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Reliability Impact of Gas Turbine Plant for Power Generation and Electricity Supply Using WeiBull Application

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Abstract— *The power station plays critical role in supporting Nation's economic development for improving standard of living; it is becoming evident that many generating companies' open cycle gas turbine power plant components are facing uncontrollable thermal loading (stress/strain) challenges particularly on compressor and turbine blades application thereby making the performances, efficiency and reliability of these blades to experienced poor power generation. Ideally, blades are essential components that play crucial role for compressing atmospheric air (for increased temperature and pressure) in order to provide inlet conditions of temperature (400 - 600℃) and pressure (10 – 30 bar). The exit conditions of the compressor must be met to engage delivery of the needed energy requirement to the combustion chamber on the view to further increase the burning process of compressed air to provide high thermodynamic energy evolving from temperature of 600℃ - 1500℃ and pressure of 10 – 30 bar necessary to extract energy for combustion chamber where expansion processes are achieved to produce the mechanical energy in order to drive the compressor and also energize generator and alternators for power generation or production. This paper considered application of Weibull and Rayleigh's distribution for the prediction of compressor/turbine blade failures due to tear and wear, thermal loading, fatigue and creeping of contaminated surfaces that may result into erosion dip that will evidently amount to outages or blackout in the grid power supply. Similarly, three (3) identical gas turbine power plant with 36MW capacity of thirty (30) blades for a period of 10 years (2016 – 2025) were examined and simulated using specialized TPC windchill quality solution (version 10.2) to determine the performance of compressor/turbine blade parameters of shape (β), scale (γ), and location (η) respectively. The results obtained from compressor blades simulation of probability – plot, probability density function (PDF) plot, reliability vs time plot, unreliability vs time plot, failure rate vs time plot are presented as: shape (β) = 2.9085, scale (γ) = 24.3296, and location (η) = -5.5962 respectively while the compressor blades characteristics are captured in Figure 1 -5. Similarly, simulation results obtained from turbine blades are also presented as: Shape (β)= 4.1353, Scale (γ) = 33.2384 and Location (η) = -12.8047. The compressor blade plot shows prediction of increasing failure rate with shape or slope parameter (β = 2.9085) greater than one (1); this means that reliability of the compressor blade is decreasing with time as contained and shown in the different plots while the scale parameters showing the spreading rate of the failure which needs to be rescaled to fit back its performance, efficiency and reliability. The location (η) parameter defines the component behavior with (η = -5.5962) not failing before -5.5962 units of time (e.g hours, days, etc.), in other words there is guaranteed period during which components won't fail, if it rescaled to maintain performance, efficiency and reliability (PER). The Weibull distribution tends to show better performance, accuracy and earlier prediction time of failure of compressor blades as compared to Rayleigh's distribution for the purpose of validation.*

Keywords— *Reliability, Aerodynamic Trajectory, Compressor, Turbine Blade Geometry, Power Generation, Blade Geometry.*

I. INTRODUCTION

Nigeria has a total of 22 major power stations spread across various regions, generating electricity from a range of source including hydroelectric gas, fired, and thermal power plant. The contemporary power system represents vast engineering infrastructure which is paramount for sustainable progress in residential, commercial, industrial and socio-economic development. Nigeria's Power stations (Generation, Transmission & Distribution) play a critical role in supporting the economic development and improving standard of living. These stations include;

- Hydroelectric power stations: Kainji power station (760MW), Jebba power station (578MW), and Shiroro power station (600MW).
- Thermal power stations: Egbin power station (1,320MW), Delta power station (900MW), Gerega power station (726MW), and Sapele power station (1.020MW).
- Gas-fired power stations: Afam power Station (776MW), Omotosho power Station (726MW), Oloriunsogo power Station (754MW), and Alaoji power Station (1074MW).

These power stations play a critical role in supporting Nigeria's economic development and improving the standard of living.

However, the current situation is that Nigeria's generating capacity is approximately 10,396MW, with an available capacity of 6,056MW. While the peak demand is around 1,280MW, leaving a mismatch between supply and demand. Following, load demand for case repairs, with population of over 200million people, Nigeria's load demand is expected to continue growing. According to the Nigeria electricity regulatory commission (NERC) the peck demand is projected to reach: 17,000 MW by 2025, 23,000 MW by 2030 and 30,000 MW by 2035

This means that to meet growing demand with respect to the generating capacity gap. Nigeria needs to increase its generating capacity significantly. The current gap between generating capacity and peak demand is around 6,744MW (12,800MW-6056MW).

Evidently, there is strong need required for generating capacity to meet projected peak demand, Nigeria needs to additional generating capacity. This shows that by 2025, this year the required generating capacity would be around 17,000MW, which represents 181% increase from the current available capacity of 6,056MW.

Essentially, the widely used distribution reliability evaluation tool and data analysis technique for predicting system characteristics behavior are the Weibull and Rayleigh distribution, they are normally used to study down time of equipment or machine parts. It is also use for fitting engineering data obtained in that regards such as thermal load, strength of materials, fracture of brittle materials. However, weibull parameter distribution is used for fitting random data because of its flexibility to various types of probability distribution. This technical paper proposed the weibull distribution with the following parameters such as shape (β), scale (μ) and location parameter (η) for the estimation of system characteristics and performance. The Weibull distribution is often used to model the reliability and failure behavior of components including compressor and turbine blades. The key characteristics of the weibull distribution relevant to these components are;

(i) Slope or Shape Parameter (β): the shape parameter (β) determines the shape of the Weibull distribution. For compressor and turbines blades:

- β = 1, indicates a constant failure rate, suggesting random failures.
- β >1, indicates an increasing failures rate over time, typically due to wear and tear, fatigue or deregulation.

(ii) Scale Parameter (η): the scale parameter (η) represent the characteristics life of t time to failure of the component for compressor ad turbines blades:

- A largely value indicates longer expected life or time to failure.
- η is often referred to as the characteristics life and is the time 63.2% of the component are expected to have failed

(iii) Location Parameter (μ): the location parameter (μ) represents the minimum time-to-failure or the threshold beyond which failure can occur. For compressor and turbines blade:

- l = 0, implies that failure can occur at any time, including serving in life.
- l > 0, indicates threshold beyond which failing are more likely to occur, suggesting a "burn-in-period or a minimum life expectancy.

These Weibull distribution characteristics can help engineers and maintenance teams to:

- predict failure rates and plan maintenance schedules
- identify potential failures modes and develop mitigation strategies
- optimize design and testing procedures for compressor and turbine blades.

The historical data was collected from the maintenance records in the oil and gas industry in the south geopolitical region of Nigeria a period of ten (10) years for thirty (30) identical compressor and turbine blades characteristics were examined and evaluated for the analysis of failure time of system behavior of the same make, thermal load, stress etc.

However, Rayleigh distribution is considered as special case of weibull distribution, often used to model the magnitude of vectors or distance between points in a plane. For reliability distribution can be applied when the failure rate increase over time, the following consideration are made:

(i) To collect time-to-failure data for the components
(ii) Estimate the scale parameter using maximum likelihood estimation (MIE) or other methods.
(iii) Use the governing equation to calculate reliability, failure rates, and time of failure.

The strong advantages of Rayleigh distribution are suitable for modeling components with increasing failure rates over time, such as those experiencing wear and tear or fatigue mechanism is dominated by single factor like stress and strain.

II. Materials And Methods

Materials Considered:

The reliability model described by three parameters estimation of gas turbine blades performance are examined based on the following conditions;

- Collecting historical data about frequency of turbine blades/compressor blades (from oil and gas industry).
- Formulate governing equations and evaluate/simulate mean time to failure (MTTF), average time to failure (AVTTF), failure rate, reliability time λ(t), etc. using TPC Windchill quality solutions software.
- The computation of parameters and governing equations of characteristics reliability index using three parameter Weibull distributions are considered in the following cases:

2.1 Formulation of Governing Equations for Prediction of Reliability of Blade Geometry in Compressor and Turbine Application for Power Generation and Electricity Supply.

CASE 1: The Mean time to failure of the three-parameter Weibull distribution (MTTF) given by:

$$MTTF = \gamma + \eta\Gamma(1+1/\beta) \quad (1)$$

where; $\gamma \geq 0$ *and* $t, \beta, \eta > 0$

$$\Gamma(x) = \int_0^{\infty} e^{-x} x^{n-1} dx \quad (2)$$

Where;

η: Scale parameter, Γ*x*: Gamma function, *γ: Location parameter*, *β:* Shape parameter, *t*: Time

The term (MTTF) is applied to non-repairable points which operates under specified condition. It is otherwise the ratio of sum of time to failure of each component to number of components under test.

CASE 2: Mean time between failure (MTBF)

The term MTBF is applied to repairable conditions, which measure the average time a particular equipment will fail and remain in service. MTBF of an equipment may gradually reduce to a potential condition which may defects and introduced by poor maintenance procedures/strategy.

$$MTBF = \frac{1}{n}\sum_{i=1}^{n}(t_k \ldots t_{k-1}) = \frac{t_n - t_o}{n} = \frac{t_n}{n} \quad (3)$$

Since, $t_0 = 0$ at the beginning.

Then,

$$MTBF = \frac{Total\ operating\ time}{No.\ of\ failures\ in\ that\ time} \quad (4)$$

CASE 3: Availability performance

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Availability performance is the ability of an item to be in a state to perform a required function under a given condition for instance of time or over a given time interval, mean that;

All items assumed operating conditions unless failed scenario.

- The exception would have been standby redundancy but this scarcely exists power station because of high power supply demand.
- The outcomes in the analysis are based on two fundamental rules for combining probabilities.
- If A and B are two independent events with probabilities $\rho(A)$ and $\rho(B)$ of occurring, then the probability $\rho(AB)$ that both events will occur is the product;

$$\rho(AB) = \rho(A).\rho(B) \qquad (5)$$

- Similarly, if two events A and B are mutually exclusive so that when one occurs the other cannot occur, the probability that either A or B will occur given by:

$$\rho(AB) = \rho(A) + \rho(B) \qquad (6)$$

CASE 4: Failure rate

- Failure may either partial or complete, gradual or sudden which may be caused by inherent weaknesses or misuse.
- These failures can manifest in the following forms as; catastrophic failures, primary failure and secondary failures.
- Failure-rate is related to both number of failures per unit time that is the number of items fails in a given time depends not only on the quality of item, Hence;
- If the number of components in operation at the time of failure is Nr

Then failure – rate $\lambda(t)$ given by:

$$\lambda(t) = \lim_{\Delta t \to \infty} \frac{1}{N} \times \frac{\Delta N_f}{\Delta_t} = \frac{1}{N_s} \times \frac{\delta N_f}{\delta t} \qquad (7)$$

CASE 5: Operational availability

The operational availability (A_0) given by;

$$A_0 = \frac{Up-Time}{Operating-Time} \qquad (8)$$

Thus, Availability,

$$(A_r) = \frac{Available\ Hour}{Period\ Hour} \times \frac{100}{1} \qquad (9)$$

- This quantity is the probability that the systems will be available after it has run for a long time and is a significant measurement of the performance of a repairable system given by;

$$R(t) = \ell^{-}\left(\frac{t-\gamma}{\eta}\right)^{\beta},\ t \geq \gamma \qquad (10)$$

CASE 6: Reliability function of the three (3) – parameter weibull distribution given by;

- The three – parameters weibull failure rate function;

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1},\ t \geq \gamma \qquad (11)$$

CASE 7: Weibull shape parameter(β), Determinants for predicting reliability of useful life of machine components;

- The weibull shape parameter (β) is also known as the weibull slope parameter. The value of β is equal to the slope of a line in a probability plot.
- When the shape parameter, β < 1 (this means that the failure rate decreases).
- When the shape parameter, β = 1 (this means that failure-rate is constant with time (t) and the distribution is equal to the exponential distribution)
- When the shape parameter, β > 1 (this means that failure rate increases)

CASE 8: Weibull scale parameter, $\boldsymbol{\eta}$

- That is increasing the value of $\boldsymbol{\eta}$ while keeping $\boldsymbol{\beta}$ constant has the effects of stretching out the probability density function (pdf).
- A change in the scale parameter ($\boldsymbol{\eta}$) has the same effect on the distribution as a change of the abscissa scale. Since the area under a pdf curve is a constant value, the peak of the pdf curves will also decreases with increase of $\boldsymbol{\eta}$.

CASE 9: Weibull Location Parameter, $\boldsymbol{\gamma}$

- The location parameter, $\boldsymbol{\gamma}$ actually accounts for the subtraction (positive or negative) value that places the points in an acceptable straight line. changing the value of the location parameter $\boldsymbol{\gamma}$, has the effects of pushing the distribution and associated function if ($\boldsymbol{\gamma}$> 0) or to the left if ($\boldsymbol{\gamma}$< 0).

CASE 10: Prediction Performance of Weibull Distribution Model

- The prediction accuracy of the model in the estimation of the compressor/turbine-blade failures with respect to actual values were evaluated based on correlation coefficient R^2, root mean square error (RMSE) and coefficient of efficiency (COE). These parameters are calculated based on the following equation as;

$$R^2 = \frac{\sum_{i=1}^{N}(y_1-z)^2 - \sum_{i=1}^{N}(x_i-z)^2}{\sum_{i=1}^{N}(y_i-z)^2} \qquad (13)$$

Similarly, the root mean square error (RMSE) given by;

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \qquad (14)$$

The coefficient of efficiency (COE) given by;

$$COE = \frac{\sum_{i=1}^{N}(y_i-x_i)^2}{\sum_{i=1}^{N}(y_i-z)^2} \qquad (15)$$

where is the *ith* actual data Xi is the *ith* predicted data with the weibull distribution (*z*) is the mean of the actual data, *N* is the number of observations.

CASE 11: Reliability model of system component and weibull-two parameter characterization.

- The rate of failure and mean time between failure (MTBF) are key parameters of reliability in the turbine blades evaluation which are estimated using weibull distribution function.
- Weibull distribution technique is a vital tool used in the systematic modeling of failure rates, forecasting failures and in modeling of failure and fault-process stemmed from their aging.
- Thus, distribution may be specified by two parameters of shape ($\boldsymbol{\beta}$) and scale ($\boldsymbol{\alpha}$) respectively;

Provided the techniques used in the estimation of weibull parameters of average rating technique and number of failure according to the equation given by;

$$\boldsymbol{F_i} = \frac{(i-0.3)}{(N-0.4)} \qquad (16)$$

where; $\boldsymbol{F_i}$ is the average rank of occurring i-th failure.

If equipment are considered as separate components, is then the adjusted rank of age of failed component and N is the total ranking number of the component, weibull parameter would be determined using the least-square relationship given by:

$$y_i = mx_i + c \quad or \quad x_i = In(t_i) \quad (17)$$

where; $\boldsymbol{t_i}$ is the independent age (year) of failed component in rank i.

Therefore,

$$y_i = In\,In\left[\frac{1}{1-F_i}\right] \quad (18)$$

From, (17) and (18) are weibull shape parameter $(\boldsymbol{\beta})$ can be calculated given by;

$$\beta = m = \frac{\sum_{i=1}^{N} x_i y_i - \frac{\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N}}{\sum_{i=1}^{N} x_i^2 - \frac{\left[\sum_{i=1}^{N} x_i\right]^2}{N}} \quad (19)$$

Similarly, the constant (c) given by;

$$C = \frac{\sum_{i=1}^{N} y_i}{N} - \frac{m\sum_{i=1}^{N} x_i}{N} \quad (20)$$

The life or scale parameter (α) can be determined given by;

$$\alpha = \ell^{-\left[\frac{c}{m}\right]} \quad (21)$$

- By the analysis of two-parameters technique the prediction becomes very necessary if the system behavior of the component according to the equipment – curve distribution is properly determined.
- Weibull probability distribution function f(t) shows probability of failure in certain time (t) given by;

$$F(t) = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{\beta-1} \ell^{-\left(\frac{t}{\alpha}\right)^{\beta}} ; for \quad \begin{matrix} \alpha > 0 \\ \beta > 0 \\ 0 \le t \le \infty \end{matrix} \quad (22)$$

The cumulative distribution function F(t), which shows the probability of failure in time (t) which would be calculated as;

$$F(t) = 1 - \ell^{-\left(\frac{t}{\alpha}\right)^{\beta}} ; for \quad \begin{matrix} \alpha > 0 \\ \beta > 0 \\ 0 \le t \le \infty \end{matrix} \quad (23)$$

Essentially, reliability function R(t) shows probability of remaining intact till the time (t) and the rates of failure λ(t) which can be expressed as;

$$R(t) = 1 - F(t) = \ell^{-\left(\frac{t}{\alpha}\right)^{\beta}} \quad (24)$$

$$\lambda(t) = \frac{F(t)}{R(t)} = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{\beta-1} \quad (25)$$

- From observation, the shape –parameter (β) affects shape distribution curve that is when shape parameter changed, the curve f(t) varies differently in shape. For example, if the curve turns to exponential distribution, then β = 1
- That is the failure rate will be decreasing while β<1, this means that the component is in the early failure state.
- Similarly, when failure rate is constant while, β=1, the components will be in its occasionally failure condition. Incidentally, the failure rate is increasing while β>1 this means the component is in its loss failure condition.

CASE 12: The Mean and Standard Deviation of Weibull Distribution Evaluation

The mean and standard deviations are presented in terms of shape and scale – parameter given by:

$$\mu = \mu\Gamma\left(1 + \frac{1}{\beta}\right) \quad (26)$$

and

$$\delta^2 = \alpha^2\left[\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)\right] \quad (27)$$

where;

$\Gamma(.)$ represents gamma function which could be estimated in the following form given by:

$$\Gamma = \sqrt{2\pi t}^{(t-0.5)} \ell^{-t}\left(1 + \frac{1}{12t}\right) \quad (28)$$

In the consideration for long term unavailability without considering restriction related to repair or replacement time of equipment in order to estimate equipment failure-rate, the Meantime to failure (MTTF) and the mean time between failure (MTBF) should be equal.

Therefore, $MTBF = \alpha\Gamma\left(1 + \frac{1}{\beta}\right)$ (29)

While, the total failure-rate for turbine-blade are considered as an important component for reliable performance given by:

$$\lambda(t) \sum_{i=1}^{N} \lambda_i(t) \quad (30)$$

Where, $\lambda(t)$ is the rate of failure in i-th critical part of equipment and n is the total subcomponents of the turbine-blades under observations.

CASE 13: Sourcing Of Data

TABLE 1: Failure Time of Gas Turbine Power Plant; Compressor-Blades

Serial number ranking of compressor blades	Failures times in hours (hrs)
1.000000	1047.000000
2.000000	1279.000000
3.000000	1340.000000
4.000000	1578.000000
5.000000	1598.000000
6.000000	1749.000000
7.000000	1804.000000
8.000000	1841.000000
9.000000	1847.000000
10.000000	1869.000000
11.000000	1879.000000
12.000000	1890.000000
13.000000	1939.000000
14.000000	1948.000000
15.000000	1949.000000
16.000000	1956.000000
17.000000	1987.000000
18.000000	1995.000000
19.000000	2004.000000
20.000000	2005.000000
21.000000	2047.000000
22.000000	2214.000000
23.000000	2287.000000
24.000000	2435.000000
25.000000	2439.000000
26.000000	2442.000000
27.000000	2581.000000
28.000000	2617.000000
29.000000	2926.000000
30 .000000	2978.000000

TABLE 2: Shows the turbine blade for failure time (hrs) (Turbine Blade)

Serial number ranking of turbine blades	Failures times in hours (hrs)
1.000000	1020.000000
2.000000	1220.000000
3.000000	1300.000000
4.000000	1525.000000
5.000000	1540.000000
6.000000	1720.000000
7.000000	1800.000000
8.000000	1820.000000
9.000000	1840.000000
10.000000	1850.000000
11.000000	1865.000000
12.000000	1880.000000
13.000000	1910.000000

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14.000000	1925.000000
15.000000	1928.000000
16.000000	1930.000000
17.000000	1948.000000
18.000000	1964.000000
19.000000	2004.000000
20.000000	2010.000000
21.000000	2030.000000
22.000000	2200.000000
23.000000	2300.000000
24.000000	2405.000000
25.000000	2450.000000
26.000000	2480.000000
27.000000	2550.000000
28.000000	2620.000000
29.000000	2802.000000
30.000000	2810.000000

Owing to the incessant breakdown of system component due to failure frequency, repair time, repair rate and earlier mortality of machine part based on collected historical data: failure of compressor and turbine blades for gas turbine power plant for ten (10) years {2016 – 2025} was cited. The failure time (hrs) of three (3) identical gas turbine power plant with consideration of thirty (30) blades for the prediction of compressor and turbine blades performance/reliability were sourced and cited as seen in tables above.

2.2 Diagramatic Representation Of Compressor And Turbine Blade Components & Its Related Problems.

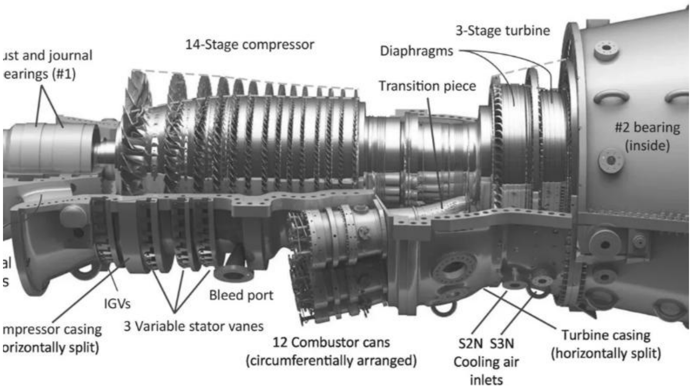

PLATE 1: A Cascade Of The Compressor Blade, Combustion Chamber And Turbine Blades

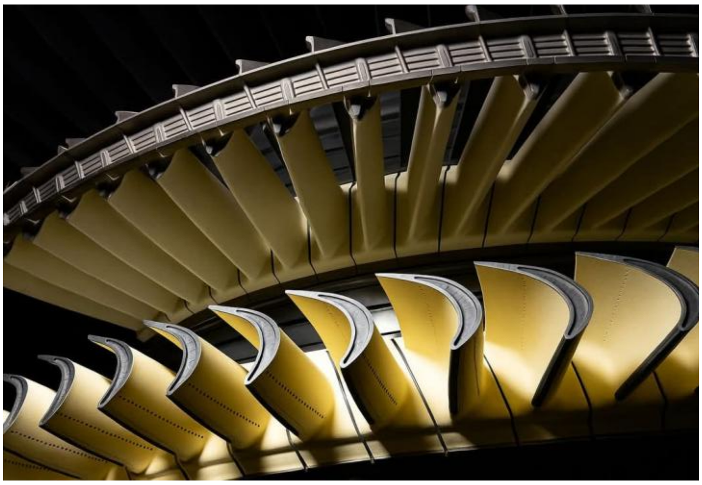

PLATE 2: Showing The Number Of Compressor Blades Configuration

PLATE 3: Contaminated Turbine Blade Surface

PLATE 4: Compressor And Turbine Blade Components Showing Tear And Wear

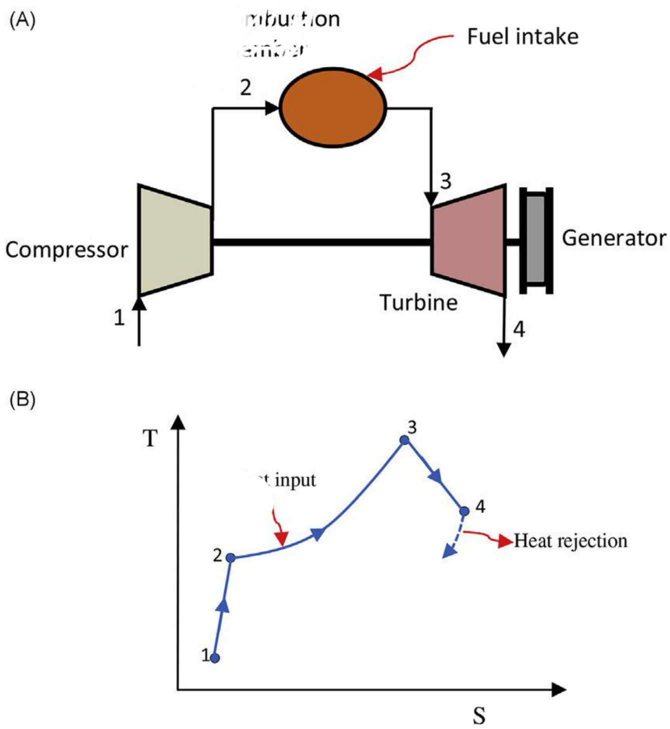

Figure 1: (a) and (b)
Figure 1(a) A Schematic Representation Of An Open Cycle Gas Turbine Power Plant
Figure 1(b) Shows The Corresponding Thermodynamic Cycle On T-S (Temperature Entropy) Diagram

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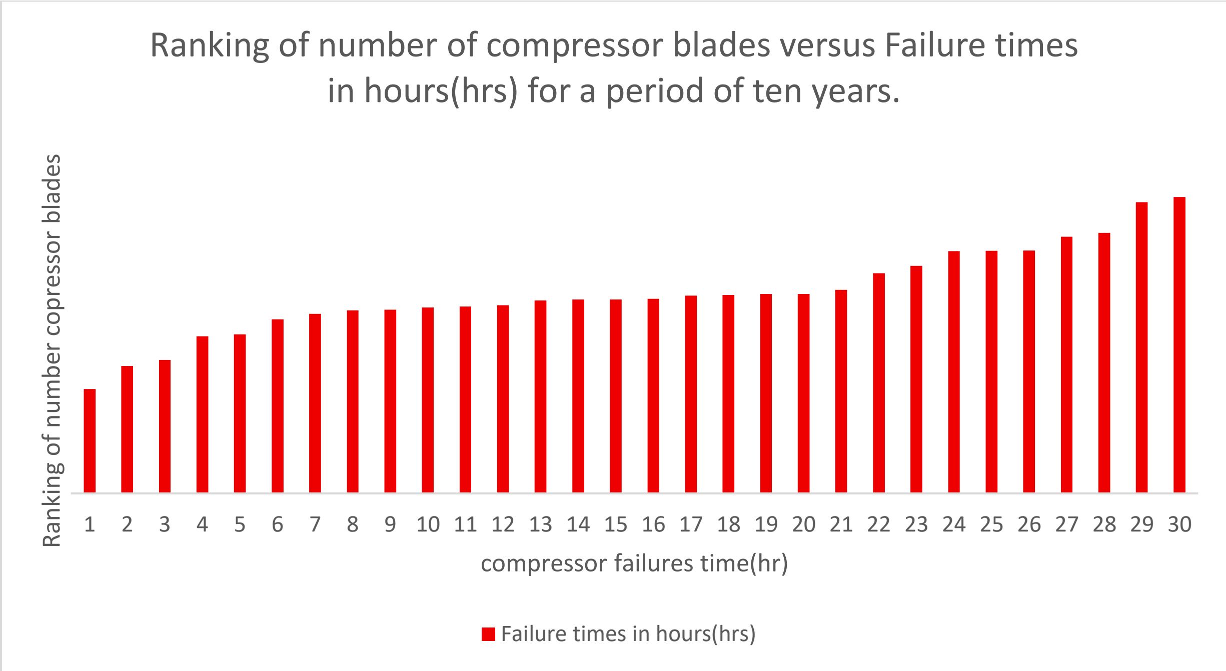

Figure 2: Shows Ranking of number of Compressor Blades vs Failure Times in hours for the period of 10 years

III. Results and Discussions

The data is analyzed using specialized weibull analysis software PTC windchill solutions 10.2, to obtain the three – parameter weibull estimates namely;

- Shape parameter (β):
- Scale-parameter (η):
- Location parameter (γ):

The simulation results produce:

- Probability-plot
- Probability density function (pdf) – plot
- Reliability – plot
- Unreliability vs time – plot
- Failure rate – plot

However, results of the simulated plots are presented and contained in table 2; which shows the result of the shape - parameter (β), scale - parameter (η) and location – parameter respectively.

Table 3: Three-parameter weibull estimates using TPC windchill quality solution 10.02:

Shape-parameter; β	Scale-parameter, η	Location parameter, γ
2.9085	24.3296	–5.5962

3.1 The Analysis of Various Cases Presented for Compressor Blades Evaluation

CASE 1: DETERMINATION OF THE TIME REQUIRED FOR MACHINE COMPONENT FAILURE (T) IN HOURS USING THE WEIBULL THREE PARAMETERS MODEL (T); GIVEN AS:

$$t = \gamma + \left(-In\left(F(t)\right)\right)^{1/\beta} \qquad (1)$$

For 10% probability of failure (which is the characteristics life) given as:

$$F(t) = 10\% = 0.1$$

$$\beta = 2.000,\ \mu = 20.945350,\ \gamma = -1.875$$

$$t = \gamma + \mu * \left(-In\left(F(t)\right)\right)^{1/\beta}$$

$$t = -1.875995 + 20.945350 * \left(-In\,(1-0.1)\right)^{1/2}$$

$$t = -1.875995 + 20.945350 * \left(-In\,(0.9)\right)^{0.5}$$

$$t = -1.875995 + 20.945350 * (0.105360515)^{0.5}$$

$$t = -1.875995 + 20.945350 * 0.324592846$$

$$t = -1.875995 + 6.79871076$$

$$t = 4.92271576\ hours$$

CASE 2: DETERMINATION OF RELIABILITY OF THREE – PARAMETERS WEIBULL DISTRIBUTION R(T) GIVEN BY:

$$R(t) = \rho - \left(\frac{t-\gamma}{h}\right)^{1/\beta} \qquad (2)$$

$$t = 4.922715\ hrs,\quad \beta = 2.00,\quad \rho = 2.718,\quad \gamma = -1.875,\ \mu = 20.945350$$

$$R(t) = 2.718 - \left(\frac{4.922715 - -1.875}{20.945350}\right)$$

$$R(t) = 2.718 - \left(\frac{6.797715}{20.945350}\right)$$

$$R(t) = 2.718 - (0.324545304)$$

$$R(t) = 2.718 - 0324545304$$

$$R(t) = 0.722880282$$

CASE 3: DETERMINATION OF FAILURE RATE, Λ(T), Three (3) parameters Weibull distribution for failure rate function given by:

$$(t) = \frac{\beta}{\mu}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1},\ t \geq \gamma \qquad (3)$$

Where;

$$\beta = 2.000,\ t = 4.922715\ hrs,\ \gamma = -1.875,\ h = 20.945350$$

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$$(t) = \frac{2.00}{20.945350}\left(\frac{4.922715--1.875}{20.945350}\right)^{2\text{-}1}$$

$$(t) = 0.095486\left(\frac{6.797715}{20.945350}\right)^{1}$$

$$(t) = 0.095486(0.324545304)$$

$$(t) = 0.002959066546/hr$$

CASE 4: DETERMINATION OF MEAN TIME TO FAILURE (MTTF) OF THE THREE – PARAMETERS WEIBULL DISTRIBUTION GIVEN BY;

$$MTTF = \gamma + h * \Gamma\left(1 + \frac{1}{\beta}\right) \quad (4)$$

Where, $\gamma \geq 0, \ \ and \ t, \beta, \mu > 0$

where, $\gamma = -1.875, \ \beta = 2.000, \mu = 20.945350$

$$MTTF = \ -1.875 + 20.945350\,\Gamma\left(1 + \frac{1}{2}\right)$$

$$-1.875 + 20.945350\,\Gamma(1 + 0.5)$$

$$-1.875 + 20.945350\,\Gamma(1.5)$$

Where , $\Gamma(1.5) = 0.886227$

Then,

$$MTTF = \ -1.875 + 20.945350 * (0.886227)$$

$$MTTF = \ -1.875 + 18.56233469$$

$$MTTF = \ 16.68733469hrs$$

CASE 5: DETERMINATION OF AVERAGE TIME TO FAILURE (AVTTF):

The AVTTF, actually it is very important to provide a valuable insight to the expected system or components under investigation is given by;

$$\text{AVTTF} = \sum_{i=1}^{NT} \frac{Central\ tendency\ of\ all\ observed\ values}{Number\ of\ values}$$

$$\text{AVTTF} = \sum_{i=1}^{NT} \frac{\sum_{i}^{NT} CD}{NV}$$

$$AVTTF = \sum_{i}^{NT} \frac{59{,}646hrs}{30}$$

$$AVTTF = \ 1{,}988.2 \ \ hours$$

The data is analyzed using specialized weibull analysis software TPC windchill solutions 10.2, to obtain the three – parameter weibull estimates namely;

- Shape parameter (β):
- Scale-parameter (η):
- Location parameter (γ):

The simulation results produce:

- Weibull probability-plot
- Probability density function (pdf) – plot
- Reliability – plot
- Unreliability vs time – plot
- Failure rate – plot

Similarly, Results of the simulated plots are presented and contained in table 4; which shows the result of the shape parameter (β), scale parameter (η) and location.

TABLE 4: Three-parameter weibull estimates using TPC windchill quality solution 10.02

Shape parameters, β	Scale parameters, η	Location parameters, γ
β : 4.1353	η : 33.2384	γ: −12.8047

3.2 Presentation of Weibull Distribution plot as shown in Figure 1 – 5 (Probability – plot, probability density function (PDF) plot, Reliability plot vs time, unreliability plot vs time, an failure rate vs time

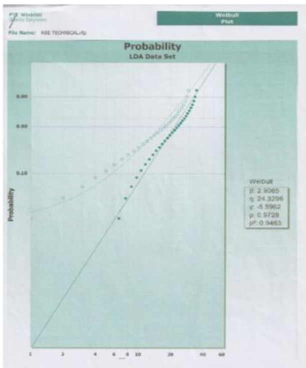

Figure 1: Shows the probability plots against time (compressor blade)

The study investigated the reliability parameters using, TPC windchill quality solution 10.02 software which were used to analyze the failure time of three (3) identical gas turbine power plant. The probability plot displays the cumulative distribution function (CDF) of the weibull distribution, It shows the probability of failure F(t), the slope parameter β=2.9085, indicates failure rate over time.

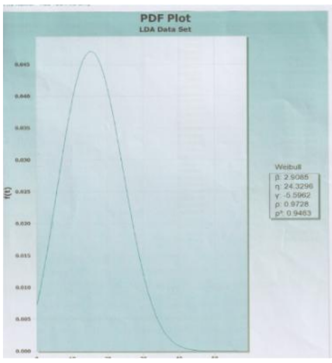

Figure 2: Shows Probability Density Function (PDF) plot against time (compressor blade)

The PDF plot shows the probability density of failures at different times, the shape-parameter (β) = 2.9085 indicates as skewed distribution with a peak at a certain time. The Scale parameter (η) = 24.3296 affects the spread of the distribution characteristics.

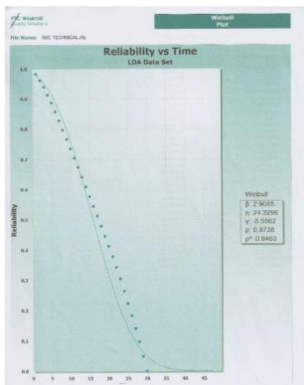

Figure 3: Shows reliability plot against time (compressor blade)

The reliability plot displays the reliability function $R(t) = 1 - F(t)$, showing the probability of survival over time. With $\beta > 1$, the reliability decreases over time.

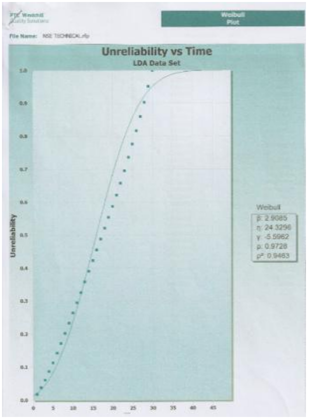

Figure 4: Shows Unreliability plot against time (Compressor Blade)

The unreliability plot is equivalent to the CDF-plot, showing The probability of failure $F(t)$ over time. The location parameter $(\eta) = -5.5962$ shifts the plots along the time in the left side axis. This is the time guaranteed within the component won't fail, but be sustained.

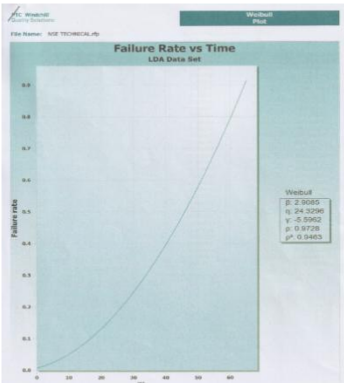

Figure 5: Shows the failure rate plot against time (compressor blade)

The failure rate plot shows the hazard function,f (t), which represents the instantaneous failures rate at time (t). with $\beta = 2.9085$, the failure rate increases over time.

The results obtained from failure times of turbine blades simulation of TPC wind chill solution software are presented in figure 1-5, which indicates various plots about reliability and performance evaluation of turbine blades under investigation as shown:

3.3 Analysis of Various Cases Presented for Turbine Blades Evaluation

CASE 1: DETERMINATION OF TIME REQUIRED FOR MACHINE COMPONENT FAILURE (T) IN HOURS USING THE WEIBULL THREE PARAMETERS MODEL (T); GIVEN AS:

$$t = \gamma + \left(-In\left(F(t)\right)\right)^{1/\beta} \quad (1)$$

For 10% probability of failure (which is the characteristics life) given as:

$$F(t) = 10\% = 0.1$$
$$\beta = 2.000,\ \mu = 20.945350,\ \gamma = -1.875$$
$$t = \gamma + \mu * \left(-In\left(F(t)\right)\right)^{1/\beta}$$
$$t = -1.875995 + 20.945350 * \left(-In\,(1 - 0.1)\right)^{1/2}$$
$$t = -1.875995 + 20.945350 * \left(-In\,(0.9)\right)^{0.5}$$
$$t = -1.875995 + 20.945350 * (0.105360515)^{0.5}$$
$$t = -1.875995 + 20.945350 * 0.324592846$$
$$t = -1.875995 + 6.79871076$$
$$t = 4.92271576\ hours$$

CASE 2: DETERMINATION OF RELIABILITY OF THREE – PARAMETERS WEIBULL DISTRIBUTION R(T):

$$R(t) = \rho - \left(\frac{t-\gamma}{h}\right)^{1/\beta} \quad (2)$$

$t = 4.922715\ hrs,\quad \beta = 2.00,\quad \rho = 2.718,\ \gamma = -1.875,\ \mu = 20.945350$

$$R(t) = 2.718 - \left(\frac{4.922715 - -1.875}{20.945350}\right)$$
$$R(t) = 2.718 - \left(\frac{6.797715}{20.945350}\right)$$
$$R(t) = 2.718 - (0.324545304)$$
$$R(t) = 2.718 - 0324545304$$
$$R(t) = 0.722880282$$

CASE 3: DETERMINATION OF FAILURE RATE, Λ(T),

The three (3) parameters Weibull distribution for failure rate function given as:

$$(t) = \frac{\beta}{\mu}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1},\ t \geq \gamma \quad (3)$$

Where;

$-\beta = 2.000,\ t = 4.922715\ hrs,\ \gamma = -1.875, \mu = 20.945350$

$$(t) = \frac{2.00}{20.945350}\left(\frac{4.922715--1.875}{20.945350}\right)^{2-1}$$
$$(t) = 0.095486\left(\frac{6.797715}{20.945350}\right)^{1}$$
$$(t) = 0.095486(0.324545304)$$
$$(t) = 0.002959066546/hr$$

CASE 4: DETERMINATION OF MEAN TIME TO FAILURE (MTTF) OF THE THREE – PARAMETERS WEIBULL DISTRIBUTION:

$$MTTF = \gamma + h * \Gamma\left(1 + \frac{1}{\beta}\right) \quad (4)$$

Where, $\gamma \geq 0,\ \ and\ t,\ \beta, \mu > 0$

where, $\gamma = -1.875,\ \beta = 2.000, \mu = 20.945350$

$$MTTF = -1.875 + 20.945350\,\Gamma\left(1 + \frac{1}{2}\right)$$
$$-1.875 + 20.945350\,\Gamma(1 + 0.5)$$
$$-1.875 + 20.945350\,\Gamma(1.5)$$

Where, $\Gamma(1.5) = 0.886227$

$$MTTF = -1.875 + 20.945350 * (0.886227)$$
$$MTTF = -1.875 + 18.56233469$$
$$MTTF = 16.68733469hrs$$

CASE 5: DETERMINATION OF AVERAGE TIME TO FAILURE (AVTTF):

The AVTTF, actually provide the valuable insight to the expected system or components under investigation is given as;

$$\text{AVTTF} = \sum_{i=1}^{NT} \frac{Central\ tendency\ of\ all\ observed\ values}{Number\ of\ values}$$

Braide S. Lucky, Kombo Theophilus Johnson, and E. C. Obuah, "Reliability Impact of Gas Turbine Plant for Power Generation and Electricity Supply Using WeiBull Application," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 8, Issue 8, pp. 49-59, 2026.

$$\text{AVTTF} = \sum_{i=1}^{NT} \frac{\sum_{i}^{NT} CD}{NV}$$

This is given as:

$$AVTTF = \sum_{i}^{NT} \frac{59{,}646hrs}{30}$$

$$AVTTF = 1{,}988.2 \ hours$$

3.4 Presentation of Weibull Distribution plot as shown in Figure 6 – 10 (Probability – plot, probability density function (PDF) plot, Reliability plot vs time, unreliability plot vs time, and failure rate vs time

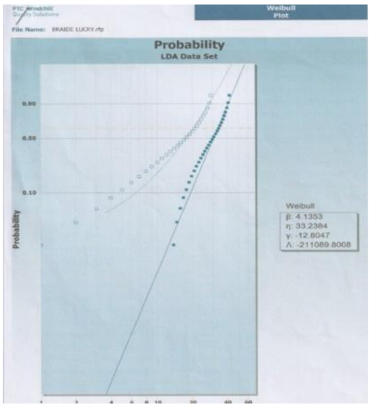

Figure 6: Shows the probability plots against time (turbine blade)

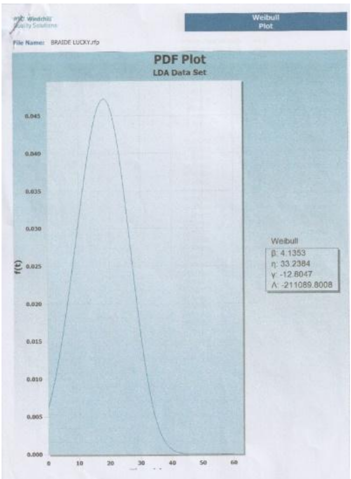

Figure 7: Shows Probability Density Function (PDF) plot against time (Turbine blade)

From the probability plot displays the cumulative distribution function (CDF) using Weibull model.

It shows the probability of failure F(t), the β=4.1353, the plot shows an increasing failure rate over time.

The PDF plot shows the probability density function of failures at different times, the shape-parameter (β) = 4.1353 indicates as skewed distribution with a peak at a certain time. The Scale parameter (η) = 33.2384 affects the spread of the distribution

The reliability plot display reliability function $R(t) = 1 - F(t)$, showing the probability of survival over time. With $\beta > 1$, the reliability decreases over time.

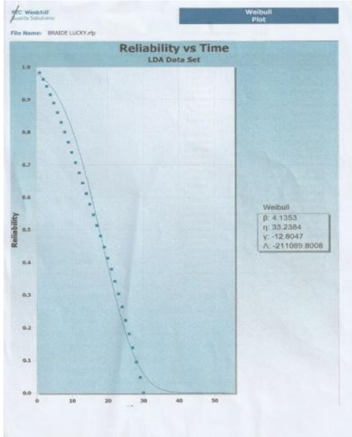

Figure 8: Shows reliability plots against time (Turbine blades)

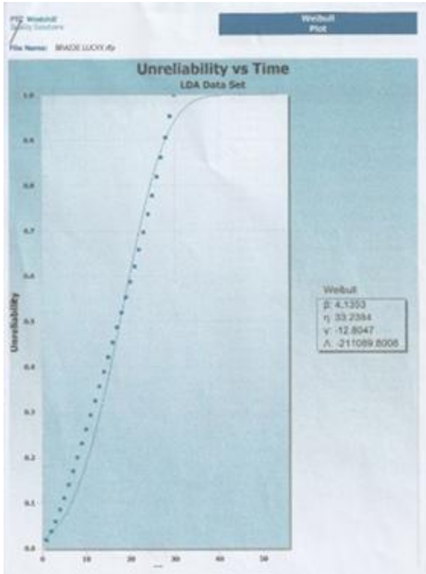

Figure 9: Unreliability plot against time (Turbine blade)

The unreliability plot is equivalent to the CDF-plot, showing the probability of failure $F(t)$ over time.

The location parameter $(\eta) = 33.2384$ shifts the plots along the time axis

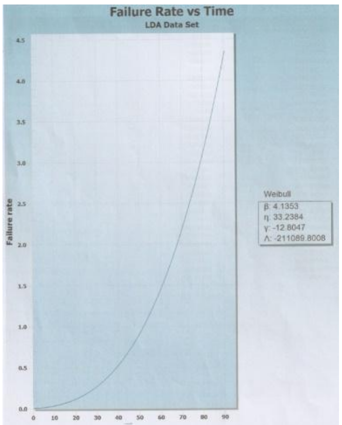

Figure 10: Shows the failure rate plot against time (Turbine blade)

The failure rate plot shows the hazard function, (t), which represents the instantaneous failures rate at time t . with $\beta = 4.1353$ the failure rate increase over time.

3.4 Comparative Evaluation of Weibull and Raylaeigh's Distribution When Fitted into Simulation Data

The results obtained in the case of Weibull distribution accounts for the shape parameter (β = 2.9085) which indicates an increasing failure rate for compressor blade overtime. While the scale parameter (γ = 24.325) which indicates how it affects the spread of the distribution. Evidently, the location parameter (η = 5.5962) suggests shift in the distribution on the view to determine the failure before time zero. Similarly, results obtained from Rayleigh's distribution are; Shape (β = 2.000), Scale (γ = 17.1717) and location (η = 0).

Evidently, both distributions indicate increasing failure rate in their prediction behavior, but Weibull parameter is closer to 3 suggesting more pronounced increase. That is Weibull distribution also shows better flexibility and has the capacity to capture early failures faster which makes it a better fit, if the data exhibits these characteristics.

IV. CONCLUSION

Conclusively, the results obtained in this research shows that the compressor and turbine blades are in their wear out period of failures, following the analysis and investigation of failure time of ten (100) identical gas turbine blades with 30 blades configuration, using parameter estimation of three Weibull distribution. The estimates were successfully obtained and the results were compared with Rayleigh's distribution using TPC windchill quality solutions, the values of the Weibull estimate and Rayleigh's distribution are found to be close, although the Weibull tends to show better and faster prediction to time of failure rates, these are represented in the wear out period of analysis as the values of the shape parameter is greater than one (1) in both cases. From the Weibull estimates obtained, the reliability, failure rate and mean time to failure of the blade were computed to achieve all three parameters of shape, scale and location in order to determine gas turbine power plant parameters.

Future Works

Subsequent presentations/research will consider design of aerodynamic trajectory impact for blade geometry in compressor and turbine application. This means that assessment of the wind dynamics and potential will be determined.

Nomenclature

β	Shape Parameter
γ	Scale Parameter
η	Location Parameter
t	Time (hours)
Λ(T)	Failure Rate
R(t)	Reliability
AVTTF	Average Time to Failure
MTTF	Mean time to Failure
T	Temperature (K)
P	Pressure (bar)

Declarations

Availability of Data and Materials

The data generated are analyzed during this current study and are highly confidential, but are made available from the corresponding on reasonable request.

Competing Interest

The authors declared that they have no form of competing financial interest or personal relationship that could have strong influence on this work reported in this paper

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Authors' Contributions

The research writing was made an original draft, writing review and editing-review, validation, visualization, data sources, conceptualization, resources, software, performed supervision, project administration, resources and methodology. All the authors read and approved the final manuscript.

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