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RESEARCH ARTICLE

Effective Maintenance Of Aircraft Antiskid Brake System

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ABSTRACT - The most effective way to reduce Mean Time to Repair (MTR) is to get to the root cause of the failure before it even occurs. Closely monitoring operational data of each component of an aircraft enables the early detection of possible causes of failure. The purpose of this research work is to determine the cause of frequent failure of the antiskid braking system UA-51 by using data collected on the performance of the component, with the aim of improving on the maintenance process. A close examination of the antiskid brake system showed that the failures occurred due to wear and tear of the drive gear. The external condition of the brake was examined and a calculation was done to ascertain the hardness of the gear teeth. The bending endurance and the contact endurance were obtained to be -6.2153 and -3.72115 respectively. The quantile of the results corresponds to the probability of failure-free operation P(t)=0.99999. Based on these results, it was discovered that the wear and tear of the drive gear was caused by negligence of the technical procedure for carrying out maintenance on the antiskid brake system. A recommended technical procedure of maintaining the antiskid brake was given.

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1.0 INTRODUCTION

Aircraft anti-skid braking system (AABS) has perpetually remained pivotal research subject due to its significant influence on enhancing the safety of ground operations for aircraft. A reliable and high-performing aircraft anti-skid braking system (AABS) plays a crucial role in ensuring the successful execution of flight missions [1]. It has a direct impact on both aircraft safety and the well-being of the on board crew. As the aviation industry undergoes rapid advancements, there is a growing need for larger and faster aircraft. To effectively reduce braking times and distances for these types of aircraft, it becomes imperative to enhance the efficiency and performance of the AABS [2]. While in the process of taxiing along a runway, an aircraft employs various means such as air resistance and reverse engine thrust to decelerate. Nonetheless, the most efficient and dependable approach for deceleration remains the use of wheel brakes.

The primary purpose of the anti-skid brake control system is to execute deceleration in accordance with the pilots' braking instructions while preventing unsafe occurrences during the braking process [3]. These potential hazards encompass tire blowouts and veering off the runway. The intricate dynamics of aircraft body and wheel rotation during braking stem from the complicated and unpredictable friction properties between the tires and the runway. This complexity poses a daunting challenge in implementing effective maintenance procedure for anti-skid braking system to ensure both efficiency and safety."

At the moment of touchdown during the landing phase, an aircraft experiences a vertical descent speed along with a horizontal gliding speed. The horizontal glide speed propels the aircraft forward along the landing strip, necessitating the use of brakes to bring it to a complete stop. These braking mechanisms are integrated into the aircraft's landing gear. In some instances, supplementary braking aids such as parachutes and arresting mechanisms may also be employed in conjunction with the primary brakes. The length required for landing has significant implications for operational, economic, and military considerations as the case may be. A shorter landing distance enhances the aircraft's versatility by allowing it to operate from smaller runways. Military aircraft often need to take off and land on rough or limited-length runways, making a short landing run essential. This attribute is crucial for deploying aircraft from aircraft carriers, and designers aim to minimize the aircraft's required landing distance as much as possible [4].

The need for a short landing distance for an aircraft is significant when considering economic, operational, and strategic factors. Excessive braking can lead to skidding which is an undesirable situation, whereas insufficient braking results in an extended landing run. Achieving the shortest feasible and optimal landing distance without skidding demands the continuous adjustment of braking force to align with the prevailing frictional force at all times.

There are currently two anti-skid braking methods employed in certain aircraft:

1. **Pulsed Braking:** With this technique, the brakes are applied and released in turns at predetermined, defined intervals, always applying the same amount of power. When the brake is applied, it is held without regard for skidding for a predefined amount of time. The wheel can recover from any skidding that may have happened

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during the free rolling phase that comes next. Until the airplane comes to a complete stop, this cycle is repeated. Although the design of this system is sturdy, it is not the best option.

2. **Skid Monitoring Systems:** In the second approach, sensors track the motion of the aircraft while applying the brakes in order to identify any indications of skidding. The brake is quickly removed to allow the wheel to restore traction and roll freely when sliding is detected. Until the airplane stops, these steps are repeated. Compared to the previous system, this strategy is more optimal since it actively addresses and mitigates skidding.
3. In both of these systems, the braking force remains constant throughout the process. However, it is important to note that these approaches are considered suboptimal because the maximum allowable braking force continuously varies with the ground reaction and wheel skid conditions.

2.0 PRINCIPLE OF OPERATION

In a study [5], the authors discussed the principle of designing and developing an experimental platform for studying the braking performance of an anti-skid device. This platform encompassed various aspects, including the principle of anti-skid device friction testing, platform structure design, mechanical transmission, wire rope brake mechanism processing, hydraulic loading system development, control system development, experiment data acquisition system development, and sensor installation.

To begin with, it is important to note that for the AABS to operate effectively, it necessitates the integration of a control mechanism. Furthermore, this task is made challenging due to the AABS's inherent non-linearity and the numerous uncertainties it encounters, such as varying runway surface conditions [6]. The conventional approach of using proportional integral derivative (PID) control with pressure-bias-modulated (PBM) [7] is ineffective in scenarios where runways are affected by disturbances, resulting in undesirable low-speed slippage issues for the aircraft [8]. To address these challenges, numerous control strategies introduced by researchers have found extensive application in the domain of AABS. These include mixed slip deceleration PID control [9], optimal fuzzy control [10], backstepping dynamic surface control [11], direct adaptive fuzzy–neural control [12], self-learning fuzzy sliding mode control [13], and more.

Qiuet al. [11] introduced a novel approach for enhancing the performance of anti-skid braking systems in electric aircraft landing systems. By combining nonlinear backstepping dynamic surface control (DSC) with an asymmetric barrier Lyapunov function (ABLF), the proposed controller ensures stable operation and adherence to output constraints. This technique not only tracks the reference slip ratio effectively but also prevents the system from entering unstable regions, thus improving the overall braking process. The use of ABLF allows for more flexible wheel slip constraints on various runway surfaces, while DSC eliminates the need for repeated differentiation, simplifying controller design and enhancing robustness against disturbances. The simulations conducted in the study validate the effectiveness of the proposed control scheme in maintaining stability, avoiding self-locking, and ensuring the boundedness of output constraints. Overall, the integration of DSC and ABLF offers a promising solution for achieving efficient and reliable anti-skid braking systems in electric aircraft landing systems. However, factors such as complex failure modes, integration challenges, performance variability, and maintenance requirements could restrict the applicability and reliability of the proposed control scheme in specific aircraft with a history of frequent anti-skid system failures.

A study was also conducted on high efficiency aircraft anti-skid brake control method with runway identification [6]. The technique utilizes observed system parameters to generate feed forward control for pressure regulation, enhancing the closed-loop wheel speed control. By analysing and compensating for nonlinearities in friction coefficients and aerodynamic drag, the algorithm achieves maximum friction force identification, leading to improved brake efficiency. This approach contributes to effective anti-skid braking systems by integrating runway characteristics to optimize braking performance and ensure aircraft safety during take-off and landing. This approach contributes significantly to the development of effective anti-skid braking systems by integrating runway characteristics for enhanced control and safety. However, in the study no detailed discussion on the challenges of implementing the proposed algorithm in diverse aircraft models and the need for extensive real-world validation was conducted. The proposed control method may therefore require further customization and validation to effectively mitigate the frequent anti-skid failures observed in certain aircraft models.

In 2020, Biancardo et al [14] presented a study on runway friction decay analysis for maintenance operations at airports, focusing on calibrating models to predict friction degradation based on aircraft loads. Through surveys at airports to monitor air traffic and pavement characteristics, the authors utilized learning algorithms to develop models for predicting friction decay and scheduling maintenance activities to ensure landing and take-off safety. The technique employed contributes to effective anti-skid braking systems by providing a method to proactively predict runway friction degradation, allowing for optimized maintenance scheduling. The calibrated models obtained from the study can be integrated into pavement management systems, enhancing safety during landing and take-off manoeuvres by ensuring optimal runway conditions. However, limitations include the need for further validation of the models for different runways and aircraft types to address potential variations in friction decay patterns, especially in specific aircrafts where frequent anti-skid system failures may occur, requiring tailored predictive models for accurate maintenance planning and improved anti-skid braking system effectiveness.

Jiao et al looked into an aircraft anti-skid brake control method that relies on a runway maximum friction tracking algorithm [15] aimed at enhancing the efficiency of aircraft braking systems by accurately identifying and monitoring the maximum friction between the tires and the runway. Through this tracking algorithm, the proposed control method ensured rapid response times and highly effective braking performance. The research involved modelling aircraft hydraulic brake components, conducting simulation tests under various runway friction conditions, and performing ground inertia test bench experiments to validate the control method efficacy. Overall, this technique contributes to the effectiveness of anti-skid braking systems by optimizing the utilization of maximum friction, thereby improving safety and performance in aircraft braking operations. The study by Liu developed an approach utilizing Deep Reinforcement Learning in reconfiguring aircraft anti-skid braking systems [16]. To improve system robustness and adaptability in fault and disturbance settings, the suggested controller integrates deep reinforcement learning with linear active disturbance rejection control. The results obtained demonstrate that even in the presence of faults, perturbations, and changing runway environments, the designed Twin Delayed Deep Deterministic - Linear Active Disturbance Rejection Control (TD3-LADRC) controller successfully increases anti-skid braking efficacy. The method improves the resilience, immunity, and environmental adaptation of airplane braking systems, hence increasing their safety and dependability. But questions concerning the TD3-LADRC controller's scalability and real-world application are raised by its complexity, as it was only proven through simulations. Further research and future development of hardware-in-loop experimental platforms are essential to assess the controller's performance under actual operating conditions and to address potential challenges related to implementation and integration into specific aircraft systems.

The issue Huang Cheng [17] found in his research on the on/off valve-based aircraft antiskid braking system was with the hydraulic aircraft antiskid braking system's use of conventional pressure valves. Conventional pressure servo valves need a lot of maintenance and are prone to contamination [17]. The study suggested an antiskid braking system for airplane applications based on an on/off valve that has a straightforward structure and a high level of contamination resistance [18]. It can lower maintenance costs and increase system reliability. Two models are developed: a longitudinal motion model for the aircraft and an on/off valve-equipped hydraulic antiskid braking system model. These models are used to build a switching controller with delay correction for an on/off valve-based aircraft antiskid braking system.

It features a switching surface derived through back stepping to govern the switching action of the valves and a pressure predictor to compensate the delay caused by response time of valves and brake lines. In addition, an approximation brake line model and a tire friction force observer are included in the controller to estimate the brake pressure and friction force, respectively. The system stability was analyzed using Lyapunov theory and Filippov framework [19]. At last, hardware-in-loop tests were conducted on a research prototype of the hydraulic brake system and a computer-based simulator embedded with aircraft motion models. Experimental results show that the proposed on/off-valve-based aircraft antiskid braking system presents a smooth braking performance, and it is robust to uncertain road conditions.

Jinsong Liu [20] studied the use of Electric Brake System in Civil Aircraft through which a general situation of the development of aircraft braking system were introduced, aiming at the shortcomings of the traditional hydraulic braking system, a type that is suitable for civil aircraft electric braking system is designed, using electromechanical actuators to replace the traditional hydraulic pressure mechanism, and through MATLAB simulation and inertia test, verify the electrical brake system simplifies the system composition, reduce the weight of the system, the system performance, safety, testing and maintenance, etc. The study also covered the development of the world's first set of aircraft brake system by the British Dunlop company since 1940 [21]. Aircraft braking system has continued to experience technological developments from the mechanical inertia anti-skid brake system, electronic anti-skid brake system, digital anti-skid brake system to digital power-by-wire anti-skid brake system, and considerable progress has been made on the systematic performance and functionality [21] [22]. However, the mechanical hydraulic actuation form is adopted in the brake system with no basic change; the high-pressure hydraulic power is provided by a centralized hydraulic pump driven by the engine.

In light of Dong Sun's [23] work, "High-efficiency aircraft antiskid brake control algorithm via runway condition identification based on an on-off valve array," this paper suggests an alternative method for pressure management that substitutes an on-off valve array for the servo valve. An effective antiskid control method that makes use of this discontinuous feature is suggested, based on this new pressure control component. Additionally, the system is able to determine the runway conditions. The Filippov framework is proposed to address the discontinuity in the process of using an on-off valve array. There is also a discussion of the system's convergence conditions [23]. To confirm the effectiveness and stability of the suggested control algorithm, the outcomes of the hardware-in-the-loop (HIL) brake trials and digital simulations are employed. The technique also demonstrates how well the on-off valve array functions as a new kind of antiskid brake pressure control component, completely replacing the servo valve.

Any attempt at optimization starts with a good and reliable data therefore, any data on component performance, particularly on failure history over time, must be collected [23] and a minimum time period must be set to ensure that enough insight is obtained from such data. In today’s setting, these tasks can be completed more easily and accurately with tools such as Computerized Maintenance Management System (CMMS) software [23]. The data on the failure history of the antiskid brake UA-51, which is the component that is being considered in this work was collected and examined. Based on the observation made on the data, it was noticed that the brake failed more frequently than the normal time of failure. In line with the observation made, an investigation was done to discover the cause of the frequent failures.

3.0 INVESTIGATION OF THE CAUSE OF FAILURE OF THE ANTI-SKID BRAKE UA-51

A failure was detected during a performance check on the anti-skid brake UA-51 of the Tu-154, which is a Russian Aircraft. When dismantling the wheel, it was discovered that the original part that collapsed was the drive gear of the anti-skid brake system. The identified failure could have led to the destruction of the pneumatics and an eventual removal of the aircraft beyond runway limits. When the drive gear was examined, discolouration and scratches were found on it. The intervals between the time of failure were recorded thus: 520, 594, 633, 693, 720, 827, 1077, 1160, 1335, 1350, 1389, 1510, 1757, 1818, 1970, 2264, 2546, 2619, 3431 and 3650 hours which was done during the inspection after the landing of the aircraft. The average operating time was 4000 hours. And the data was obtained from the Computerized maintenance management system (CMMS) of Samara University's Aerodrome.

Based on the data obtained during the preliminary acquaintance with the defective gear, we were able to conclude that the reasons for its damage are due to:

i. Insufficient structural strength of the gear;

ii. Poor manufacturing quality of the gear (material defects, non-compliance geometric dimensions);

iii. Violation of operating conditions and failure to comply with maintenance technology when replacing wheels and brake discs.

The conclusions were made in relation to findings by the authors in reference [24]

3.1 Analysis of the external condition of UA-51

As a result of an external inspection of the UA-51 drive gear, an irregular bend of about 2mm was established along the width of the rim throughout the entire circumference of the gear tips as well as scratches on the end of the gear.

The following steps were taken to determine the cause of wear and failure on the gear:

i. Calculation of the hardness of the gear teeth
ii. Analysis of the operating conditions of the UA-51
iii. Evaluating conformity of the fabrication to the design specifications
iv. Verifying the mechanical properties of the materials used in the fabrication
v. Consideration of the procedures of maintenance

Calculating the hardness of the gear teeth
The design is shown in Figure 20 [25]

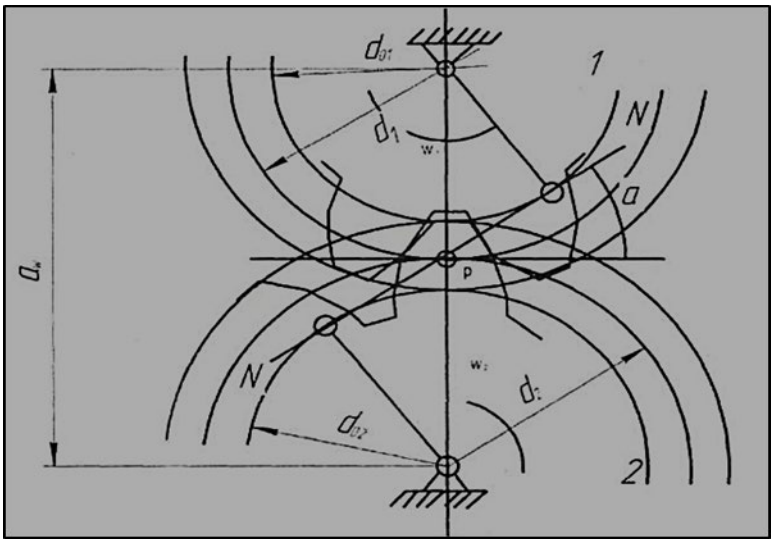

Figure 1: Design of the drive gear [24]

Table 1: Initial data for calculations

Serial	Characteristic Parameter	Obtained value
	Gear power N, W	0.015
	Diameter of the initial circle of the gear d_{w1}, mm	28
	Center distance α_w, mm	135
	Crown width w, mm	5
	Calculation of gear rotation speed n_1, min^{-1}	-
	Wheel diameter, mm	930

$$\omega = \frac{V}{\pi \,.\, D} = \frac{240\,.1000}{3{,}14\,.\,0{,}93\,.\,60\,.\,60} \quad (1)$$

Where **V** is the landing speed of the aircraft
D - Wheel diameter KT141
Let's find the gear ratio:
Number of gear teeth: 113
Number of gear teeth UA-51: 14

$$U = \frac{113}{14} = 8{,}07$$
$$n_1 = U\,.\,\omega = 8{,}07\,.\,1380 = 11138{,}6 \quad (2)$$

Gear rotation speed **n1**, min-1 = 11138.6

$$T_1 = 9555\frac{N}{n_1};$$
$$T_1 = 9555\frac{0{,}015}{11138{,}6} = 0{,}012867 \quad (3)$$

$$F = \frac{2000T}{d_{w1}};$$
$$F = \frac{2000\,.\,0{,}012867}{28} = 0{,}919, \quad (4)$$

Specific design circumferential force of the crown:

$$\omega_{H_t} = \frac{2000T_1}{b_w\,.\,d_{w_1}}\, K_{H\alpha}\,.\,K_{H\beta}\,.\,K_{Hv}\,, \quad (5)$$

where $\boldsymbol{K_{H\alpha}}$ is a coefficient that takes into account the load distribution between the teeth. Let's take it to be 1.
$\boldsymbol{K_{H\beta}}$ is a coefficient that takes into account the distribution of the load over the width of the crown. Let's take it to be 1.053.
$\boldsymbol{K_{Hv}}$ is a coefficient that takes into account the dynamic load occurring in the gearing

$$K_{H_v} = 1 + V_H\,;\; K_{Hv} = 1 + 864{,}555 = 865{,}555 \quad (6)$$

Dynamic additive:

$$V_H = \frac{\omega_{Hv} \, . \, b_w \, . \, b_{w1}}{2000 \, . \, T_1 \, . K_{H\alpha} \, . K_{H\beta}} \, ; V_H = \frac{167{,}346 \, . \, 5 \, . \, 28}{2000 \, . \, 0{,}012867 . \, 1{,}053} = 864{,}555 : \tag{7}$$

Specific circumferential dynamic force:

$$\omega_{Hv} = \delta_H \, . \, g_0 \, . \, n \, . \sqrt{\frac{d_w}{U}}; \; \omega_{Hv} = 0{,}06 \, . \, 8.185 \, , 64 \sqrt{\frac{136}{8{,}07}} = 167{,}346 \tag{8}$$

$$\omega_{H_t} = \frac{2000 \, .0{,}012867}{5.28} \, 1 \, . \, 1{,}053 \, . \, 865{,}555 = 167{,}5396 \tag{9}$$

Evaluating the contact endurance
Estimated contact stress in the engagement pole:

$$\sigma_H = z_H \, . \, z_M \, . \, z_\varepsilon \, . \sqrt{\frac{\omega_{Ht} . (U+1)}{d_{w_1} \, . \, U}} \leq \sigma_{HP} \tag{10}$$

where $\boldsymbol{z_H}$ = 1.76 is a coefficient that takes into consideration the shape of the mating surfaces of the teeth.
$\boldsymbol{z_M}$= 86.9 – coefficient taking into consideration the mechanical properties of the material of the mating gear wheels.

$$z_\varepsilon = \sqrt{\frac{4 - \varepsilon_\alpha}{3}} \; ; \; z_\varepsilon = \sqrt{\frac{4 - 1{,}945}{3}} = 0{,}8276 \tag{11}$$

$$\sigma_H = 1{,}76 \, . \, 86{,}9 \, . \, 0{,}8276 \, . \sqrt{\frac{167{,}5396 \, . \, (8{,}07+1)}{28 \, . \, 8{,}07}} = 328{,}2461 \tag{12}$$

Allowable contact stress for gear:

$$\sigma_H = \frac{\sigma_{Hlim}}{S_H} \, . \, z_R \, . \, z_v \, . \, K_L \, . \, K_{XH} \tag{13}$$

Where $\boldsymbol{\sigma_{Hlim}}$, $\boldsymbol{\sigma_{Hlim}}$ the endurance limit of the tooth contact surface.
$\boldsymbol{\sigma_{Hlim}}$= 2HB + 70; $\boldsymbol{\sigma_{Hlim}}$= 2*170 + 70 = 410 (MPa); (25)
$\boldsymbol{S_H} -$ safety factor. $\boldsymbol{S_H}$= 1,1;
$\boldsymbol{z_R}$ = 0.9 – coefficient taking into consideration the roughness of the mating surfaces of the teeth;
$\boldsymbol{z_v}$= 0.85*n0.1 = 1.43 – coefficient taking into account the peripheral speed.
$\boldsymbol{K_L}$ – coefficient taking into consideration the influence of lubrication, $\boldsymbol{K_L}$ = 1;
$\boldsymbol{K_{XH}} -$ coefficient taking into consideration gear dimensions, with dw ≤ 700 (mm) $\boldsymbol{K_{XH}}$= 1

$$\sigma_{HP} = \frac{410}{1{,}1} \, . \, 0{,}9 \, . \, 1{,}43 \, . \, 1 \, . \, 1 = 479 \tag{14}$$

The inequality $\boldsymbol{\sigma_H} \leq \boldsymbol{\sigma_{HP}}$ is true, therefore, the strength condition is satisfied.
Let's calculate the wheel's probability of failure-free operation.
We determine the coefficients of variation of partial load factors:

$$v_A = 0{,}1\ ;$$

$$V_{H\beta} = \frac{1}{9}\frac{\bar{k}_{H\beta} - 1}{\bar{k}_{H\beta}} = \frac{1}{9}\frac{1{,}053 - 1}{1{,}053} = 0{,}0056; \tag{15}$$
$$V_{H\gamma} = 0{,}17\frac{\bar{k}_{HV} - 1}{\bar{k}_{HV}} = 0{,}17\frac{1{,}053 - 1}{1{,}053} = 0{,}0086;$$

Load factor variation coefficient

$$v_{H\Sigma} = \sqrt{v^2{}_A + v^2{}_{H\beta} + v^2{}_{HV} + v^2{}_{H\alpha}} = \sqrt{0{,}010153182169} = 0{,}100763 \tag{16}$$

$$v_{\sigma H} = 0{,}5 v_{H\Sigma} = 0{,}05038 \tag{17}$$

Taking the variation coefficient of the base sample $\boldsymbol{v^0{}_{Hlim}}$=0.09, and determining the coefficient of gear variations

$$v_{Hlim} = \sqrt{(v^0{}_{Hlim})^2 + 0{,}05^2 = 0{,}0103} \tag{18}$$

Safety factor for medium stress:

$$\bar{n}_H = \frac{\sigma_{Hlim}}{\bar{\sigma}_H} = \frac{410}{328{,}2461} = 1{,}249 \tag{19}$$

Quantile of normal distribution:

$$U_p = \frac{\bar{n}_H - 1}{\sqrt{\bar{n}^2{}_H . v^2{}_{Hlim} + v^2{}_{\sigma H}}} = -\frac{1{,}249 - 1}{\sqrt{1{,}249^2 . 0{,}103^2 + 0{,}05038^2}} = -3{,}72115 \tag{20}$$

The quantile corresponds to the probability of failure-free operation P(t)=0.99999 [26], therefore, gear destruction due to the influence of contact stresses can be excluded.

Investigation of bending endurance of the teeth
The calculation is intended to ascertain fracture of the teeth due to fatigue [27]
Design tooth bending stress:

$$\sigma_F = Y_F . Y_\varepsilon . Y_\beta . \frac{\omega_{Ft}}{m} \le \sigma_{FP} \tag{21}$$

where $\boldsymbol{\omega_{Ft}}$ – specific circumferential design force, (N/mm)

$$\omega_{Ft} = F_{Ft} . \frac{K_{Fa} . K_{F\beta} . K_{Fv}}{b_w} \tag{22}$$

where $\boldsymbol{K_{Fa}}$ is a coefficient that takes into account the distribution of load between the teeth. For gear
For sixth precision, we take the coefficient to be1.
$\boldsymbol{K_{F\beta}}$ is a coefficient that takes into account the distribution of load across the width of the rim, let's take it to be 1,11

$\boldsymbol{K_{Fv}}$ – coefficient taking into consideration dynamic load;

$$K_{Fv} = 1 . \frac{\omega_{Fv} . b_w . d_{w1}}{2000 . T_1 . K_{F\alpha} . K_{F\beta}}\ ;\ K_{Fv} = 1 + \frac{20{,}66 . 5 . 28}{2000 . 0{,}012867 . 1 . 1{,}11} = 102{,}254 \tag{23}$$

$$\omega_{Fv} = \delta_F . g_0 . n . \sqrt{\frac{\alpha_w}{U}}\ , \omega_{Fv} = 0{,}016 . 3{,}8 . 85{,}95 . \sqrt{\frac{136}{8{,}07}} = 20{,}66\ ; \tag{24}$$
$$\delta_F = 0{,}016$$

$$\omega_{Ft} = 0{,}914\,.\frac{1\,.\,1{,}11\,.\,102{,}254}{5} = 20{,}75, \tag{25}$$

$\boldsymbol{Y_F}$– coefficient taking into consideration the shape of the tooth will be taken equal to 3.79;
$\boldsymbol{Y_\varepsilon}$ – coefficient taking into consideration the overlap of teeth

$$Y_\varepsilon = \frac{1}{\varepsilon_\alpha} \tag{26}$$

$\boldsymbol{Y_\beta}$ is a coefficient that takes into account the inclination of the teeth. For spur gears it is 1;
$\boldsymbol{m}$ – module;

$$m = \frac{d_1}{z_z};\ m = \frac{32}{14} = 2 \tag{27}$$

$$\sigma_F = 3{,}79\,.\,1\,.\frac{20{,}75}{2}\,0{,}514 = 20{,}3148 \tag{28}$$

Permissible stress when calculating endurance:

$$\sigma_{FP} = \frac{\sigma_{Flim}}{\delta_F}\cdot\gamma_S\,.\gamma_R\,.\,\gamma_{XF}\,. \tag{29}$$

where σFlim is the fracture endurance limit of the teeth;
$\boldsymbol{\sigma_{Hlim}}$= 1.8HB = 1.8*170 = 306 (MPa); (37)
$\boldsymbol{\delta_F}$ – safety factor;
$\boldsymbol{\delta_F}$ = SF" * SF';
$\boldsymbol{\delta_F}$' – takes into account the instability of material properties and the responsibility of the gear drive.
$\boldsymbol{\delta_F}$' = 2.2
$\boldsymbol{\delta_F}$" – takes into account the method of obtaining the gear;
For stamping $\boldsymbol{\delta_F}$" = 1;
$\boldsymbol{\gamma_S}$. is a coefficient that takes into account the stress gradient and the sensitivity of the material to stress concentrations.
For structural steels it is determined depending on the modulus. $\boldsymbol{\gamma_S}$. = 1.02;
$\boldsymbol{\gamma_R}$. – coefficient taking into account surface roughness will be taken equal to 1;
$\boldsymbol{K_{XF}}$ – coefficient taking into account the dimensions of the gear, will be taken equal to 1;

$$\sigma_{FP} = \frac{306}{2{,}2}\,.\,1{,}02\,.\,1.1 = 142 \tag{30}$$

The inequality $\boldsymbol{\sigma_F \leq \sigma}$ is true, therefore, the strength condition is satisfied.
Let's calculate the probability of failure-free operation.
The value and coefficient of variation of the tooth bending stress are respectively equal to:
$\boldsymbol{\sigma_F}$= 20.3148 MPa; $\boldsymbol{\sigma_F}$= 0.12.
In accordance with the recommendations for improved wheels, we take the coefficient of variation of the endurance limit of the base sample $\boldsymbol{v^0{}_{Flim}}$= 0.09, and coefficient $\boldsymbol{\alpha_Z}$ = 0.6.

$$v_{Flim} = \sqrt{(\alpha_z\, v^0{}_{Flim})^2 + 0{,}14^2} = \sqrt{(0{,}6\,.\,0{,}09)^2 + 0{,}14^2} = 0{,}15; \tag{31}$$

Safety factor:

$$\bar{n}_H = \frac{\sigma_{Hlim}}{\sigma_H} = \frac{306}{20{,}3148} = 15{,}0629 \tag{32}$$

Quantile of normal distribution:

$$u_P = \frac{\bar{n}_F - 1}{\sqrt{\bar{n}^2{}_F . v^2{}_{Flim} + v^2{}_{\alpha F}}} = -\frac{15{,}0629 - 1}{\sqrt{15{,}0629^2 \ . \ 0{,}15^2 + 0{,}12^2}} = -6{,}215318432323697 \quad (33)$$

The quantile corresponds to the probability of failure-free operation P(t)=0.999999 [27], therefore, it is possible to exclude the damage of the gear due to bending stress.

4.0 ANALYSIS OF THE OPERATING CONDITIONS OF UA-51

This analysis was aimed at checking the dimensions of the broken gear to ensure they correspond to the geometrical measurements in the drawings. The mechanical properties of the material used in the fabrication of the UA-51 were also examined [28]. In respect of the measurements, the engagement diameter was found to be d = 17 mm, the crown width, b = 5 mm. Deviations of the specified parameters from the drawing did not exceed the specified tolerances. The surface cleanliness corresponded to what obtains in the drawings.

Hardness tests were used to determine the mechanical properties of the material, and the results indicated that the gear has a value of HB = 170 MPa, which is in line with the design parameters [29]. Consequently, the manufacturing conditions of the gear could not lead to its failure [30].

Based on the analysis therefore, we can conclude that the reason for the failure may be a violation of maintenance procedures.

5.0 RESULTS AND DISCUSSION

As a result of this study, it was found that the cause of the failure of the anti-skid brake was due to the violation of operating conditions (non-compliance to maintenance procedure when replacing a wheel). It follows that, when installing a wheel without preliminary removal of the anti-skid brake, the drive gear of the UA-51 may engage the wheel gear which may lead to eventual damage on the drive train of the UA-51 gears.

Therefore, it is imperative to closely adhere to the technological processes for replacing wheels in order to prevent failures. It can also be necessary to remove the anti-skid brake UA-51 before disassembling side wheels, and to wait to replace the UA-51 until after the wheel has been mounted. Strict adherence to the technical procedure of maintaining the antiskid brake system will improve its performance and significantly reduce incidences of failure.

The findings in this work finds conformity with the theory of obtaining or ensuring maintenance optimisation, to which, if a particular component is having a low Mean Time Between Failures (MTBF), the root cause of the failure may need to be investigated so as to mitigate its impact. When combined with other maintenance techniques, such as failure codes and root cause analysis, and extra maintenance metrics, such as Mean Time To Repair (MTR), it will assist airline operators in preventing expensive malfunctions, enhancing the effectiveness of flight operations, and guaranteeing aviation safety.

6.0 CONCLUSION

The cause of the frequent failure of the anti-skid brake was found to be due to negligence of the technicians in adhering to the maintenance procedures of the anti-skid brake system. Following this discovery, it is recommended that Aircraft maintenance engineers and technicians should strictly adhere to the technical procedures of maintaining the antiskid brake system in order to improve its performance and significantly reduce incidences of failure. The technical procedures should be properly documented in the maintenance manual by the maintenance team. And each practical step should be judiciously followed and ticked upon completion. These procedures are being implemented by the maintenance engineers of the C-130 Hercules belonging to the Nigerian Air Force.

Human factors and organisational policies are potential barriers to the adoption of the technical procedures for this type of maintenance therefore, the technicians should be properly trained on how to carry out the operations. And the maintenance operations should be carried out under strict supervision of an engineer without any form of compromise.

A recommended area of research is on the design of the landing gear in such a way that the side wheels can be safely dismantled without the removal of the anti-skid brake. This will significantly reduce some of the errors that occur during maintenance.

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