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# Failure Mode Effect Analysis (FMEA) Utilization of T-56 Turboprop Engine Turbine

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**Abstract**

Failure Modes and Effects Analysis (FMEA) was used to analyze the failure modes, causes, and effects of the T-56 engine turbine. Failure location and contributing factors were identified and categorized. To give an insight into risk assessment and priority for corrective action, FMEA data were ranked using RPN ranking. From the FMEA matrix, the major failure mode of the T-56 engine turbine was found to be the mechanical damage due to structural failure caused by several factors like erosion and sand ingestion. On the other hand, field data capture the operational and environmental stresses associated with the actual usage conditions and allows for more accurate predictions of the reliability performance of the components. This enables the operators to develop appropriate inspection or replacement programs, and spare part plans based on their own operational and environmental conditions, which result in decreasing maintenance costs and minimizing flight delays and cancellations due to unexpected failures.

***Keywords:*** Failure Modes; Severity; Risk Priority.

## 1. Introduction

FMEA is used to identify potential failure modes, evaluating their causes, determine their effect on the performance of the product, and identify actions to mitigate them. While anticipating every failure mode is not possible, prioritizing failure risk based on its consequence is very essential. An FMEA is a crucial tool to manage costs incurred from unpredicted failures [1]. Over the last few decades, FMEA technique has been utilized as a qualitative analysis in design and control of US military systems [2], and [3]. wind turbines [4], and [5], solar modules [6], and [7], induction machines [8], and motor drives [9]. Further, to enhance maintenance planning, an identification and assessment of the consequences associated with potential failure modes are performed using FMEA technique including a listing of failure modes, potential causes for each failure, effects of the failure and their seriousness and corrective actions that might be taken.

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## 2. Methodology

Files FMEA typically includes a listing of failure mode, potential causes for each failure, effects of the failure and their seriousness and corrective actions that might be taken. FMEA process will typically adapt and apply the process to meet their specific needs. To rank the failure modes, FMEA assigns a numerical value to each risk associated with a causing failure by calculating the risk priority number (RPN) using severity of a failure (S), probability of the occurrence (O), and probability of failure detection (D):

$$RPN = S \times O \times D$$

The main advantage of RPN value is to prioritize the failure mode for corrective action. Table 1 states the definitions of terms used according to [10], and [11].

**Table 1:** FMEA definitions of terms

| | |
|---|---|
| Failure | Termination of the ability of an item to perform a required function |
| Failure mode | The way in which a design fails to perform as intended or according to specifications |
| Failure cause | Means by which an element of the design results in a failure mode |
| Failure effects | The impact on the customer resulting from the failure mode |
| Severity | Refers to the magnitude of the end effect of a system failure |
| Probability of occurrence | Refers to the frequency that a root cause or failure mode is likely to occur |
| Detection | Refers to the likelihood of detecting a root cause before a failure can occur |

For various industries, there are many different standards of FMEA application. Reference (MIL-STD-1629), [12], evaluates 45 FMEA standards based on industry specific needs. The most widely used standard is MIL-STD-1629A, which has been employed, in many different industries for general failure analysis. Due to the complexity and criticality of military systems, this standard provides a reliable foundation to perform FMEAs on a variety of systems. In the present work, MIL-STD-1629A standard is used to scale the severity, probability of the occurrence, and detection factors using a numerical scale (rating) from 1 to 10 as specified in Table 2, Table 3, and Table 4.

**Table 2:** Severity classification for T-56 Turbine failure data

| | | |
|---|---|---|
| Hazardous without warning | Very high severity ranking when a potential failure mode affects safe system operation without warning | 10 |
| Hazardous with warning | Very high severity ranking when a potential failure mode affects safe system operation with warning | 9 |
| Very High | System inoperable with destructive failure without compromising safety | 8 |
| High | System inoperable with equipment damage | 7 |
| Moderate | System inoperable with minor damage | 6 |
| Low | System inoperable without damage | 5 |
| Very Low | System operable with significant degradation of performance | 4 |
| Minor | System operable with some degradation of performance | 3 |
| Very Minor | System operable with minimal interference | 2 |
| None | No effect | 1 |

**Table 3:** Probability classification for T-56 Turbine failure

| Probability of Failure | Failure Probability | Ranking |
|---|---|---|
| Very High: Failure is almost inevitable | >1 in 2 (50%) | 10 |
| | 1 in 3 (33%) | 9 |
| High: Repeated failures | 1 in 8 (12.5%) | 8 |
| | 1 in 20 (5%) | 7 |
| Moderate: Occasional failures | 1 in 80 (1.25%) | 6 |
| | 1 in 400 (0.25%) | 5 |
| | 1 in 2,000 (0.05%) | 4 |
| Low: Relatively few failures | 1 in 15,000 (≤ 0.01%) | 3 |
| | 1 in 150,000 (≤ 0.001%) | 2 |
| Remote: Failure is unlikely | <1 in 1,500,000 (≤ 0.0001%) | 1 |

**Table 4:** Detection classification for T-56 Turbine failure data

| Detection | Likelihood of Detection by Design Control | Ranking |
|---|---|---|
| Absolute Uncertainty | Design control cannot detect potential cause/mechanism and subsequent failure mode | 10 |
| Very Remote | Very remote chance the design control will detect potential cause/mechanism and subsequent failure mode | 9 |
| Remote | Remote chance the design control will detect potential cause/mechanism and subsequent failure mode | 8 |
| Very Low | Very low chance the design control will detect potential cause/mechanism and subsequent failure mode | 7 |
| Low | Low chance the design control will detect potential cause/mechanism and subsequent failure mode | 6 |
| Moderate | Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode | 5 |
| Moderately High | Moderately High chance the design control will detect potential cause/mechanism and subsequent failure mode | 4 |
| High | High chance the design control will detect potential cause/mechanism and subsequent failure mode | 3 |
| Very High | Very high chance the design control will detect potential cause/mechanism and subsequent failure mode | 2 |
| Almost Certain | Design control will detect potential cause/mechanism and subsequent failure mode | 1 |

After scaling the severity, occurrence, and detection factors, an algorithm is developed to create the FMEA as shown in Figure. 1.

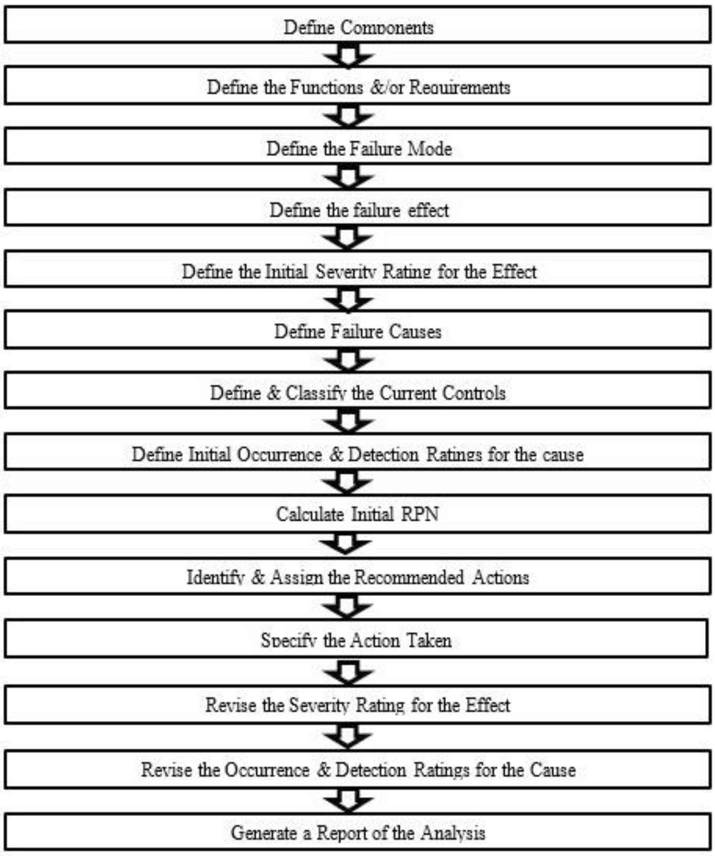


**Figure 1:** An algorithm to create a FMEA project

## 3. Application analysis of the proposed approach to the T-56 turbine

A description of subsystems and components of a turbine system is necessary to completely analyze its failures. The main components of the T-56 turbine are, inlet casing, vane casing, vane, and seal support, four stages of stator and rotor, thermocouples, and rear bearing support. as shown in Figure. 2. [13].

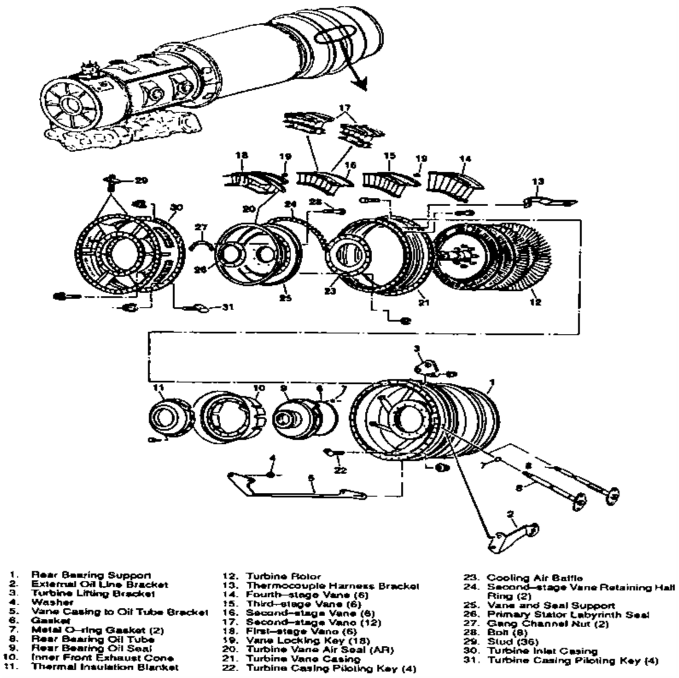


**Figure 2:** Turbine Unit Assemblies.

Based on the FMEA analysis in [14], Failure location, cause, and failure classification mode, were performed. This methodology enabled the analysis and classification of ninety-five failures in 12873.5 turbine operating hours, over the period 33 years. Figure. 3 shows T-56 turbine failure location based on the turbine failure data.

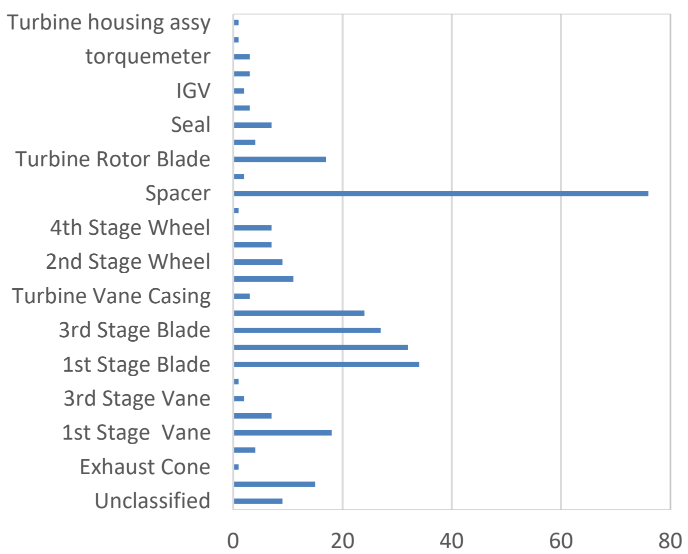


**Figure 3:** T-56 turbine failure location

The different failure modes were investigated where it was found that the major failure mode of the T-56 engine turbine is a mechanical damage due to structure failure which caused by several factors like erosion and sand ingestion. Figure. 4 shows the failure modes distribution.

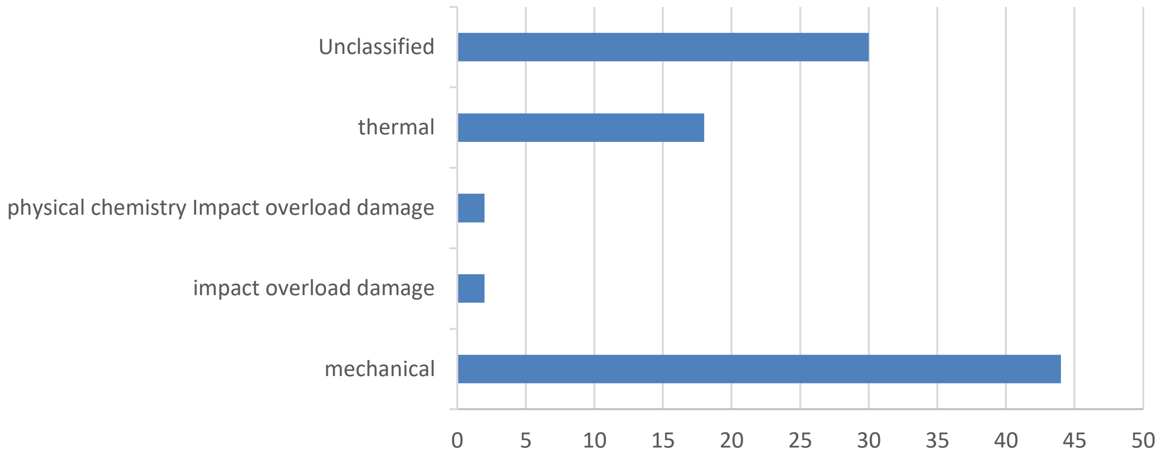


**Figure 4:** Failure mode distribution

Based on reasons of failure and failure consequences, turbine failures data was divided into seven categories: failures effect the turbine performance, failure caused by structural damage, scheduled overhaul maintenance, failure caused by FOD, failure caused by contamination, and failure effecting other maintenance. Figure. 5, illustrates those categories.

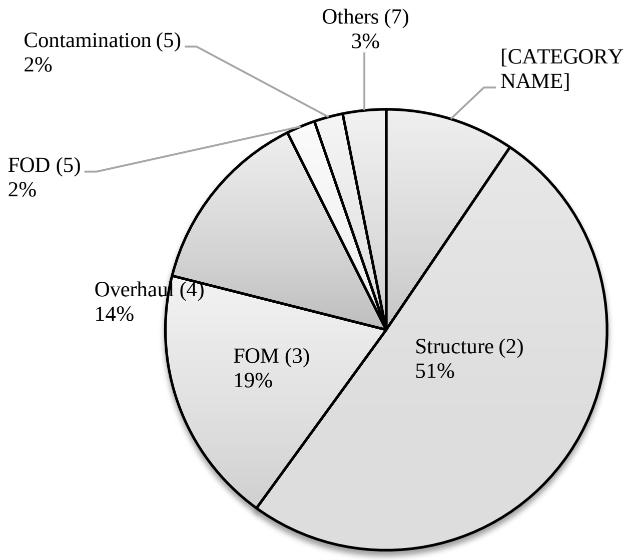


**Figure 5:** Failure categories for T-56 turbine

The status of overhaul actions in reference to each failure category were provided as shown in Figure. 6.

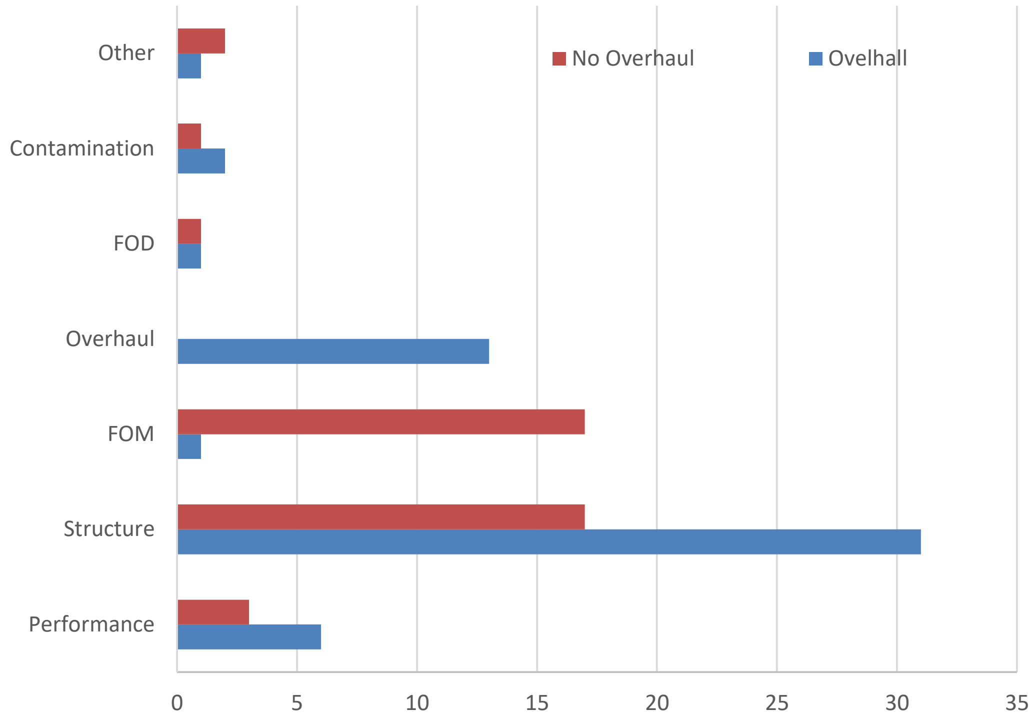


**Figure 6:** The status overhaul actions for each failure category

## 4. Conclusions

In this work, more than thirty years of local data was used to predict and validate the failure rate of the T-56 engine turbine with respect to turbine life data. FMEA, was used to analyze the failure modes, causes, and effects of the T-56 engine turbine. Failure location and contribution factors were identified and categorized. To give an insight into risk assessment and priority for corrective action, FMEA data were ranked using RPN ranking. From FMEA matrix, the major failure mode of the T-56 engine turbine was found to be the mechanical damage due to structure failure which caused by several factors like erosion and sand ingestion. On the other hand, field data capture the operational and environmental stresses associated with the actual usage conditions and allows for more accurate predictions of reliability performance of the components. This enables the operators to develop appropriate inspection or replacement programs, and spare part plans based on their own operational and environmental conditions, which result in decreasing maintenance cost and minimizing flight delays and cancellations due to unexpected failures.

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