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Design Fabrication and Reliability Analysis on Scaled Modeled Aircraft Rigid Type Nose Wheel Landing Gear

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ABSTRACT

Reliability is defined as the ability of a component to perform its intended function for a specified time. For an aircraft, reliability is the probability that the aircraft as a whole, or a flight. The material capacity associated with the progressive "damage" mechanism, i.e., residual strength or critical crack size, fracture toughness.

Landing gear is the most important structure of an aircraft, as it is solely responsible for the aircraft to do all the ground operations from taxing to take- off and landing, but it was found that landing gear creates a massive drag when the aircraft is in air. So, in order to reduce the drag and increase the efficiency of aircraft, landing gear is retracted when the aircraft is in air and extended just before reaching ground. The overall strength of an aircraft structure will depend on the individual strengths of the components that make up the structure. The strength of one component can be different to the strength of another component with the same design and manufactured from the same materials. This difference may result from manufacturing variations or the reduction in the strength of the component because of fatigue and cyclic loads. Because of these differences, there will always be some variability in the failure times of components of the same design.

This work allows us to determine the life span of a scale modeled aircraft landing gear for a series of scheduled Landings. And also to Draw Bath-Tub curve for the design, fabricated and tested model to verify the failure rate with respect to time. This analysis also gives scope to conduct load test on scale modelled aircraft landing gear for sequence of loadings to attain statistical data related to cumulative no of failures, failure density, and failure rate in turn (reliability) life span of such a landing gear. This statistical result then validated with computationally predicted results using commercial software ANSYS.

Keywords: Reliability, Nose Wheel, Strut, FEM, Failure rate, Bath tub curve

1. INTRODUCTION

1.1 Reliability

Reliability engineering consists of the systematic application of time-honored engineering principles and techniques throughout a product lifecycle and is thus an essential component of a good Product Lifecycle Management (PLM) program. The goal of reliability engineering is to evaluate the inherent reliability of a product or process and pinpoint potential areas for reliability improvement. Realistically, all failures cannot be eliminated from a design, so another goal of reliability engineering is to identify the most likely failures and then identify appropriate actions to mitigate the effects of those failures.

The reliability evaluation of a product or process can include a number of different reliability analyses. Depending on the phase of the product lifecycle, certain types of analysis are appropriate. As the reliability analysis is being performed, it is possible to anticipate the reliability effects of design changes and corrections. The different reliability analyses are all related, and examine the reliability of the product or system from different perspectives, in order to determine possible problems and assist in analyzing corrections and improvements.

In observational research, reliability of data refers to the degree of agreement between sets of observational data collected independently from the same scene by two different observers (inter observer agreement) or by the same observer at different times in the data collection process (intra observer agreement). Reliable data are a first prerequisite for answering research questions. It is important to determine whether data sets that are collected by different observers or at different times differ so little that one can safely assume that they are equally valid for analysis. Reliability analysis is also used to train new observers in coding schemes and observational data collection-for example, by testing their data against a reference data set, both collected from the same video recording.

Reliability engineering is engineering that emphasizes dependability in the lifecycle management of a product. Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability engineering represents a sub-discipline within engineering. Reliability is theoretically defined as the probability of success (Reliability=1-Probability of Failure), as the frequency of failures, or in terms of availability, as probability derived from reliability and maintainability. Maintainability and maintenance is often defined as a part of "reliability engineering" in Reliability Programs. Reliability plays a key role in the cost-effectiveness of systems.

1.2 Landing gear

Since the birth of Aviation, aircraft landing gears have been essential components of every aircraft. They are used during takeoff, landing and ground operation to support the aircraft. One hundred and ten records have been found related to landing gears in the Service Difficulty Report in the United States in 2009. All reports have been recorded due to some level of difficulties to the landing gears. The difficulties vary from a nose gear to a main gear to a tail gear.

The National Advisory Committee for Aeronautics (NACA) spent several years studying the characteristics of the landing gears during landing. Many aircrafts ranging from 1000 lbs. to 50,000 lbs. were used in the study. Until September 1942, the NACA technical note 863 came out to report the results and formulas for all external forces on the nose, main and rear landing gear.

Many manufacturers do not use FEM to test the nose landing gear because the FAA does not require FEM as part of the approval process. This thesis will help landing gear manufacturers answer many questions related to the nose gear during landing, and these answers can be used in the early stage of future the designs. For example, this analysis will help manufacturers determine what part in the nose gear will yield the highest stresses and at what location. It will help determine how to design, analyze and optimize the nose gear properly so physical testing can be used for verification instead of trial and error. The cost for physical testing of the wheel assembly is as approximately $85,000 and can take up to 6 months; therefore, optimizing the design to its best performance before physical testing is very important. The main focus of the analysis in this thesis is the moment during landing; however, the model is set to be used for other load case scenarios.

Although the finite element analysis (FEA) theory was first introduced in 1943 by Richard Courant, the study of the nose gear using FEA is not heavily studied and published. Most of the studies have been performed by physical testing by landing gear manufacturers. In order to perform FEA, many steps have to be completed in order to obtain accurate results, including the application of the parts, and the appropriate assumptions.

All components making up the nose gear must be modeled in three dimensional (3-D) computer-aided design (CAD) software. In this study, the Solid Works CAD software was used. Once 3-D modeling is accomplished, calculations are performed to obtain the load on the nose gear during landing. Then kinematic analysis is performed and modeling decisions are then made on how to transfer the loads into the finite element 3 model (FEM). The FEM is then used in predicting the stress behavior during landing. The FEA software used in this analysis is Algor by Autodesk. Figure 1 shows the Twin Otter aircraft with the nose gear and main gear configuration.

Landing gear is the undercarriage of an aircraft or spacecraft and is often referred to as such.

The landing gear system includes:

- Strut.
- Shock absorber.
- Extraction/ Retraction mechanism.
- Brakes.
- Wheel and
- Tyre.

2. LOADS ACTING ON THE LANDING GEAR

2.1 Ground Loads

The term ‘ground loads’ refers to the loads acting on the landing gear tires which loads the axel. On the typical arrangement common to most civil and military aircraft, there is a single Nose Landing Gear (NLG) and two Main Landing Gear (MLG) attached to either the wing or the fuselage in the area of the wings. The share of the aircraft weight on the NLG or the MLGs is the based on the centre of gravity of the aircraft .During ground manoeuvring events such as braking, the NLG can seen added loading due to pitch over which is a function of mass, vertical c.g location, and deceleration. The load across the MLGs can be distributed during manoeuvring events such as a turning event where a centrifugal force at the aircraft c.g forcing more load on the MLG furthest from the turning centre.

For all ground landing conditions considered, the loads are calculated for each landing gear in terms of a orthogonal coordinate system in either ground or aircraft reference frames. The three dimensions of the load coordinate frame are defined as vertical. Drag, and side where vertical is up (Z), drag is positive aft (X), and side is positive inboard for each landing gear in terms of an orthogonal coordinate system in either ground or aircraft reference frames. The three dimensions of the load coordinate frame are defined as vertical. Drag, and side where vertical is up (Z), drag is positive aft (X), and side is positive inboard(Y). As a standard for MLG analysis, the port gear is typically analyzed. Figure 3 shows the right handed coordinate system used in landing gear structural analysis.

2.2 Design of the Landing Gear

Landing gear features an oleo-pneumatic shock strut which, as the name suggests, is filled with oil and air. The strut has a dual function: to dissipate the kinetic energy of vertical velocity on landing, and to provide ease and stability for ground maneuvering. A schematic of an oleo-pneumatic shock strut is shown in. When the airplane lands, the oil is forced from the lower chamber to the upper one through an orifice. Most struts have a metering pin extending through this orifice that stroke with the piston. By varying pin diameter, orifice area is varied, allowing optimization of the shock strut efficiency. Figure 2 shows typical landing gear components. The landing gear also enables the aircraft to roll up to its takeoff position and to take off without using a launching catapult or trolley, as well as to carry its own means of braking,

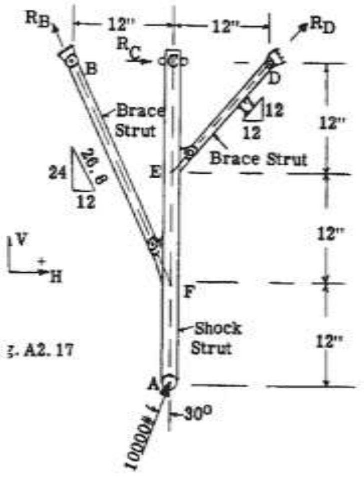


Figure 2.1 Design of the Landing Gear

The most widely used configuration is cantilever, which is also the most cost and weight efficient. With this type, the shock strut supports drag and side loads. Illustrations of single-axle and double-axle cantilever gear are shown in Figure

Articulated gears are used for cases in which the ground clearance is low or stowage room is limited. They offer a maintenance advantage, since the shock strut can be removed in the field without major effort. European companies often prefer articulated gear to obtain a smoother taxi ride over uneven runways. The shock strut is pin ended and does not support drag and side loads.

Semi-articulated gear configuration is similar to fully articulated, except that the cylinder also acts as a structural member, and carries drag and side loads. This type of gear is not widely used. Fully articulated and semi-articulated gears are shown in Figure ***5.*** Flotation analysis determines the capability of an aircraft to operate on a specific airfield. Flotation capability is primarily a function of total shock strut load, single-wheel load, and tire pressure. On this basis, the number of tires, tire size, and tire spacing are determined. Main gear is typically of a tandem, dual-tandem, or tri-dual-tandem configuration. Nose gear consists of a single or dual arrangement. Some gear must undergo sequenced shape change, such as retraction or planning, to fit in the wheel well when retracted. A rotating or planning mechanism is then designed into the gear.

Another method consists of shrinking the shock strut during retraction to clear the gear into the wheel well. Other special features include provisions for unlocking the gear in the wheel well, bogie petitioners' to adjust the attitude of the truck beam for stowage and launching mechanisms for nave applications. Although it might be assumed that the landing gear is subjected to its highest loads during landing, in reality, landing conditions are critical for only about 20% of the landing gear structure.

Ground handling conditions, especially turning and taxiing, are critical for the remainder of the structure. Every landing gear has its own set of loads, which are critical for various components of the gear. For a given gear, landing load conditions which may be critical include maximum sink speed landing, level landing, tail landing, lateral drift landing, spin up, and spring back. Critical ground handling load conditions include taxiing, towing, turning, jacking, braking, pivoting, and steering. Other load conditions consist of extension and retraction actuator load, brake application during retraction, brake chatter, shimmy, rebound, catapult launching, unlock/ down lock, and tie-down loads. Landing gear loads include limit loads, which are the highest loads that the gear may be subjected to during its service life.

Ultimate loads are limit loads multiplied by a safety factor of 1.5. Fatigue loads consist of a spectrum of realistic loads to which the structure will be subjected during its service life. Sustained loads are those on the gear components from carrying the weight of the airplane, 1-g, in static condition, or those due to shrinking the shock strut. Structural analyses of landing gear include static, fatigue, fracture mechanics, damage tolerance, sustained stress, finite element, and weight strength optimization analyses.

Figure2.2 Landing Gear

Static analysis incorporates tests for the following:

- ultimate static strength - stresses due to ultimate loads are not allowed to exceed the ultimate allowable of the component material
- Yield strength - stresses due to limit loads are not- allowed to exceed the yield allowable of the component material (no permanent deformation is permitted under limit loads)
- Static and dynamic gear stability - especially during high speed takeoff roll
- Component stability - column checks of compression-loaded components.

In the detailed analysis, all the stresses - axial, shear, bending, and torsion - are calculated at a section, and a stress ratio is calculated for each by dividing the stress by the allowable strength of the component material. Then a utilization factor is determined by combining all the stress ratios. This factor must be maintained at less than 1.0 to have a positive margin of safety. Fatigue design criterion of aircraft structures are usually one of the following: infinite-life, safe-life, fail-safe, and damage-tolerant design. Because landing gear structures do not have redundancy in their means of support, the safe-life criterion is used. The calculation of the component's life may be based on stress life or strain-life relations. The safe life includes margins for the scatter of fatigue results and for other unknown factors. The fatigue life consists of crack-initiation and crack-propagation stages.

Landing gear materials usually feature an initiation stage, consisting of 90-95% of the total life, and a propagation stage of 5- 10% of the total life. Because of this safe life Criterion, landing gear must have defined inspection techniques, frequencies, and replacement times so that probability of failure due to fatigue cracking is extremely remote. Many military programs require sufficient residual strength for a damaged structure to be able to withstand limit loads without catastrophic failure. In the detailed fatigue analysis, each load/unload cycle constitutes a fatigue pair. Stresses/ strains at each end are determined. An equivalent, fully reversed stress level or strain range is calculated, and from the stress-life or strain-life relation, the life is determined.

These relations are curves of test data for the material. By dividing the life read from the curve by the required life for the subject load pair, the damage ratio for this loading condition is determined. Similarly, the damage ratio is determined for all loading conditions. The summation of all damage ratios is referred to as cumulative damage ratio - and it should not exceed 1.0. Fracture mechanics and damage tolerance analyses are performed to predict the growth of an existing crack. Sustained stresses caused by 1-8 static reaction are checked on components such as axles, truck beams, and trunnion pins, and must be below the allowable sustained stress threshold of the material.

The finite element method (FEM) of analysis has become widely used in areas of redundant load paths and complex geometric transitions. Weight/strength optimization is an especially important task of the structural analysis.

Figure 2.3 components and sub assembly

2.3 Landing Gear Wheel

Wheel refers to a circular metal/plastic object around which the rubber “tire” is mounted. The brake system is mounted inside the wheel to slow the aircraft during landing. However, in majority of cases, the entire wheel, tire, and brake system is also referred to as the wheel. The fundamental materials of modern tires are synthetic or natural rubber, fabric and wire, along with other compound chemicals. Today, the vast majority of tires is generally pneumatic inflatable and includes a doughnut-shaped body of cords and wires encased in rubber. So they consist of a tread and a body. Tires perform four important functions with the assistance of the air contained within them.

1. Tires support the aircraft structure off the ground.
2. They help absorb shocks from the runway surface.
3. They help transmit acceleration and braking forces to the runway surface.
4. They help change and maintain the direction of motion.

A tire carries the load almost entirely by its internal pressure. Tire sizing includes the calculations of the tire outer diameter (Dt), and tire width (Wt); and then, select the closest tire in the market from a manufacturer’s catalog figure 5.3. Tire selection should be based on the smallest diameter which rated to carry the desired dynamic and static loads. Generally speaking, for a tricycle configuration, nose tires may be assumed to be about 50 -100% the size of the main tires. For quadricycle and bicycle configurations, the front tires are often the same size as the main tires.

Figure 2.3 Shock Strut & Main Strut

2.4 Shock strut

The landing gear must be able to absorb the shocks exerted on the structure during the landing operation (mainly at touch-down phase). Some light, ultra-light, small and homebuilt, most helicopters, and plus sailplanes are built with rigid axles or solid spring, relying solely on the tires and solid springs for absorbing shocks. Although the tires themselves provide some shock-absorbing abilities by deflection, but for medium/large aircraft, the requirements for absorbing shock are higher than what tires are offering. The solid spring, which tends to be fairly simple in design, is employed in many GA light aircraft. However, almost all modern transport aircraft and military fighters are equipped with oleo-pneumatic shock absorbers or “oleo” figure. The oleo combines a mechanical coil spring (in air) with a hydraulic damper (piston-oil-cylinder-orifice).

2.5 Strut Sizing

The wheel strut must be sized, in that the cross section and its area need to be determined. The cross section is primarily a function of aircraft mass, load per wheel, landing gear height, safety factor, strut deflection, strut material, and “g” load during touch-down. There are various mechanical engineering references in the literature such as figure5.4 that the reader is referred to for more details. Two typical strut cross sections are circular and rectangular. If the landing gear is a non-retractable one, it is recommended to use fairing for struts; such that the cross sectional area resembles a symmetric airfoil. This technique will considerably reduce the strut drag.

3. ANALYTICAL CALCULATIONS AND FEM RESULTS

1. **Failure rate :**

$$\text{Failure rate} = \frac{(\text{No. Of failures during particular unit interval})}{(\text{Avg. population during that interval})}$$

2. **Failure density, f_d:**

$$\text{Failure Density} = \frac{(\text{Number of failures during a give interval of time})}{(\text{Total number of items at the beginning of the test})}$$

3. **Reliability(R):**

$$\text{Reliability} = \frac{(\text{Number of survivors at a given time})}{(\text{Total initial population})}$$

3.1 Experimental Analysis

Failure test conducted on the three landing gears and there failure rate at various times also for varying landing gears. For first landing gear at 125 KN and for the duration of 0 to 50 hours. Later the tests sequence conducted for the duration of 50 to 100 and 100 to 150 hours.

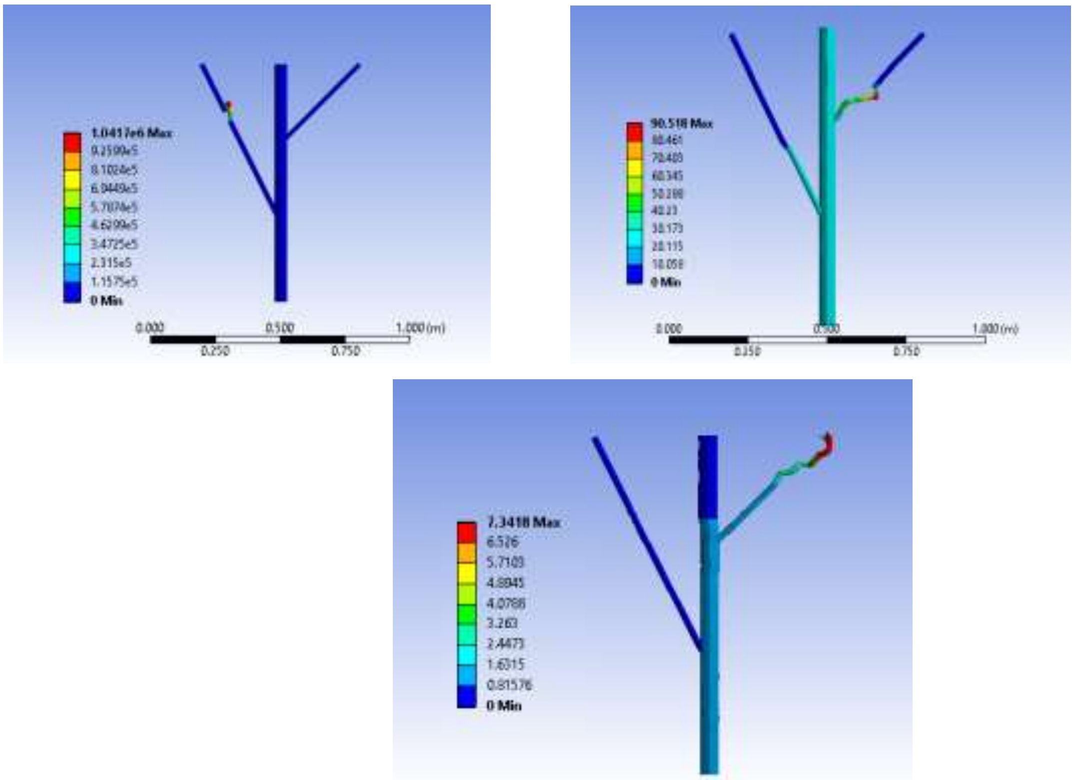


Figure 3.1 Failure of Landing Gear for various operating schedules

4. RESULTS AND DISCUSSIONS

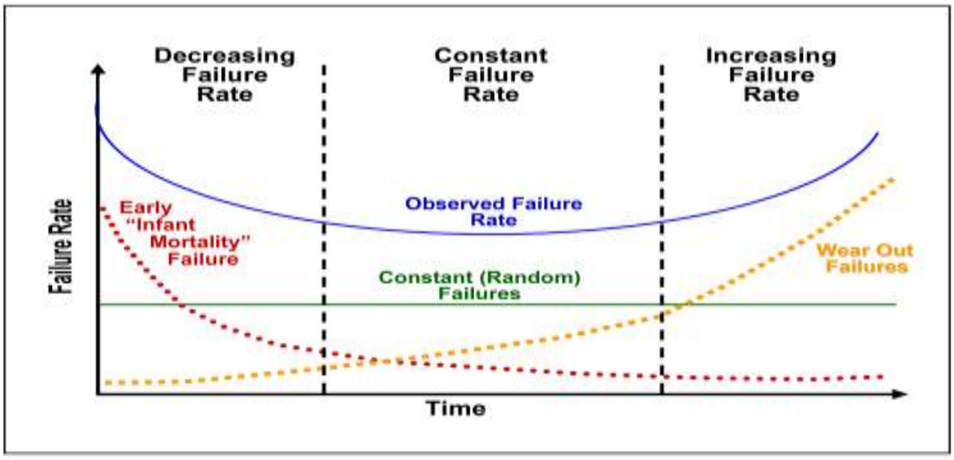
From the above analysis it is observed that the maximum strength that the nose wheel landing gear scaled model can withstand up to 1.040 x10^6 N/m^2 at a load capacity of 125 KN and at first 0 to 50 Hours of landing schedules. In the case of second landing gear failure occurs at 100 to 150 hours in the total duration of 200 hours analytical data. From the above contour plot, it is observed that the maximum strength that the nose wheel landing gear scaled model can withstand up to 90.518 N/m^2 at a load capacity of 125 KN and at from 100 to 150 Hours of landing schedules. In case of third landing gear failure occurs at 125KN about 150 to 200 hours in the total duration of 200 hours. From the above contour plot, it is observed that the maximum strength that the nose wheel landing gear scaled model can withstand up to 7.3418 N/m^2 at the same load capacity of 125 KN and at from 150 to 200 Hours of landing schedules.

4.1 Bath Tub Curve Comparison Plot

A test is conducted on three landing gears on impact testing Machine. The total duration of the test is 200 hours and all those three landing gears have failed at different durations but at the same load i.e.125 KN the number of components failing during hourly interval is noted and the results obtained are tabulated as follows:

Time T	**No. of Failures f**	**Cumulative failures F**	**No. of survivors S**	**Failure Density f_d**	**Failure Rate Z**	**Reliability R**
0	**-**	**0**	**3**	**-**	**-**	**1**
50	**1**	**1**	**2**	**0.333**	**0.4**	**0.666**
100	**0**	**1**	**2**	**0**	**0**	**0.666**
150	**1**	**2**	**1**	**0.333**	**0.666**	**0.333**
200	**1**	**3**	**0**	**0.333**	**2**	**0**

Table 4.1 Reliability Analysis on Landing Gear



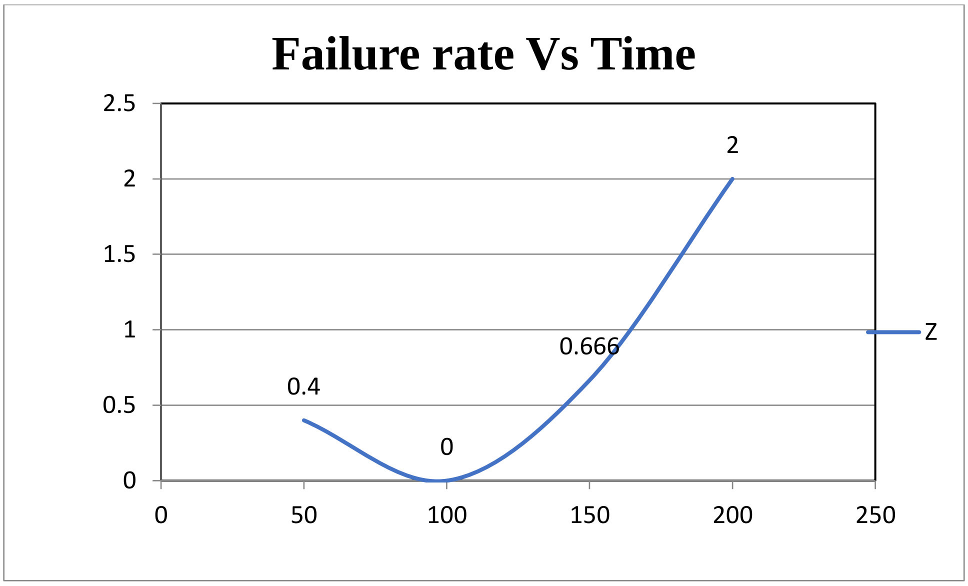
Graph-4.1 Theoretical Bath Tub Curve

The infant mortality period, also known as the early failure period, begins when a product is used for the first time. It is an interval characterized by a decreasing failure rate, and it starts from a high failure occurrence, quickly decreasing to a lower failure rate, and plateauing. Failures that occur within this time are usually driven by manufacturing defects or installation issues. Other causes of failure events in this period could be design flaws or improper start-up procedures.

Normal Life Period, Once the failure rate levels out after the initial operation period, the normal life kicks in. This region of the curve is also known as the useful life period, and operators expect assets in it to have a relatively constant failure rate. The majority of assets will spend most of their operational life in this state.

Assuming a constant failure rate also implies that breakdowns are due to random events. With increased usage, and as the assets undergo normal wear, failure events become less random and more predictable. This marks the beginning of the next period in the bathtub curve.

Wear-out period, Assets naturally deteriorate over time. The number of failure occurrences that an asset experiences predictably increases after a certain usage period. The wear-out region in the bathtub curve is characterized by this increasing failure rate trend. As failure rates increase quickly before the end of an asset life cycle, the bathtub curve slopes sharply upward. Eventually, this leads to the total failure of an asset.



Graph 4.2 Bath Tub Curve Plotted from tested values

From the above Bath tub curve obtained from the tested and analytically calculated data, the scaled modelled nose wheel landing gear is tested for 200 hours applying sudden load of 125 KN. It is clearly observed from bath tub curve the model failure rate decrease for the first 50 to 100 hrs schedules, where as it gradually increases failure rate from 100 to 150 and finally it reaches to the wear-out stage from 150 to 200 hrs schedules. Since the bathtub curve helps us determine the asset's expected useful life and reliability, it's easier to keep it under control. But the main advantage is undoubtedly being able to more accurately plan how and when to perform maintenance.

5. CONCLUSIONS AND FUTURE SCOPE

Load test on scale modelled aircraft landing gear is conducted for the sequence of loadings to attain statistical data related to cumulative no of failures, failure density, and failure rate in turn (reliability) life span of such a landing gear. This statistical result then validated with computationally predicted results using commercial software. Failure test data for the design fabricated and tested landing gear model may be tabulated. Failure rate v/s reliability curves have been drawn. Mean Time To Failure (MTTF), Mean Time between Failure (MTBF), Mean Time To Repair (MTTR) estimated for the test data analysis. Since the bathtub curve helps us determine the asset's expected useful life and reliability, it's easier to keep it under control. But the main advantage is undoubtedly being able to more accurately plan how and when to perform maintenance.

6. REFERENCES

1) Yin Yin, Nie Hong, Wei Xiaohui, etc. Performance analysis of landing gear retractable system under the influence of multiple factors[J]. Journal of Beijing University of Aeronautics and Astronautics, 2015, 41(5): 953-960.

2) Sun Yuan. Landing gear drop shock simulation and strength optimization design based on ADAMS and ANSYS [D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2012.

3) Wu Weiguo, Sun Jianqiao, Leng Yonggang, etc. Aircraft landing gear dynamics modeling and landing random response analysis[J]. Acta Aeronautica Sinica, 2016, 37(4): 1228-1239.

4) Feng Yunwen, Zhu Zhengzheng, Yao Xionghua, etc. Research on the safety analysis method of civil aircraft landing gear[J]. Journal of Northwestern Polytechnical University, 2016, 34(6): 969-975.

5) Wang Xiang. Research on Civil Aircraft System Safety Analysis Technology Oriented to Continuous Airworthiness [D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2017

6) Fukashima T., Shimonishi H., Hayashi K., Shiraishi M., Simulation of a vehicle running on to a curb by using tire and vehicle FE Models. 4th European LSDyna Users conference, Detroid, 1998.

7) Ossa E. A., Failure analysis of civil aircraft landing gear, Engineering Failure Analysis, Vol. 13, 2006, pp. 1177-1183.

8) Azvedo C. R., Hippert E., Fracture of aircraft's landing gear, Engineering Failure Analysis, Vol. 9, 2002, pp. 265-275.

9) Lee H.C., Hwang Y.H., Kim. T., Failure analysis of nose landing gear assembly. Engineering Failure Analysis, vol.10, 2003, pp.77-84.

10) Norman S. Currey, Aircraft Landing Gear Design: Principles and Practices, AIAA, 1988

11) Hollenbeck, A. R. (1978). Problems of reliability in observational data. In G. P. Sacket (Ed.), *Observing behavior: Vol. 2. Data collection and analysis methods* (pp. 79-98). Baltimore: University Park Press.

12) Shooman, L.M., Probabilistic Reliability; An Engineering Approach, New York; McGraw-Hill, 1968.

13) Singh, C., “On the behavior of failure frequency bounds”, IEEE Transactions on Reliability, vol.R-26, Apr.1997.

14) Singh,C., and Billinton, R.,System Reliability modeling and evaluation, London England; Hutchinson Educational,1977.