

OPERATIONAL IMPACTS OF ENGINE REMOVAL AND REPLACEMENT ON KEY PERFORMANCE INDICATORS IN AL-31FP ENGINES OF THE SUKHOI SU-30MKM

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ABSTRACT

The Sukhoi Su-30MKM, a high-performance fighter jet utilized by the Royal Malaysian Air Force (RMAF), relies on two AL-31FP engines for its mission-critical operations. One of the primary threats to these engines during flight is bird strikes, which can inflict severe damage on key components such as the rotor blades, leading to engine deficiencies or, in some cases, complete failure. This study documents the systematic process of removing and installing an AL-31FP engine after a bird strike compromised its performance. The engine replacement was executed in full compliance with the Aircraft Maintenance Manual (AMM) and RMAF protocols, ensuring procedural accuracy, safety, and efficiency. The process encompassed several key phases: preparation, tool selection, damage assessment via endoscopy, and post-replacement performance testing. Three key performance indicators were monitored: low-pressure rotor speed (N_1), high-pressure rotor speed (N_2), and maximum vibration level (VIB_{max}). Post-installation performance data showed a marked improvement in key engine parameters, with N_1 increasing from 76.4% to 92.5%, and N_2 from 79% to 92%, both now operating within the designated tolerance limits. Additionally, VIB_{max} decreased significantly from 70.21 mm/sec to 30.12 mm/sec, well within the acceptable safety threshold of 50 mm/sec. This study, focused on training mode, highlights the importance of structured maintenance practices and precise parameter monitoring in restoring engine functionality and ensuring operational readiness, providing valuable insights for aviation maintenance in military contexts.

Keywords: Sukhoi Su-30MKM, AL-31FP engine, bird strikes, rotor blade damage, aircraft maintenance

1. INTRODUCTION

The Sukhoi Su-30MKM, a multi-role fighter jet, is a critical asset to the RMAF. It is powered by two AL-31FP engines, which provide the aircraft with the agility, power, and manoeuvrability needed for high-performance missions in combat and strategic operations [1]. These engines, originally designed by the Russian-based company Lyulka, are Saturn AL-31FP turbofan engines with a twin-spool axial flow compressor, capable of generating 12,500 kgf of thrust at full reheat, with each engine weighing 1,570 kg. As an advanced version of the AL-31F, featuring thrust vector control, the engine's high-thrust performance is essential to the aircraft's capability, and it features

advanced technologies such as variable low-pressure compressor guide vanes and high-pressure compressor stator blades, which regulate airflow to maintain efficiency across various engine ratings [2,3].

The AL-31FP is also equipped with a swivelling thrust vectoring nozzle, which enhances the aircraft's manoeuvrability by allowing thrust direction changes of up to 14 degrees. Its by-pass ratio of 0.57:1 and multi-mode swivelling exhaust nozzle contribute to the engine's high performance, making it ideal for combat scenarios where agility and quick response times are paramount. The engine's control and monitoring systems, managed by the electronic controller, ensure that operational parameters remain within safe limits, further optimizing performance. Additionally, a special mode of operation allows for an increase in thrust by 6-8%, which is particularly useful during high-stress combat operations [2,3].

The performance of the AL-31FP engine is monitored through three key indicators: N_1 , N_2 , and VIB_{max} . N_1 and N_2 are critical in maintaining airflow efficiency and fuel optimization, directly influencing thrust generation and overall engine performance. Meanwhile, VIB_{max} measures the level of vibration, a key indicator of mechanical stress and potential component misalignment or failure. Excessive vibration can lead to premature wear of engine components, posing risks to long-term reliability. Additionally, the engine operates in three modes: training, combat, and special mode. Training mode is designed to reduce operational strain and prolong engine lifespan, while combat and special modes are optimized for peak performance, with the latter offering maximum thrust but higher stress levels [2,3].

Despite these sophisticated features, the AL-31FP engine remains susceptible to external hazards, particularly bird strikes. Bird strikes are a frequent and significant issue in both civilian and military aviation, especially during low-altitude operations such as take-off and landing. In the case of military aircraft like the Su-30MKM, where engine performance is mission-critical, the risk of rotor blade damage from bird strikes poses serious operational challenges [4]. The rotor blades, essential for maintaining air compression and efficient combustion, are vulnerable to deformation or cracking from high-speed impacts with birds. According to the Civil Aviation Authority of Malaysia (CAAM), there were 117 reported bird strike incidents across various Malaysian airports in 2022, with engine damage accounting for a substantial portion of the associated repair costs [5]. Figure 1 (A) shows the removal of the AL-31FP engine, and (B) shows the rotor blade damages, marked with an X for the Su-30MKM fighter.



Figure 1: (a) AL-31FP engine removal and (b) Rotor blade damages for Su-30MKM fighter

Rotor blade damage can have severe consequences for engine performance. Even minor deformations, such as dents exceeding 2mm or cracks longer than 5mm, require immediate attention, as shown in Figure 1. Damage to the blade's leading edge can disrupt airflow through the engine, reducing its ability to compress air efficiently. This can lead to a decrease in engine thrust, increased fuel consumption, and, in more severe cases, a potential engine stall [2, 3]. For the Su-30MKM, which relies heavily on its engines for combat readiness, timely maintenance is crucial to avoid extended downtime and ensure the aircraft remains operational.

This study focuses on the the AL-31FP engine's performance and recovery in Su-30MKM under training mode, where maintaining efficiency with minimal mechanical wear is prioritized. The aim of this study is to provide aviation technicians with a detailed understanding of the engine removal and replacement process while emphasizing the importance of adhering to maintenance protocols to minimize aircraft downtime and restore the Su-30MKM's full operational capability.

2. PROBLEM STATEMENT

Military aircraft, particularly the Su-30MKM, face operational risks from bird strikes, which frequently result in rotor blade damage beyond field-repairable limits. The Sukhoi Su-30MKM, powered by AL-31FP engines, is particularly susceptible to this hazard during low-altitude operations such as take-off and landing. The AL-31FP engine, a twin-spool axial flow turbojet, is particularly susceptible to such damage due to its complex rotor blade architecture [4,5]. Bird strikes can lead to significant rotor blade deformation or breakage, which negatively impacts engine performance by reducing thrust, increasing fuel consumption, and risking complete engine failure [4,5]. In cases where damage exceeds the limits outlined in the AMM, field repairs are insufficient, necessitating a full engine replacement [6-15]. The problem addressed by this study is the technical and operational challenge of efficiently replacing a damaged AL-31FP engine following a bird strike, ensuring that the aircraft is returned to service with minimal downtime while adhering to strict aviation maintenance protocols. Maintaining mission readiness in military operations, where engine failures can significantly disrupt operational capabilities, is critical.

3. SIGNIFICANCE OF RESEARCH

This research holds significant importance for aviation technicians and military maintenance crews, as it provides a detailed account of the procedures required to safely and effectively replace a severely damaged engine in a high-performance aircraft like the Sukhoi Su-30MKM. By documenting the process of AL-31FP engine removal, installation, and post-installation testing, the study emphasizes the role of adherence to maintenance standards and protocols, which is essential to prevent further damage and ensure the engine's full operational functionality. The findings from this case study contribute valuable insights into minimizing aircraft downtime through efficient engine replacement techniques, enhancing operational readiness in military fleets. Furthermore, the study highlights the importance of coordinated logistics and teamwork, showing how the rapid procurement of replacement parts and the precise execution of maintenance tasks directly contribute to the overall effectiveness of military aviation operations. For aviation technicians, this research underscores the critical role they play in ensuring that high-performance military aircraft are always combat-ready and capable of executing missions without delays due to preventable engine issues.

4. RESEARCH METHODOLOGY

The engine replacement procedure adhered to a systematic and detailed process based on the AMM and RMAF guidelines [2,3]. The methodology was divided into five key phases: (1) preparation and planning, (2) engine removal, (3) engine installation, (4) functional testing and leak detection, and (5) final inspection and task closure.

4.1 Preparation and Planning

The process commenced with the receipt of a task card issued by the Maintenance Controller, confirming that the rotor blades of the AL-31FP engine had sustained damage exceeding the AMM's repairable thresholds. Rotor blade damage beyond 2mm depth for dents or 5mm for cracks requires complete engine replacement. The maintenance team conducted a briefing to allocate tasks, review safety protocols, and ensure that all necessary tools and resources were prepared. Emphasis was placed on ensuring operational continuity and minimizing aircraft downtime during the replacement.

All necessary tools were retrieved from the RMAF Tool Store and inspected for compliance with AMM standards. Key tools included power tools for panel removal, engine trolleys for transport, and calibrated torque wrenches for secure tightening of engine components. Attention to detail in tool preparation ensured that the process would proceed smoothly, without delays caused by equipment failure or missing tools.

4.2 Engine Removal

The engine removal involved several critical steps. The aircraft's fuel and oil lines were safely disconnected to prevent leakage or contamination. Flexible shafts linking the aircraft accessory gearbox (AAGB) and engine accessory gearbox (EAGB) were detached, allowing the damaged engine to be lifted using a crane and transferred to an engine trolley. Exposed connectors and openings were sealed off to prevent contamination from foreign objects.

4.3 Engine Installation

The replacement AL-31FP engine installation necessitated precise alignment and secure fastening to the airframe. Using a crane, the new engine was positioned and aligned with the AAGB and EAGB. Fuel and oil lines were reattached, and all fasteners were torqued according to AMM specifications. Ensuring proper torque values was essential to preventing operational issues during flight.

4.4 Functional Testing and Leak Detection

After installation, functional testing began with a controlled engine start-up. Key performance indicators such as N_1 and N_2 and VIB_{max} were monitored and recorded using flight data recorder. Leak detection tests were performed on all fuel and oil lines to ensure system integrity. Ground crew and cockpit personnel maintained clear communication throughout testing to ensure that any anomalies could be addressed immediately.

4.5 Final Inspection and Task Closure

Final inspection was conducted to verify that all maintenance procedures adhered to AMM and RMAF standards. The work area was inspected for loose tools and potential contaminants to prevent foreign object damage (FOD). Once the inspection was completed, the task card was signed off, and the maintenance actions were documented in the *Sistem Pengurusan Komputer Bersepadu* system for future reference and compliance tracking, ensuring that the aircraft was fully operational and ready for return to service.

5. RESULTS AND DISCUSSION

During a routine training mode operation, the Sukhoi Su-30MKM encountered a bird strike that caused significant damage to the rotor blades of the AL-31FP engine. Training mode is typically employed to reduce engine stress and prolong operational lifespan, but the impact of the bird strike severely compromised the engine's performance. This incident primarily affected the rotor blades responsible for maintaining air compression and thrust generation, necessitating immediate engine removal and replacement. As a result, the AL-31FP engine replacement on the Sukhoi Su-30MKM, necessitated by rotor blade damage from a bird strike, was executed following the guidelines of both the RMAF and AMM [6-15]. The enhanced performance of AL-31FP engines was illustrated in Figure 2 and Figure 3, with N_1 , N_2 , and VIB_{max} as three key indicators to assess the damage and recovery of engine performance. These parameters play a critical role in evaluating the efficiency and safety of the engine during and after maintenance procedures [2,3].

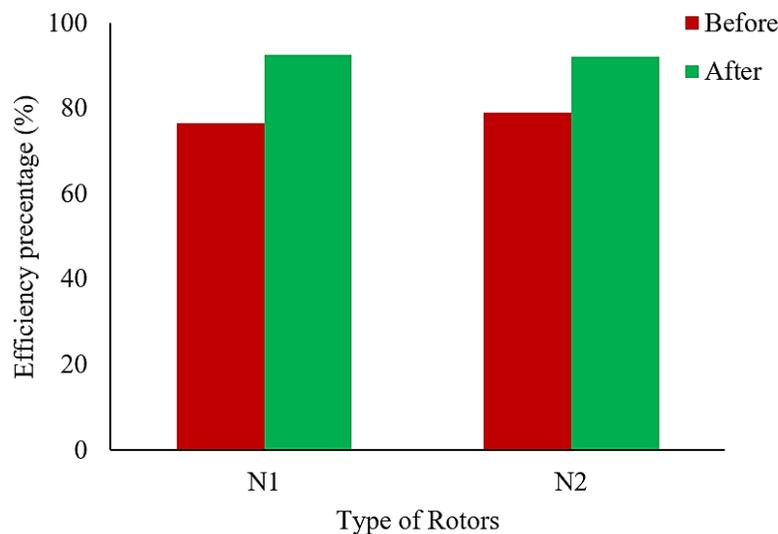


Figure 2: N_1 and N_2 monitoring of the AL-31FP engine in Sukhoi Su-30MKM

As shown in Figure 2, the N_1 rotor blade efficiency before engine replacement was 76.4%, below the operational threshold of 82% to 98.8%. This indicated a reduction in low-pressure air compression, leading to reduced thrust generation and compromised flight performance. After engine replacement, N_1 efficiency improved to 92.5%, well within the acceptable operational range. Similarly, N_2 rotor blade efficiency, which was initially 79%, below the minimum acceptable limit of 84%, improved to 92% post-replacement. These improvements highlight the restoration of both the low- and high-pressure compressors, crucial for maintaining optimal engine performance.

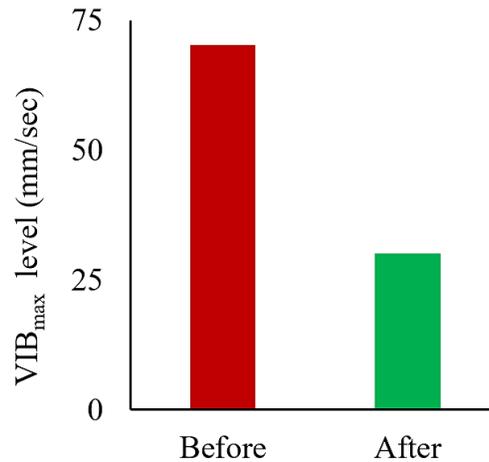


Figure 3: VIB_{max} monitoring of the AL-31FP engine in Sukhoi Su-30MKM

Meanwhile, excessive vibration, such as the 70.21 mm/sec recorded before the engine replacement, poses a significant risk of component wear and eventual failure. VIB_{max}, which measures the maximum vibration level within the engine, is a key indicator of mechanical stress and alignment. Excessive vibration can lead to mechanical stress and eventual failure of engine components. After the engine replacement, as shown in Figure 3, VIB_{max} was reduced to 30.12 mm/sec, well within the safe operational range, ensuring proper alignment of engine components and restoring the engine's mechanical integrity and long-term reliability.

In military aviation, maintaining mission readiness is paramount. When N_1 , N_2 , and VIB_{max} are within their operational ranges, the engine is considered to be in optimal condition, ensuring that the aircraft can be deployed without the risk of performance degradation or unexpected failures. The AL-31FP engine replacement successfully restored the efficiency of key performance indicators N_1 , N_2 , and VIB_{max} within the acceptable range, ensuring that the aircraft could return to full operational status specifically for training purposes. The post-maintenance tests confirmed that the engine met all necessary performance and safety standards, and the reduced vibration levels further validated the integrity of the replacement process. The timely restoration of the aircraft minimized downtime, which is crucial in maintaining operational readiness for military missions[4,5,16]. Ultimately, these numbers are crucial for maintaining the balance between safety, performance, reliability, and operational efficiency in demanding military environments.

6. CONCLUSION AND RECOMMENDATION

The replacement of the AL-31FP engine on the Sukhoi Su-30MKM, after the bird strike damage, successfully restored the engine's performance. Before replacement, N_1 was at 76.4% and N_2 at 79%, both below their operational ranges, leading to reduced air compression and thrust. After the engine replacement, N_1 improved to 92.5% and N_2 to 92%, bringing both values back within optimal performance limits. Additionally, the VIB_{max} recorded at 70.21 mm/sec, well above the safe limit of 50 mm/sec, were reduced to 30.12 mm/sec post-replacement, confirming proper alignment and reducing mechanical stress. These improvements demonstrate that the engine was returned to safe and efficient operating conditions. The successful maintenance ensured that the aircraft could quickly return to operational readiness, highlighting the importance of monitoring N_1 , N_2 , and VIB_{max} to ensure long-term engine reliability and performance. The aircraft's timely restoration was critical in minimizing downtime and ensuring the Sukhoi Su-30MKM's operational readiness for future military missions. By adhering to AMM damage limits, technicians ensure

that the engine's integrity is restored, preventing further performance degradation or potential engine failure. Future efforts should focus on enhancing bird strike prevention systems at airbases to reduce the frequency of such incidents. Moreover, ongoing technician training and improved logistical support for sourcing replacement engines will further enhance the operational readiness of military fleets.

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