INTERNATIONAL SCIENTIFIC CONFERENCE
20-22 November 2025, GABROVO

INSPECTION OF AIRCRAFTS' WHEELS, THEIR MATERIALS AND APPLICATIONS – A REVIEW

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Abstract

As of today, when people discuss regarding aviation, it is seen that it has become an important factor that affects the lives of millions of people all around the world. Not only as civil aviation, but also as an important factor for determining borders in wars. When we consider civil aviation, airplanes shorten distances, allowing us to re-evaluate the terms of time and distance, making modern humans access to almost every land mass in the world. It is generally accepted that civil aviation began with the first powered flight by the Wright Brothers in North Carolina in 1903. However, it is a fact accepted by almost everyone that mankind's love of flying dates back much further. Hezarfen Ahmet Çelebi, who lived in the Ottoman Empire between 1609 and 1640, is the best example of this. According to the story in the Seyahatname (travel book) of Evliya Çelebi, one of the Ottoman travelers, Hezarfen Ahmed Çelebi, jumped from the Galata Tower with a southwestern wind in 1632, wearing a device resembling bird wings, glided 3,358 meters across the Bosphorus and landed in Üsküdar. It is a well example for mankind's passion for flying. However, if we consider about flight with engine how The Wright Brothers did, civil aviation became a rapidly developing sector after this flight onwards and air transportation became an important sector around the world with the start of commercial flights. Rapid development and widespread use of aircrafts have also revealed the importance of aircraft components. One of the most important of these components is the landing gear and the aircraft wheels, which are part of this landing gear. Aircraft wheels, which play an active role in the take-off and landing moments of aircraft, are the most intense area which exposed to impact and are one of the components that absorb these impacts.
In this article, we inspect and understand aircrafts' wheels, their materials and applications.

Keywords: Aircraft, wheel, rim, NDT (Non Destructive Testing), aviation, safety.

INTRODUCTION

In modern and developing times, aircraft wheels and tires are one of the most stressed parts. Impact loads, periodic loads, overheating, and corrosion can lead to landing gear wheel failure and various disasters after failure. As an example, the failure of wheels can result in multiple component failures, causing major safety threat to maintenance personnel or the entire aircraft itself. An aircraft wheel is designed to contain the selected tire, brakes, and minimum weight to provide long durability and component life. Manufacturers of this component must also adopt limited design in terms of cost. It is also proven fact that cost analysis for aircraft wheels and tires should be calculated according to the number of landings, not the flight hours [1].

The number of landings is important in terms of fatigue life of the wheels, durability, and exposure to force. After a certain period of time, the force, which the wheels are exposed to, causes damage and cracks. In modern aircraft, the areas that are most commonly damaged are the bolt areas with the least strength, these areas exposed to corrosion, and the areas susceptible to design-related sensitivity. Throughout history,

doi: www.doi.org/10.70456/..........................

airplanes' wheels, one of the most important components, have developed in parallel with the development of technology and industry [Fig.1.].

Although the landing gear and the wheels that are part of it were initially very weak in the aviation industry, today aircrafts have a very strong design that can absorb forces [Fig.2.].

Fig. 1. *Nieuport Fighter in Aisne, France 1917*

Fig. 2. *Wheel on a Lockheed P-3 Orion aircraft*

The functions of landing gear are to support the aircraft during ground maneuvers, reduce vibration, and absorb landing shocks. It also provides ground steering and braking functions when it is necessary. These goals are achieved by many different designs, depending on the type of aircraft to which the landing gear is fitted and the degree of complexity required. For example; As airplanes get larger, they use more wheels to cope with the increased weight, since the weight of the airplane needs to be distributed more evenly [2].

Aircrafts' wheels, their materials and applications

An aircraft tire is generally designed to withstand extremely heavy loads. Aircraft tire tread designs are arranged to facilitate stability in high crosswind conditions, repelling water to prevent water accumulation, and providing braking effect. Forged aluminum alloy is the most preferred material for wheel rims over other magnesium and steel alloys due to its low weight and high resistance to corrosion. If the user company accepts the high cost, titanium alloy wheels can also be used. In such cases, the initial cost of forging titanium with the required precision can be almost ten times higher than forging aluminum.

<u>Below we take an in-depth look at the importance of aircraft wheels and rims</u>

Two-piece rim: One-piece rims cannot be used on aircrafts because tires are very hard and need to be compressed. For this reason, the inner and outer rims are connected to each other with bolts after the tire is placed. Aluminum or magnesium alloy: Lightweight but high strength materials are preferred. Rims are produced from these materials by casting or forging. Aircraft wheels and rims are one of the most vital parts of flight safety. They can withstand both the sudden forces of take-off and landing and extreme hot and cold changes. When they are designed to provide the necessary durability and work together with the right materials and maintenance processes, safe and non-trouble operations are possible.

<u>Wheel Inspection</u>

All aircraft wheels are inspected for defects those occurred during manufacturing process so that they provide to ensure a flawless product. Inspection is very important throughout the service life of the aircraft wheel. Inspection of the wheel is also very important detecting disaster cracks. Such kind of crack detection needs NDT (Non Deforming Test) inspection. This is affected by several factors such as NDT method, material, configuration, inspector's

"UNITECH – SELECTED PAPERS" vol. 2025
Published by Technical University of Gabrovo
ISSN 2603-378X

doi: www.doi.org/10.70456/.........................

competence and environment. A location of cracks has a crucial role in detection by NDT techniques during standart and routine inspection. The location where inspection can be done without removing the tire can usually be performed as a routine inspection, but a few places such as tubewell bead seat, flange areas etc. cannot be inspected without removing the tire. In this case, it is necessary to remove the tire and inspect it in details. For example; Cracks in the bead seat and flange areas can only be detected during tire changes.

The Most Commonly Used NDT Methods in Non-Destructive Testing

The non-destructive testing method is generally selected according to the type, shape and types of defects of the structure or component which is tested. Each method has advantages and disadvantages to the other. Consequently, it is not absolute to say that any method is the best on its own. It is usually accepted that in order to achieve 100% control in the testing of a component, more than one method is often required [3].

1. Radiographic Testing

This Non-Destructive Testing (NDT) method uses penetrating (short wavelength) radiation. The radiation passing through the sample is absorbed in different amounts due to differences in density or thickness in the material. The radiation emitted from the opposite surface of the sample is usually recorded on radiographic film.

2. Ultrasonic Testing

This Non-Destructive Testing (NDT) method uses high-frequency sound waves in the range of 0.2 - 25 MHz to detect interruptions in the part to be tested. Here, Hertz (Hz) is the frequency unit and it is equal to the number of vibrations per second. Ultrasonic Testing is based on the principle that the sound beam spreading in the material. It is partially or completely reflected (echoed) as a result of the change in acoustic impedance (resistance of a material to the spreading of sound).

3. Eddy Current Method (Eddy Current)

This Non-Destructive Testing (NDT) method generally works with a generator, a test coil and an indicator. The generator provides alternating current (AC) to the test coil that creates the magnetic field. The alternating magnetic field induces eddy currents into the conductive test piece. These induced eddy currents create a second magnetic field in the opposite direction to the magnetic field of the coil. A change in the properties of the test piece or an interruption causes a change in the electrical resistance and the amount of current changes the magnetic field. The indicator (needle or cathode ray tube) records how the material affects the eddy currents. ***This method is generally used for aircraft wheel inspections.***

Advantages

- Test conditions can be adapted according to the test location.
- It shows the condition of the material immediately, no time is needed for the indication to develop.
- The devices are usually portable since they are self-charging or battery-powered.
- The magnetic field connection between the test device and the material does not damage the material.

Disadvantages

- The accuracy of the test method depends on the elimination of variables around the material and the skill of the technician.
- It is only applied to conductive materials.
- The measurement depth is limited to 1 1/4 inches.
- Testing of ferromagnetic metals is sometimes difficult [4].

4. Liquid Penetrant Method

This Non-Destructive Testing (NDT) method is used to detect surface discontinuities in non-porous materials. When the penetrant is applied to a clean surface, it penetrates into the surface discontinuity by capillary effect.

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After a sufficient penetration time, excess paint is cleaned from the surface. Paint that has entered the surface discontinuity is pulled back to the surface with the help of an absorbent developer and creates a visible indication on the surface of the part.

5. Magnetic Particle Testing

This Non-Destructive Testing (NDT) method is used to detect surface and near-surface discontinuities in ferromagnetic materials. For this, it is necessary to apply a magnetic field to the material and a magnetic powder sensitive to the leakage field formed on the discontinuity. The powder is held by the leakage field on the surface of the part and turned into visible indications. Interpretation of discontinuity indications must be done by qualified operators.

<u>*Literature Reviews*</u>

Kobayashi and Shockey, studied on failed aircraft wheel assembly [5]. In this study, a failed wheel assembly on a Hawker 125-800XP passenger jet was examined to determine the root cause of the failure. There are 12 connecting bolt/nut pairs that hold the flange to the wheel. The varying levels of damage to these nut pairs indicated that the failure was a progressive sequence, starting with one pair and spreading to adjacent pairs. The bolt/nut pair thought to have initiated the failure showed stepped threads on one side of the bolt. The characteristics of these stepped threads indicated that the nut had cracked, separated, and caused the failure of other bolt/nut pairs. The nut was not available for examination. Therefore, the conclusions that a cracked nut was the root cause of the failure could not be confirmed. However, a cracked nut was observed on another wheel assembly sometime later. Examination of the bolt showed similar thread deformation, supporting the initial conclusion. The nut fracture surfaces showed an intragranular zone surrounded by a ductile area. This intragranular zone is most likely the crack initiation point where the grain boundaries are weak. As a conclusion, the root cause of the wheel assembly failure was a cracked nut that may have been embrittled by hydrogen during cadmium plating.

Bagnoli and Bernabei, inspected fatigue analysis for wheel flange of P180 aircraft [6]. The inner wheel flange of a Piaggio Avant P180 aircraft separated from its right wheel while taxiing on the runway. This separated wheel was made of 2014-T6 aluminum alloy and had been in service for 22 years. The fracture surfaces were examined morphologically and revealed that the main cause of the failure was fatigue. The crack had grown to approximately 8 cm in length and 5 cm in depth prior to the final catastrophic failure and originated from a corrosion pit supported by wear from the inner tube housing. This led to the removal of the protective coating. By examining the fatigue life, an estimate of the number of flight cycles until failure occurs was also provided. As a result, it was recommended to reduce the inspection interval by one third of the normal one and to introduce a suitable maintenance procedure to remove corrosion and re-protect the component.

B.Kosec, Kovacic and L. Kosec, studied on fatigue cracking on wheels of aircraft [7]. In case of malfunctions in aircraft parts, fault detections are usually revealed by non-destructive testing methods and examination is provided accordingly. These faults can be complex in some cases. Fractographic and metallographic methods are definitely important for the detailed description and interpretation of fault. This article concerns a crack in an aircraft wheel rim. The wheel is made of 2014-T6 aluminum alloy. The crack was found during a regular inspection by the non-destructive testing maintenance unit of the Slovenian Airline Adria Airways. The crack in the examined rim is a typical fatigue crack. Rims are subjected to strong mechanical stress and atmospheric effects during landing and take-off. The crack in the rim examined in this article is a fatigue crack. There are many pits on the rim surface and the crack spreads

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over them. Therefore, it is concluded that the pits act as stress concentrators on the rim surface and one of them eventually initiates the fatigue crack.

Fig. 3. *The crack in the rim of an aircraft wheel.*

Bagnoli, Dolce, Colavita and Bernabei, in this study, the left main landing gear (LH-MLG) of a civil aircraft was damaged during take-off due to the fracture of its swinging lever, which was manufactured from a forged block (aluminum alloy) [8]. While visual inspection of the fracture surface, it was possible to observe typical marks which indicate that fatigue failure had occurred. Further investigations showed that the fatigue was caused by a pre-existing material defect on the outer surface due to an abnormal silicon concentration in the crack region and was probably related to the manufacturing process. Stress analysis of the component, performed via finite element analysis (FEA), also confirmed that the crack origin was located in the most stressed area and simulation of crack propagation via AFGROW analysis showed that propagation started early in service. As a result of this investigation, all swinging levers produced from the same batch were removed from service. They concluded that the defects likely occurred during the production phase of the forging.

Cantoni, Gobbi, Mastinu and Meschini, they studied brake and pneumatic wheel performance assessment [9]. A completely new test setup has been introduced to evaluate the physical performance of the pneumatic wheel and brake. Proper design of a vehicle braking system requires examining not only the brake itself but also the brake and wheel assembly.
This requires accurate measurement of the forces and moments applied to both the brake and the wheel. This study analyzes the measurement uncertainties of the new test setup. The new test setup provides excellent accuracy. The dynamometer demonstrated that the pneumatic wheel can be dispersed to 30% of the power consumed by the brake. This unreferenced result is valid for both the automotive and aerospace sectors.

Vashi, Anand, Jayakrishna, Rajyalakshmi and Aravind Raj, worked on Design and analysis of 3D printed UAV (Unmanned Aerial Vehicles) wheel. The wheel designs were modeled in Solidworks. Finite Element Analysis was also performed in Ansys to examine the static and dynamic radial strength of the wheel, ignoring any bending and torsion during landing. A Charpy impact test was also performed on the sample to examine crack propagation during impact.

Dong, Jin, Jia, Qi, Chen, He, Zou, studied and inspected Design and passability study of soil-plowing wheel facing soft terrain [11]. The wheel designs were modelled in Solidworks. Finite Element Analysis was also performed in Ansys to examine the static and dynamic radial strength of the wheel, ignoring any bending and torsion during landing. A Charpy impact test was also performed on the sample to examine crack propagation during impact.

Plenzig, Held, Holz, Kals and Verhoff, they worked on fatalities of stowaways traveling in airplane wheel wells [12]. Even though it is not directly related with aircraft wheels, it shows another aspect of wheels and landing

doi: www.doi.org/10.70456/.........................

gears for aviation industry. Five cases were included in the study. All of the deceased were male and aged between 14 and 26. All dies due to the being stowaway in aircrafts. It indicates that gap area in landing gears has also difficult conditions that provide non-vital area

Zhang, Jiao, Shang, Liu, Qi and Wu, they researched regarding Ground maneuver for front-wheel drive aircraft via deep reinforcement learning [12].

While ground maneuvering time accounts for 10-30% of flight time, for short-haul aircraft, this figure consistently exceeds 50% when ground traffic is dense. There is an urgent need to reduce aircraft ground taxiing time. Autonomous driving is currently the best solution for aircraft that can save maneuvering time. The wheels are driven by the APU (auxiliary power unit) engines, operating at the APU's peak, which is expected to significantly reduce emissions, fuel consumption, and noise. Under certain conditions, the DRL (Deep Reinforcement Learning)-based controller has proven to be superior to traditional forward-looking controllers. Using the DRL approach proposed in this article, it is possible to design a controller for aircraft ground taxiing.

Farstad, Netland and Welo, experienced on surface friction of rapidly prototyped wheels from 3D-printed thermoplastic elastomers [13]. It is an other article that does not directly deal with aircrafts, but deal with wheels. The experiments presented in this paper demonstrate that 3D prints produced with soft materials can be used as fully functional drive wheels on a smooth surface such as an aluminum rail and in other applications where high friction is desired for functionality.

Pytka, Józwik, Budzynski, Łyszczyk, Tofil, Gnapowski and Laskowski, prepared an article about wheel dynamometer system for aircraft landing gear testing [14]. The objective of this study is to design, develop, and implement a wheel dynamometer for aircraft landing gear testing. The dynamometer system is designed to measure two force components acting along the longitudinal and vertical axes of the wheel, and three moments acting about the longitudinal, transverse, and vertical axes.

The prototype system was calibrated on a fixed test stand and then mounted on a PZL 104 Wilga 35A aircraft for airfield testing. Primary test measurements were conducted while the aircraft was taxiing at "walking man" speed, demonstrating the system's performance. Certification is being considered for the presented dynamometer system for aircraft ground and flight testing.

Papa, Tanelli, Panzani and Savaresi, studied on wheel-slip estimation for advanced braking controllers in aircraft [15]. Most aircraft are equipped with Anti-Lock Braking Systems (ABS), which are active during landing and takeoff maneuvers and maximize road friction. Due to stringent certification requirements, the brake controller must operate using signals specific to the landing gear, the aircraft subsystem housing the brake actuators.

This article investigates how to obtain reliable wheel slip prediction using wheel speed and brake pressure signals, and analyzes different wheel slip observer options. Specifically, we propose a model-based approach using a sliding-mode observer, a black-box approach based on nonlinear autoregressive models with eXogenous input, and a neural network implementation. Both approaches are tested and compared on experimental data, demonstrating that the resulting prediction performance is sufficient for use in closed-loop braking systems.

In addition to all these esteemed people, ***Gao, Fao and Wang*** wrote an article regarding dynamic behavior and nonlinear characteristics of aircraft landing gear retraction mechanism considering atmospheric corrosion [16]. ***Lian, Yi, Wang, Zhao, Zhou, Zhang, Xue, Zhang and Yue,*** made a study for experimental and numerical research of aircraft tire debris impact on landing gear brake pipe [17].

doi: www.doi.org/10.70456/.........................

Diltemiz, studied on Failure analysis of aircraft main landing gear cylinder support [18]. ***Shen, Su, Deng and Huang,*** Investigation of high-cycle fatigue property and fatigue crack propagation behavior of a die-forged 2014 aluminum alloy aircraft wheel [19]. ***Liu, Chong, Liang, Chen, Wang, Li and Liu,*** Improved design, development and field investigation of the wheel-soil interaction measurement system under aircraft load [20].

CONCLUSION

Corrosion, over-torquing of nuts, Hydrogen embrittlement and bolt failures are the main factors for leading to reduced life of aircraft wheels. Corrosion plays a significant role in reducing fatigue life of aircraft wheels. Corrosion on aircraft wheels occurs due to deicing products (PDP), increased temperatures in tires and during braking, pre-anodization process, quality of grease used, etc. Using the recommended methods, aircraft wheels can be protected from corrosion. Braking force, landing impact and tire inflation pressure can affect the rate of crack growth in aircraft wheels. Eddy current testing, Liquid penetrant and Ultrasonic testing are the most commonly used NDT techniques to check for cracks in aircraft wheels, where Liquid penetrant testing is the most economical and Eddy current is the most reliable.

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Figures

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