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# Failure Mode Analysis and Improvement Strategies for the AW189 Rescue Hoist Electric Motor

Tongbin Zhu, Huojie Gu

East China Sea Air Rescue Service / Ministry of Transport of P.R.C., Shanghai, 200137, China

**ABSTRACT**
This study focuses on the "Goodrich 44316-1-1 hoist" as the research subject, systematically analyzing four major fault modes in its motor system: Burnout of power resistors on the filter board, Fragmentation of rotor magnets in the motor, Fracture of connecting pins on the bridge arm capacitor board and Damage to operational amplifiers, Through in-depth analysis of the failure mechanisms, corresponding technical solutions and preventive measures are proposed.

**KEYWORDS**
Goodrich; Hoist motor; Fault analysis; reliability; Preventive maintenance

## 1 Introduction

### 1.1 Research background

The AW189 rescue hoist, as the core equipment of the helicopter rescue system, plays an irreplaceable role in complex environments such as floods, mountains, and maritime areas. The 44316-1 series rescue hoist system is a core component of the AW189 helicopter's rescue equipment, and its performance is directly related to the success of rescue missions and personnel safety. As the "lifeline" of aerial rescue, the hoist system enables helicopters to overcome terrain limitations and achieve precise lifting operations in various complex scenarios. The AW189 rescue hoist typically features a rated load capacity of 600 pounds and a lifting/lowering speed of 250 feet per minute, ensuring the safe evacuation of casualties and supplies within the golden rescue window (typically under 20 minutes).

### 1.2 Key role of the hoist system in rescue operations

The hoist system, through its precision mechatronic design, provides multiple safety assurances for aerial rescue operations. The overload protection mechanism can withstand sudden impact loads, and the electronic cable-cut function offers a final safety disengagement method when the cable is snagged. These designs significantly reduce the risk of secondary accidents. Modern hoist systems, represented by the Goodrich 44316-1, incorporate multiple safety redundancies, making them irreplaceable core equipment in aerial rescue.

### 1.3 Research significance

As China's maritime rescue missions become increasingly frequent and complex, the reliability requirements for the hoist motor system are also constantly rising. Motor failures can not only lead to the failure of rescue missions but may also endanger the lives of both rescue personnel and those being rescued. Therefore, in-depth research on the fault mechanisms of hoist motors and the development of effective prevention and resolution measures are of significant importance for enhancing aerial rescue capabilities.

## 2 Overview of the hoist motor system

The 44316-1 series rescue hoist motor system primarily consists of core components such as the motor body, control circuit board, filter, capacitor bank, and drive board. These components achieve precise control and reliable operation of the hoist through intricate electrical connections and mechanical coordination.

## 3 Theoretical models and analysis methods

### 3.1 Failure Mode and Effects Analysis (FMEA) theory

Failure Mode and Effects Analysis (FMEA) is a systematic reliability analysis method that employs a bottom-up inductive approach. For the hoist motor system, the FMEA analysis includes the following steps:

(1) Failure Mode Identification: Identify the potential failure modes for each component within the system.

(2) Effects Analysis: Analyze the impact degree of each failure mode on the system's functions.

(3) Risk Assessment: Calculate the Risk Priority Number (RPN) by evaluating the Severity (S), Occurrence (O), and Detection (D) of each failure mode.

(4) Improvement Measures:Formulate preventive and improvement measures targeted at high-risk failure modes.

### 3.2 Fault Tree Analysis (FTA) theory

(1) Fault Tree Analysis (FTA) is a deductive failure analysis method that starts from a top-level undesired event and analyzes the system to identify all plausible causes of that event. The basic elements of FTA include:

(2) Top Event: Complete failure of the hoist motor system.

(3) Intermediate Events: Subsystem-level faults.

(4) Basic Events: Fundamental component failures.

(5) Logic Gates: Logical relationships such as AND gates and OR gates, which model how basic and intermediate events combine to cause the top event.

Table 1

| Dimension | Criteria | Score | Evaluation Criteria |
|---|---|---|---|
| Severity (S) | Catastrophic Hazard | 9-10 | Loss of control over the motor system, threatening personnel safety. |
| | Critical Hazard | 7-8 | Motor system inoperable, but does not threaten personnel safety. |
| | Moderate Hazard | 4-6 | Motor system malfunction, affecting normal lifting operations. |
| | Minor Hazard | 2-3 | Motor system malfunction, but does not affect normal lifting operations. |
| | Negligible Hazard | 1 | Motor system malfunction, only indicators are abnormal. |
| Occurrence (O) | Very High | 9-10 | Statistically, the number of failure occurrences exceeds 15. |
| | High | 7-8 | Statistically, the number of failure occurrences is between 10-15. |
| | Moderate | 4-6 | Statistically, the number of failure occurrences is between 5-10. |
| | Low | 2-3 | Statistically, the number of failure occurrences is below 5. |
| | Remote | 1 | Statistically, the number of failure occurrences is zero. |
| Detection (D) | Undetectable | 7-10 | Failures are not identified during line maintenance, base maintenance, or overhaul checks. |
| | Very Low Chance | 5-6 | Failures are detected during overhaul checks. |
| | Moderate Chance | 2-4 | Failures are detected during base maintenance. |
| | Very High Chance | 1 | Failures are detected during line maintenance. |

### 3.3 Failure Mode Effects and Criticality Analysis (FMECA)

FMECA is an extension of the Failure Mode and Effects Analysis (FMEA), incorporating Criticality Analysis (CA) on the basis of the failure mode and effects examination. It conducts a quantitative assessment of the criticality level of each failure mode, thereby providing a scientific basis for maintenance decision-making.

### 3.4 Weibull distribution mode

The Weibull distribution stands as one of the most crucial life distribution models in reliability engineering, particularly applicable to wear-out failure modes in electromechanical products like hoist motor systems. Its probability density function is expressed as follows:

$f(t) = (\beta/\eta) \times (t/\eta)^{(\beta-1)} \times \exp[-(t/\eta)^\beta]$

thereinto：

· $\beta$：the shape parameter , which determines the shape of the distribution curve and indicates the failure rate characteristic.

· $\eta$：the scale parameter , also known as the characteristic life, representing the time at which approximately 63.2% of the population is expected to have failed

· t：represents time (or the number of cycles, distance, etc.).

The Weibull distribution effectively describes the failure characteristics of a hoist motor system across different stages of its life, which can be interpreted through the value of the shape parameter ($\beta$) as follows :

· $\beta < 1$：Early failure period (decreasing failure rate)

· $\beta = 1$：Random failure period (constant failure rate)

· $\beta > 1$：Wear-out failure period (increasing failure rate)

## 4 Analysis of main fault types

Based on the theoretical framework of FMEA (Failure Mode and Effects Analysis), a fault mode identification and analysis system has been established through long-term observation and data collection of the AW189 rescue hoist motor system. System failures are primarily manifested as the hoist's failure to operate, and the root causes can be categorized into the following four main types：

Table 2

| Failure mode | Failure Cause | Failure Effect | S | O | D | RPN | Physics-of-Failure Model | Key Improvement Point |
|---|---|---|---|---|---|---|---|---|
| Filter Board Power Resistor Burnout | Abnormal Power Supply Voltage | Hoist Fails to Start | 8 | 6 | 4 | 192 | Joule heating accumulation ($P=\Delta V^2/R$) → Resistor carbonization (>220°C) → PCB ablation | Add TVS transient voltage suppressor (36V/1500W) |
| Motor Rotor Magnet Fragmentation | Vibration >5 Grms + Magnet Porosity >0.1% | Hall Signal Loss / Motor Stall | 9 | 4 | 6 | 216 | Alternating stress → Micro-crack propagation → Cleavage fracture of NdFeB magnet → Air-gap magnetic field distortion (Br <1.2T) | Magnet vacuum impregnation with epoxy resin + Silicone buffer layer |
| Connector Pin Fracture | Temperature Cycling ΔT >110°C + Salt Spray Corrosion | Signal Interruption, Controller No Response | 7 | 7 | 5 | 245 | Stress corrosion cracking of pin (φ0.8mm) → Micro-cracks → Increased contact resistance → Local fusing | Gold-plated copper alloy pin + Potting reinforcement (MIL-STD-810H) |
| Operational Amplifier Damage | Supply Overvoltage >36V or Insulating Varnish Coating Missed | Current Loop control, Motor Jitters | 8 | 5 | 4 | 160 | Gate breakdown (Vds >55V) → AD8676 chip burnout → Control signal distortion (THD >25%) | Op-amp power supply voltage limiting circuit |

## 5 Analysis of four specific fault types

Through an in-depth analysis of four typical faults—filter board power resistor burnout, motor rotor magnet fragmentation, connector pin fracture, and operational amplifier damage—system-level weaknesses can be identified, enabling the formulation of corresponding improvement measures.

### 5.1 Filter board power resistor burnout

#### 5.1.1 Fault phenomenon

Filter board power resistor burnout is a relatively common failure in hoist motor systems. This resistor is primarily installed on the circuit board at the end of the filter, serving the critical functions of voltage filtering and overvoltage protection.

#### 5.1.2 Fault mechanism

The root cause of resistor burnout lies in abnormal power supply voltage. When the supply voltage exceeds the designed peak voltage threshold or exhibits instability, the protective resistor on the filter board automatically conducts to protect the downstream circuits. However, if the abnormal voltage persists for too long, the prolonged conduction of the protective resistor generates excessive heat, ultimately leading to its burnout and failure.

#### 5.1.3 Influencing factors

· Unstable onboard power system
· Poor quality of ground power supply
· Aging electrical wiring or poor connections
· High ambient temperature affecting heat dissipation

### 5.2 Motor rotor magnet fragmentation

#### 5.2.1 Fault phenomenon

When the motor rotor magnet fragments, it directly affects the normal operation of the Hall sensor, leading to Hall signal loss. This fault typically manifests as hoist power-on self-test failure, motor inability to start, or abnormal operation.

#### 5.2.2 Fault mechanism

Rotor magnet fragmentation is a mechanical failure with a complex mechanism. The inherent brittleness of the magnet material makes it prone to crack formation under impact, vibration, or stress concentration, which can develop into complete fracture.

#### 5.2.3 Influencing factors

· Material defects: Internal bubbles, impurities, or crystal defects within the magnet material

· Improper processing technology: Internal stresses generated during the magnet processing that are not effectively relieved

· Stress concentration: Localized stress concentration arising from the assembly process

· Mechanical vibration: Continuous vibrational loads during helicopter flight

### 5.3 Bridge arm capacitor board and drive board connector pin fracture

#### 5.3.1 Fault phenomenon

This is a relatively common fault type in the Goodrich electric hoist system. Fracture of the connector pins interrupts the electrical connection between the capacitor board and the drive board, preventing the drive board from receiving normal control signals and ultimately causing the hoist motor to fail operating normally.

#### 5.3.2 Fault mechanism

The connector pin, being a critical component for electrical connection, has relatively weak mechanical strength. In the complex aviation environment, the pin is susceptible to various adverse factors leading to fracture.

#### 5.3.3 Influencing factors

· Temperature cycling: Alternating high and low temperatures leading to material fatigue

· Mechanical vibration: Continuous vibration loads causing pin fatigue fracture

· Corrosive effects: Moisture and salt spray environments accelerating pin corrosion

· Assembly stress: Improper assembly methods generating additional stress

### 5.4 Capacitor board operational amplifier damage

#### 5.4.1 Fault phenomenon

The operational amplifier is a key electronic component on the capacitor board, responsible for signal amplification and processing functions. Damage to the operational amplifier affects the normal operation of the entire control loop.

#### 5.4.2 Fault mechanism

Operational amplifier damage is typically caused by an excessively high supply voltage. When the supply voltage exceeds the operational amplifier's rated working voltage, it causes breakdown of the internal transistors, resulting in irreversible damage.

#### 5.4.3 Influencing factors

· Supply voltage exceeding the design range

· Poor quality of protective coating (insulating varnish)

· Excessively high ambient temperature

· Electromagnetic interference

## 6 Technology-based solutions rooted in reliability theory

### 6.1 Risk control strategy based on FMECA

Based on the FMECA results, control strategies are prioritized according to the RPN values:

(1) High-Risk Failure Modes (RPN > 200)

Connector Pin Fracture: Enhance equipment sealing and conduct regular inspections.

Motor Rotor Magnet Fragmentation: Improve material processes and add buffer designs.

(2) Medium-Risk Failure Modes (RPN 150-200)

Filter Board Power Resistor Burnout: Install overvoltage protection and monitor power supply quality.

Operational Amplifier Damage: Improve heat dissipation design and use high-reliability components.

### 6.2 Maintenance strategy based on the weibull model

Based on the Weibull distribution analysis, differentiated maintenance strategies are formulated:

(1) Components with Early-Life Failure Characteristics ($\beta < 1$)

Filter Board Power Resistors: Strengthen incoming inspection.

Maintenance Cycle: Include them in the hoist's regular inspection items.

(2) Components with Random Failure Characteristics ($\beta \approx 1$)

Operational Amplifiers: Focus on condition monitoring; replace upon failure.

Maintenance Cycle: Perform functional tests when the hoist is returned to the depot; maintain as needed.

(3) Components with Wear-Out Failure Characteristics (β > 1)
Connector Pins, Rotor Magnets: Implement preventive replacement.
Maintenance Cycle: Replace when 80% of the characteristic life is reached.

## 7 Implementation solutions

### 7.1 Maintenance organizations

Maintenance organizations must strictly control repair quality during the process to ensure the reliability of all electrical connections. Simultaneously, they are required to implement all necessary protective measures, including:

(1) Using high-quality soldering materials and processes to increase the safety margin of key components；
(2) Strictly adhering to technical specifications during assembly；
(3) Performing necessary protective coating treatments；
(4) Enhancing spare parts management by establishing a scientific spare parts management system.

### 7.2 Aircraft maintenance preventive measures

(1) Inspect ground equipment for safety: for example, check the power supply quality of ground power units；
(2) Perform thorough airframe inspections to avoid derivative faults: for example, conduct regular airframe vibration checks, onboard power supply pressure checks, and airframe circuit inspections.
(3) Conduct post-flight logistics work effectively: for example, enhance post-flight salt spray treatment and perform anti-corrosion treatment on corresponding components.

### 7.3 Operational notes for hoist operators

(1) Control the continuous operating time of the hoist to avoid motor overheating；
(2) Maintain smooth and controlled operation during hoist use, avoiding abrupt stops；

## 8 Conclusions and outlook

Through in-depth analysis of AW189 rescue hoist motor failures and the application of reliability theory, the following main conclusions are drawn:

(1) Effectiveness of Theoretical Models: Reliability theories such as FMEA, FTA, the Weibull distribution, and Markov models can effectively guide failure analysis and maintenance decision-making for hoist motors.

(2) Systematic Nature of Failure Mechanisms: The four main failure modes of the hoist motor system have specific mechanisms and influencing factors. RPN analysis determined the risk priority, with connector pin fracture being the highest-risk failure mode.

(3) Differentiated Maintenance Strategies: Based on the different failure characteristics identified by Weibull analysis, differentiated maintenance strategies should be adopted. Focus on strengthening quality control for early-life failure components and implement preventive replacement for wear-out failure components.

(4) Dynamic Nature of Condition Management: The Markov model provides a theoretical basis for dynamic condition management, allowing for timely adjustments to maintenance strategies based on system state changes.

By implementing these measures, the reliability and safety of the AW189 rescue hoist system can be effectively enhanced, providing strong support for the development of aerial rescue operations.

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