuring flight safety. The objective of this study is to understand and assess the differential degradation pattern of aeroengines operated in marine environment in comparison to their counterparts operated in non-marine environment. In this study, a sample of 257 ex-service aeroengines of same type and make, operated in marine and non-marine environment were randomly selected and their degradation pattern observed. After obtaining the data on component degradation, further statistical analysis was carried out and the statistical significance of the observations were computed. Out of the ten major components considered in this study, five of them were found to have statistically significant differential degradation due to operation in marine environment. For the remaining components adequate evidence was not available to substantiate differential degradation due to operation in marine environment. These findings serve as valuable input for maintenance inventory planning as well as component improvement programme.

Keywords: Helicopter engine, marine environment, corrosion, differential degradation, field data analysis

1. INTRODUCTION

Helicopters and small aircraft are extensively employed for commuting between sea bound installations, coastal patrolling and for Naval aviation. A significant portion of the operational cost in aviation activity is attributed to engine maintenance expenditure[1,2]. And hence assessment of the effect of marine environment on these aero engines is crucial in deciding their longevity and planning operational support. In marine environment, the sea winds carry several kilograms of salt per cubic kilometer of air which promotes corrosion in the engine components. Although the engine components are designed to withstand given stresses and to provide a specified factor of safety, erosion and corrosion changes the mechanical characteristics of the materials thus reducing the margin of safety and endangering the flight leading to aircraft accidents[3,4]. Unless the corrosion is detected and treated, it becomes a serious problem that hampers the flight safety of the aircraft[5-7].Persistence of such issues despite extensive precautions taken by the designers and users indicate the need for further research. The menace of marine corrosion on aeroengines is far wider than the generally described aqueous corrosion observed in marine applications. It includes atmospheric corrosion of metals exposed in the marine environment and hot salt corrosion in engines operating at sea or taking in salt-laden air[8-11]. Further, the mechanism of corrosion that occurs on control equipment may be similar to that which occurs on the basic structure but a small amount of corrosion on avionics equipment can cause serious degradation or complete system failure. Thus the amount of corrosion that is detrimental varies from component to component and the corrosion tolerance of each component is an important factor while considering the overall system safety.

As mentioned above, this study has been motivated by the fleet maintenance issues encountered during the operation of aeroengines in marine environment. The information on the differential degradation of engines exposed to marine environment serves as an important input for maintenance inventory planning. Hence a field study has been carried out on a large fleet of helicopter engines operated in temporal climatic region with a portion of the population exposed to marine environment. Based on the physical observations of these engines, a few components were identified for the detailed study regarding their differential degradation due to operation in marine environment. Data on the degradation level of these components were recorded for the entire sample of engines studied and the components were classified on the basis of their tolerance to marine environment. The field data collected during this exercise corresponds to approximately 3,00,000 h of cumulative flying spread over several calendar years. This prolonged duration of

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study involving a large sample of engines help to gather the aggregate average system response and to control the effect of any inadvertent heterogeneities in degradation arising out of seasonal variations, operational mission profiles, isolated maintenance issues, local climatic variations, etc.

Though the accelerated degradation of the engines operated in marine environment is intuitively understandable, no systematic study has been reported on how the degradations in aeroengines operated in marine environment differs from their non-marine counterparts. One can observe a few general studies[10,12-17] reported in the literature on the performance degradation of aero gas turbine engines due to various environmental effects. The most prominent among them is AGARD-CP-558[17] which discusses the sand erosion issues encountered during the military operation in the deserts of Gulf region. Similar studies have been reported by Narayanamurthy[18], *et al.* regarding the component deterioration of helicopter engines due to environmental effect mainly due to the sand erosion during desert operation by the Indian Armed Forces. These papers on the environmental effect on engine deterioration generally focuses on the material degradation mechanisms or atmost limit their scope of study to sub-system level such as compressor fouling and its effects due to sand ingestion during desert operation or flying in the vicinity of volcanic eruption[16,18]. Majority of them with the exception of a few[19,20] do not distinguish between marine and non-marine environment while discussing the engine deterioration. Airworthiness authorities often intuitively assume the severity of marine environment and limit the operational life of aeroengines operated in marine environment at a level much lower than their non-marine counterparts. The published literature is sparse on this aspect and to the best of the author's knowledge no article has been published on the comparative evaluation of the aeroengine degradation due to the operation in the marine and non-marine environments. This article fulfills the above literature gap and provides a methodology for comparative assessment of the degradation of aeroengines operated in marine environment vis-a-vis non-marine environment.

2. METHODOLOGY FOR DIFFERENTIAL DEGRADATION ASSESSMENT

An empirical field study has been chosen for analysing the differential degradation of aeroengines operated in marine environment. In addition to the operational environment, the extent of damage observed on the engine components depends on many factors such as material used, coatings applied, presence of degradation accelerating factors such as stress concentration, high temperature prevailing inside the aeroengine, presence of combustion products etc. In order to assess the marginal effect of marine environment, one needs to control all other influencing variables through appropriate research methodology. Therefore in the current study, instead of focusing on the 'physics of failure', a comparative evaluation of the engines operated in marine environment has been carried out with reference to those engines of same make and model having identical performance characteristics but operated in non-marine environment. The overall plan of research includes selection of a random sample of engines and classifying them into two mutually exclusive groups based on their operating environment for subsequent assessment of the degradation in its constituent components as shown in Fig. 1.

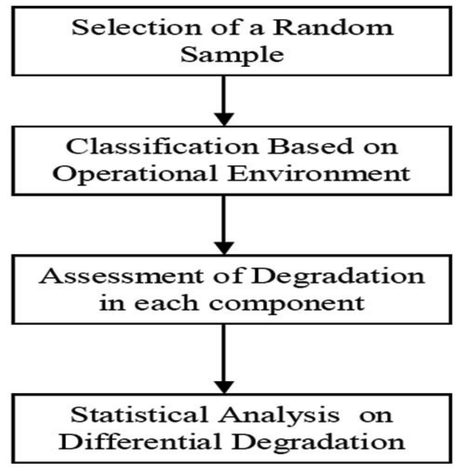

Figure 1. The scheme of the proposed research.

During this research, a large sample of aeroengines were selected and their degradation patterns observed after a predetermined duration of operation, i.e., each engine included in the sample needs to complete a minimum period of operation in the given environment so that the environmental effect if any could be visible on its components. This minimum operational duration specified as 1200 h in this study corresponds to the authorized time between overhauls of the given engine.

In summary, the formal research approach identifies the degradation noticed on critical components of the aeroengine measured on a categorical scale as the variable and the operational environment as a factor. This leads to classification of the sample of engines into two mutually exclusive sets on the basis of their operational environment thus formulating the investigation as a typical two sample problem for differential comparison. Thus the research problem boils down to comparing the proportions of degradations in the marine sample with those of the non-marine sample as described in the following subsections.

2.1 Sampling Scheme and the Data

The sample consists of helicopter engines drawn from various operating bases that includes marine as well as non-marine locations. Since it is extremely difficult to implement a probabilistic random sampling design in the actual military operational scenario, a non-probabilistic sampling design is adopted on an *adhoc* basis and subsequently the sample randomness has been verified using probabilistic methods as follows. To provide the statistical justification of the randomness of the sample selected, a runs test based on the theory of runs[21] has been used. The identification number of the engine has been taken as the base reference and a run is defined based on the succession of the unit serial number in the order in which it has been included in the sample. The central idea is to ensure that there are no definite groupings or alternating patterns in the selection of engines as evidenced by too few runs or too many runs. Let n_1 be the occurrences of *type 1* sequences and n_2 be the number of occurrences of *type 2* sequences and r indicate the number of runs. Based on the sampling distributions of r, the mean μ_r and the standard deviation σ_r are given by (vide Eqns. 15.8 and 15.9 of Canavos[22])

$$\mu_r = \frac{2n_1 n_2}{(n_1+n_2)} + 1 \tag{1}$$

$$\sigma_r = \sqrt{2n_1 n_2 \frac{2n_1 n_2 - n_1 - n_2}{(n_1+n_2)^2 \left(n_1+n_2-1\right)}} \tag{2}$$

Now for testing the null hypothesis concerning the randomness of the field data, a two tailed test would be appropriate as too many or too few runs would indicate that the process of sample selection is not random. Also it is well known that for a sufficiently large number (say > 10) of n_1 and n_2 , the sampling distribution of r is closely approximated by Normal distribution. Therefore, based on the z- value for a significance level of 0.1, one can test the hypothesis on the randomness of the given sample. Once a random sample of engines is available, one needs to formulate the theoretical frame work for the differential degradation analysis. Even before that, one has to have clarity on the data needed and how to extract the data. The data extraction is proposed as per the scheme shown in Figure 2 for the entire sample of engines studied. Let each engine included in the sample fall into the Group {**M**} or {**N**} where {**M**} includes the engines operated in marine environment and {**N**} includes the engines operated in non-marine environment. Based on the operational practice, there is no exchange of engines between marine and non-marine operations and hence {**M**} and {**N**} are mutually exclusive.

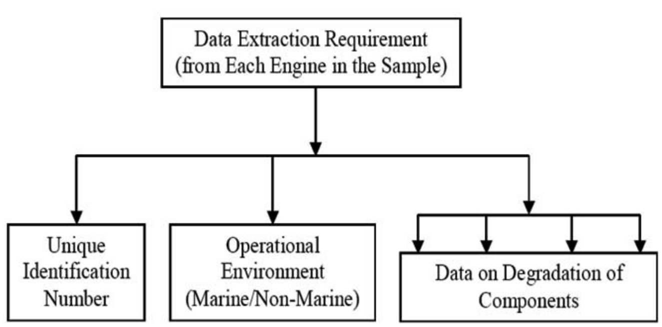

Figure 2. The data extraction scheme.

Given the set of engines in both marine and non-marine category, the investigation now focuses on degradation of the critical components of each of these engines. A pilot study on a few engines (say 25 Nos.) belonging to both the above categories is proposed to identify a few components which are sensitive to the environmental degradation for further study. These components might typically include compressor blades, diffuser, labyrinth, turbine casing etc. However the material details of these parts are not included in this article as the focus of this research is on the differential degradation of a given part with respect to marine *vs* non-marine environment. Quantification of the extent of degradation on complex geometries of these components is done using the standards provided by the engine manufacturer for deciding reuse of these components during overhaul. For the maintenance inventory planning of a large fleet of engines, the primary information needed is the degradation rates of these parts and hence discussion on the material degradation mechanisms and mitigation methods shall not be included in this article.

2.2 The Theoretical Framework

Suppose the data on the degradation observed on the major components of a large number of engines is available, the next step is to evaluate the proportion of degradations in each sample. ie., for a given component, one is interested in comparing the proportions of degradations evident in the marine engines with that of non-marine engines. Let P_{M_J} be the proportion of marine operated engines that had undergone degradation in j-th component and P_{N_J} be the proportions of non-marine engines that had degradation in j-th component. Let N_M and N_N denote the sample sizes from marine and non-marine category respectively and let X_j and Y_j be the observed number of degradations corresponding to marine and non-marine engines for a given part j. The sample proportions $P_{M_j} = X_j / N_M$ and $P_{N_j} = Y_j / N_N$ are the maximum likelihood estimators of P_{M_J} and P_{N_J} respectively. Once the sample proportions are known, the differential degradation of j-th component Δ_j which is defined as the difference in proportion of degradation between the marine and non-marine engines with respect to j-th component can be obtained as

$$\Delta_j = P_{M_J} - P_{N_J} \tag{3}$$

Further to check whether the marine operations cause a differential degradation to part j, the following hypothesis testing is proposed.

$H_o : P_{M_J} = P_{N_J}$ or $P_{M_J} - P_{N_J} = 0$ against the alternative $H_a : P_{M_J} \neq P_{N_J}$

In order to test the above hypothesis, let us consider the statistic $\hat{P}_{M_j} - \hat{P}_{N_j}$. Since by the assumption, X_j and Y_j are binominal random variables, the variance estimators are given by

$$Var\left(\hat{P}_{M_j}\right) = Var\left(\frac{X_j}{N_M}\right) = \frac{\hat{P}_{M_j}\left(1-\hat{P}_{M_j}\right)}{N_M} \tag{4}$$

$$\mathrm{Var}\left(\hat{P}_{N_j}\right) = \mathrm{Var}\left(\frac{Y_j}{N_N}\right) = \frac{\hat{P}_{N_j}\left(1-\hat{P}_{N_j}\right)}{N_N} \tag{5}$$

Under Ho, the two proportions are assumed to be equal. ie., let the common proportions be $P_{M_j} = P_{N_j} = P_{O_j}$ where P_{O_j} is the pooled estimate of the proportion of degradations. Then, if null hypothesis is true, for sufficiently large number of samples, the statistic $\hat{P}_{M_j} - \hat{P}_{N_j}$ is approximately normally distributed with mean

$$E\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = 0 \tag{6}$$

and Variance,

$$Var\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = \frac{P_{O_j}\left(1-P_{O_j}\right)}{N_M} + \frac{P_{O_j}\left(1-P_{O_j}\right)}{N_N} \tag{7}$$

Therefore the standard deviation (SD) follows as,

$$SD\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = \sqrt{P_{O_j}\left(1-P_{O_j}\right)\left(\frac{1}{N_M} + \frac{1}{N_N}\right)} \tag{8}$$

Since P_{O_j} is unknown, let us try to get the best estimator of P_{O_j} as $\hat{P}_{O_j}$ by pooling the information from both samples from the marine and non-marine operating environment to determine the pooled estimates, i.e.,

$$\hat{P}_{O_j} = \frac{X_j + Y_j}{N_M + N_N} \tag{9}$$

where X_j and Y_j are the number of degradations in sample of marine and non-marine engines respectively for the j-th component. Therefore standard deviation

$$SD\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = \sqrt{\hat{P}_{O_j}\left(1-\hat{P}_{O_j}\right)\left(\frac{1}{N_M} + \frac{1}{N_N}\right)} \tag{10}$$

Under Ho, for large N_M and N_N, the distribution of the static $\hat{P}_{M_i} - \hat{P}_{N_i}$ is approximately normal, i.e.,

$$\frac{\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right)}{\mathrm{SD}\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right)} \sim N(0,1) \text{ therefore,}$$

$$z = \frac{\hat{P}_{M_j} - \hat{P}_{N_j}}{\sqrt{\hat{P}_{O_j}\left(1-\hat{P}_{O_j}\right)\left(\frac{1}{N_M} + \frac{1}{N_N}\right)}} \tag{11}$$

and the p-value is given by

$$P\left(z > z_{obs}\right) = 1 - P(z \le z_{obs}) \tag{12}$$

When the p-value is high, we have no adequate evidence to reject the null, i.e., As far as Ho is concerned, the analyst does not have adequate evidence to say that the degradation of this component is affected solely by the marine operations. On the corollary; we can infer that marine environment operations has no significant effect on the life of the component in comparison with operations in non-marine environment.

One might further be interested in examining the confidence interval (CI) for the differential degradation. The statistic of interest is the difference between the two sample proportions $\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right)$. Since $E\left(\hat{P}_{M_j}\right) = P_{M_j}$ and $E\left(\hat{P}_{N_j}\right) = P_{N_j}$, it could be shown that $E\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = P_{M_j} - P_{N_j}$ and $Var\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = Var\left(P_{M_j}\right) + Var\left(P_{N_j}\right)$. It implies that

$$Var\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = \frac{P_{M_j}\left(1-P_{M_j}\right)}{N_M} + \frac{P_{N_j}\left(1-P_{N_j}\right)}{N_N} \tag{13}$$

For sufficiently large number of samples, the distribution of the statistic $\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right)$ is approximately normal with mean and variance as shown above. Then the distribution of z is obtained as follows.

$$z = \frac{\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) - \left(P_{M_j} - P_{N_j}\right)}{\sqrt{\frac{P_{M_j}\left(1-P_{M_j}\right)}{N_M} + \frac{P_{N_j}\left(1-P_{N_j}\right)}{N_N}}} \tag{14}$$

Therefore the probability of the random interval $(\hat{P}_{M_j} - \hat{P}_{N_j}) \pm \Phi^{-1}_{1-\alpha/2} SD\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) = (1-\alpha)$ where $\Phi(.)$ is the standard Normal cumulative density function and hence the $100(1-\alpha)\%$ confidence interval of the differential degradation of the j-th component due to operation in marine environment is given by

$$\left(\hat{P}_{M_j} - \hat{P}_{N_j}\right) \pm \Phi^{-1}_{1-\alpha/2} \times \sqrt{\frac{P_{M_j}\left(1-P_{M_j}\right)}{N_M} + \frac{P_{N_j}\left(1-P_{N_j}\right)}{N_N}} \tag{15}$$

As described above, one can obtain the sample proportions and other statistical properties of the differential degradation of the engines operated in the marine environment. These quantities provide the theoretical basis for the differential degradation assessment of engines presented in this article.

3. DATA ANALYSIS

Now let us move on to the assessment of differential degradations of a fleet of helicopter engines based on the field observations. It covers a large fleet of engines out of which a portion is exclusively used for marine aviation and hence provides an opportunity to study the effect of marine environment on the degradation of engine components. For large samples of data collected over a period of time, one need not be very pessimistic on the randomness of the sample due to the non-probabilistic sampling technique adopted. The total number of engines and the environment wise break-up are given in Table 1. Here the sample sizes of both marine operated and non-marine operated engines are large enough to approximate the sampling distribution of the 'number of runs' (r) by Normal distribution. The number of runs is counted based on the order in which the engines are withdrawn from service and the run test result with p-value = 0.36249 indicate that there is no evidence against the randomness of the selected sample.

Table 1. Number of engines sampled

Marine	Non-marine	Total
48	209	257

While the randomness of the sample selection has been ensured using statistical test, the identicalness of the units considered in the sample is ensured by means of engineering analysis. Due to their similarity in both construction as well as functional characteristics, the assumption of identical systems forming a homogeneous sample is implicitly tenable. The engineering details such as the standard of preparation, constructional aspects, embodiment of modifications etc. of each engine included in the sample have been verified from the records available with the engine manufacturer.

On observing the physical condition of the ex-service components, the criteria for assessing the degradation has been adopted from the engine manufacturer as indicated in the overhaul manual. Domain expertise has been extensively involved in the above decision process. Based on the physical observations made during the pilot study, ten components have been identified for further investigation. Let us denote these components as C_1, C_2, …., C_{10} without getting into the engineering details. Let the degradation level of each ex-service component be indicated in a nominal scale as follows. If the component is physically degraded (component *rejected* in industrial terms prescribed by the engine manufacturer) denote the observation as `1' or else denote it as `0'. A snapshot of the data base generated on this basis is shown in Table 2.

Table 2. A snapshot of the database

Engine S. No.	Environ ment	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Exxx	Marine	0	0	1	0	1	0	1	0	0	0
Exxy	Non-marine	1	0	0	1	0	0	1	0	0	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
Exyx	Marine	1	1	1	0	1	0	1	0	0	0
Exyy	Non-marine	0	1	1	1	0	0	1	0	0	1

The physical condition of components C_1, C_2, …., C_{10} have been observed for all the ex-service engines included in the study. Different components exhibited varying levels of degradation after prolonged exposure to the operating environment. A summary of the number of degradations observed in each component is presented in Table 3. One important feature observed is the high number of degradations for some engine components (eg. component C_4) irrespective of the operating environment. If one looks at the marine operated engines alone, it may lead to wrong conclusion. For instance, in 42 cases out of 48 marine engines, component C_4 has been degraded giving a prima facie impression that degradation of component C_4 is due to its exposure to marine environment. However if one closely examines the case of engines operated in non-marine environment, component C_4 has the maximum number of degradations (163 cases out of 209 engines) and one may not find any statistical support for the argument for differential degradation on component C_4. Similarly for component C_5, degradation during non-marine operation seems to be more severe than the marine operation.

Table 3. Number of degradations observed in each component C_1, C_2, …., C_{10}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	Total
Marine	5	25	3	42	14	40	3	38	27	7	204
Non-marine	18	35	17	163	115	6	14	89	16	4	477
Total	23	60	20	205	129	46	17	127	43	11	681

Having obtained the data on the differential degradation due to the operational environment, further statistical analysis has been carried out. The point estimates of the proportion of degradation in different environments, the point and interval estimates of the differential degradation and the Statistical significance of the observations were computed and tabulated as shown in Table 4. Out of the ten major components considered in this study, five of them were found to have statistically significant differential degradation due to operation in marine environment. For the remaining components adequate evidence is not available to substantiate differential degradation due to operation in marine environment.

4. DISCUSSION

Motivated by the maintenance issues of helicopter engines that are used in marine as well as non-marine environments, a systematic study on the differential degradation assessment of aeroengine has been carried out as illustrated in this article. The severity of marine environment is often taken as a basic premise and many airworthiness engineers believe that the aeroengines operated in marine environment have very limited life potential compared to engines operated in non-marine environment. This intuitive assumption needs a formal verification and hence a hypothesis test has been proposed. Under the null hypothesis it is assumed that $\Delta j = 0$. It implies that under null, the marine operating environment has no marginal effect on the component deterioration. The above hypothesis has been tested based on the data collected from a random sample of engines to confirm the differential degradation if any. Statistically significant differential degradation due to operation in marine environment has been observed in five components C_2, C_6, C_8, C_9 and C_{10} with *p*-values 2.58141×10^{-06}, 7.17953×10^{-36}, 1.09585×10^{-04}, 2.70403×10^{-14} and 3.46773×10^{-04} respectively as shown in Table 4. However, for components C_1, C_3, C_4 and C_7 the *p*- values obtained are 0.38492, 0.34456, 0.32181 and 0.39008 respectively indicating

Table 4. Significance (p-value) of the differential degradation (Δ_j) noticed on different components

Comp ID	$\hat{P}_{M_j}$	$\hat{P}_{N_j}$	Δ_j	95% CI of Δ_j	*p*- value
C_1	0.09615	0.08451	0.01165	-0.07676, 0.10005	0.38492
C_2	0.48077	0.16432	0.31645	0.17182, 0.46108	2.58141×10^{-06}
C_3	0.05769	0.07981	-0.02212	-0.09520, 0.05096	0.34456
C_4	0.80769	0.76526	0.04243	-0.07887, 0.16374	0.32181
C_5	0.26923	0.53991	-0.27068	-0.40857, -0.13278	8.69469×10^{-04}
C_6	0.76923	0.02817	0.74106	0.62441, 0.85772	7.17953×10^{-36}
C_7	0.05769	0.06573	-0.00804	-0.07962, 0.06355	0.39008
C_8	0.73077	0.41784	0.31293	0.17537, 0.45049	1.09585×10^{-04}
C_9	0.51923	0.07512	0.44411	0.30377, 0.58445	2.70403×10^{-14}
C_{10}	0.13462	0.01878	0.11583	0.02129, 0.21038	3.46773×10^{-04}

that there is no adequate evidence available to prove the differential degradation due to marine environment. However for component C_5 non-marine degradation seems to be more predominant than degradation induced by marine environment. Figure 3 depicts the 95% confidence intervals of the differential degradation for the components C_1, C_2, …., C_{10} in a lucid manner and provides a bird's eye view of the results obtained.

This study reveals varying response of different components to the differential degradation while operating in marine environment. Marine environment surely affects the degradation of certain components, but this statement needs to be interpreted carefully. As revealed in this study, operation in marine environment cannot be solely responsible for the component degradation as many components degraded during non-marine operation as well. This probably negates the conventional wisdom of imposing arbitrary life restrictions on marine engines under the pretext of harsh marine environment. This result opens up a large area of research in life management of critical components of complex systems operated in marine environment. As mentioned above, this study emphasizes the need for detailed material analysis and institution of degradation mitigation plans leading to judicious

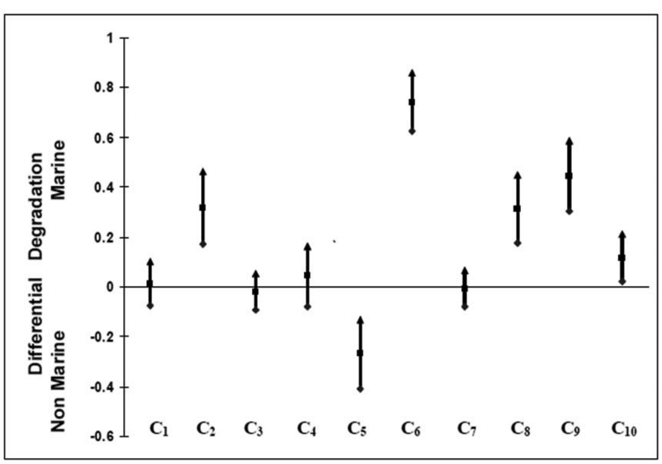

Figure 3. 95% Confidence interval for differential degradation of components C_1, C_2 , …., C_{10}

life management of aeroengines. Some components are susceptible for higher rate of degradation in marine environment such as C_2, C_6, C_8, C_9 and C_{10} and these may be identified for further study under component improvement programme. Similarly component C_5 needs some re-look from the engineering perspective related to the non-marine operation, probably issues related to operation at high altitudes or hot desert conditions and so on. The remaining components C_1, C_3, C_4 and C_7 have degradation as a result of operational exploitation but one cannot attribute it on the harshness of marine environment. These components are affected by some degradation mechanisms prevailing both at marine and non-marine environments. These aspects offer new venues of research and can be explored further as an extension to this work.

Further, the component rejections during engine overhaul is directly linked to the extent of degradation and thus the outcome of this study provides an essential input for maintenance planning and inventory management. The demand rate of these high value inventory and their differential consumption pattern for marine vis-a-vis non marine application is an indispensable information for the maintenance-repair-overhaul (MRO) supply chain management.

5. CONCLUSION

An assessment of the differential degradation of a typical helicopter engine operated in marine environment has been carried out. While discussing the practical issues, methodological issues were also addressed. Data analysis revealed that five out of the ten selected components of the given aeroengine do exhibit statistically significant differential degradation due to operation in marine environment. This study brings out the need for systematic assessment of the environmental degradation on critical components of complex systems. Through the analysis of operational feedback collected from a large fleet of engines, this article highlights the methodology to assess equipment degradation due to operation in marine environment through a field survey.

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