Jurnal Teknologi Kedirgantaraan (JTK)
Vol. 11, No. 1, February 2026, page. 100 – 106
ISSN: 2528-2778 (Print); 2684-9704 (Online)
https://doi.org/10.35894/jtk.v11i1.347

JTK
Jurnal Teknologi Kedirgantaraan
(Journal of Aeronautical Engineering)

Reliability Analysis of Autoflight Servo System Failures: A Case Study of the Airbus A330-300 at International Airline X

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Article Info

Article History:
Submitted: August 22, 2025
Revised: December 25, 2025
Accepted: February 25, 2026

Keywords:
Reliability, Auto flight Servo, failure, Airbus A330-300, Risk Priority Number

ABSTRACT

The autoflight servo system plays a critical role in maintaining aircraft stability during automated flight operations, where sustained manual control by the pilot is impractical. Due to its integration with multiple aircraft systems, servo failures may propagate and affect overall flight control performance. This study investigates the failure characteristics, root causes, and mitigation strategies of the autoflight servo system in the Airbus A330-300 operated by International Airline X. A descriptive quantitative approach was adopted using a case study methodology. Primary data were obtained from maintenance records, technical documentation, and interviews with relevant personnel, while secondary data included historical failure reports and repair procedures. Risk Priority Number and fishbone diagram was employed to identify dominant failure mechanisms. The results indicate that failures were primarily electrical (27.91%), followed by mechanical (20.93%), hydraulic (17.44%), and human error (6.98%). Electrical failures represent the highest risk category. In response to servo failure, the system automatically transitions to Secondary Flight Control Computer (SEC) or alternate law mode, allowing pilot control via sidestick input. Preventive measures include periodic connector cleaning (1–2 years) and actuator seal monitoring through hydraulic oil particle analysis to detect early wear.

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INTRODUCTION

Air transportation is a service provided by airlines, whose primary activity is transportation from one location to another, supported by airport infrastructure. To ensure the airworthiness of an aircraft, proper maintenance is essential [1]. If any component of an aircraft is damaged, the damage will result not only in the loss of the damaged component but also in the aircraft itself, the lives of passengers, flight crew, cargo, and various other losses. Almost all components must be maintained in good condition to prevent accidents, including servos, which are used for flight control on aircraft [2].

Servos are cylinders with pistons inside that convert fluid energy into work and create the power needed to move the aircraft's systems or flight controls. The servo's role during autoflight is crucial, as the pilot would be unable to maintain aircraft stability for extended periods [3]. With this autoflight system, the pilot and co-pilot's workload can be reduced, as the pilot only directly controls the aircraft during takeoff and landing. During flight, the pilot and co-pilot only monitor various instruments in the cockpit to anticipate system failures [4].

The Airbus A330 is a medium- to long-range, large-capacity, wide-body, twin-engine commercial jet aircraft. This modern, wide-body aircraft is equipped with an advanced fly-by-wire autopilot system that relies on a Flight Control Unit (FCU), Flight Management and Guidance Computer (FMGC), and dual autopilots (AP1 and AP2). In recent years, there has been an increase in reports of damage to autoflight servo components in several airlines, directly impacting safety, flight comfort, and operational efficiency. This phenomenon is increasingly relevant with the Airworthiness Directive (AD) AD/A330/16 issued by the Australian Civil Aviation Safety Authority (CASA) published on April 4, 2003 and came into effect on May 15, 2003.

Although previous studies have discussed general autopilot and flight control failures, limited research specifically investigates the dominant failure mechanisms of autoflight servo systems at the operational maintenance level using structured engineering diagnostics. This gap creates uncertainty in identifying the most critical contributing factors and establishing targeted preventive strategies.

Based on preliminary observations, this study hypothesizes that electrical subsystem degradation represents the dominant root cause of autoflight servo failures compared to mechanical, hydraulic, or human factors. Therefore, the objective of this research is to (1) identify and classify autoflight servo failure modes, (2) determine their root causes using Risk Priority Number and Fishbone diagram, and (3) propose preventive and mitigation strategies to enhance system reliability and reduce operational disruptions.The Fishbone diagram method is employed as a systematic analytical framework to trace failure events from symptoms to underlying causes by examining technical, human, and operational factors. Through structured data collection from maintenance records, operational documentation, and interviews, this study aims to provide an engineering-based foundation for improving autoflight servo reliability in the Airbus A330-300 fleet.

METHODS

The next stage was developing a design related to the problems discussed. This research used descriptive quantitative research with MTBUR parameter, risk priority number data analysis, and fishbone diagram. The data types in this study use primary data sourced from related documents such as the Aircraft Maintenance Manual (AMM), Illustrated Part Catalog (IPC), Troubleshoot Manual (TSM), Company Maintenance Manual (CMM) and Pilot Operating Handbook (POH) and the results of interviews with engineers, senior engineers and inspectors regarding problems that occur, maintenance determination, planning and failure management. Secondary data in this study comes from the results of direct observations in the field.

After the research method design was developed, data collection proceeded. Field data collection was conducted in stages, starting with primary and then secondary data. Data collection was then verified against research needs. If the collected data was insufficient, re-collection was conducted with adjustments to the research method. After all data was collected, MTBUR parameter calculate for reliability analysis, determine RPN, and using a fishbone diagram approach for root cause analysis. The results of the analysis were discussed using relevant literature. Based on data analysis, conclusions and recommendations were drawn that align with the research. The three main parameters used were Severity (S), or the severity of the failure impact; Occurrence (O), or the frequency of failure occurrence; and Detection (D), or the ability to detect the failure before it has an impact. The value of Severity and

Detection based on criteria in **Table 1**. Number of events in three months operation is Occurrence number. These three parameters were multiplied to produce a Risk Priority Number (RPN), a risk priority number that serves as the basis for determining corrective or preventive actions. Observations were conducted from April to June 2025.

Table 1. Severity and Detection criteria

Rating	Severity	Detection
1	No malfunction is detected and there is no impact on the system.	Capable of detecting the presence of a problem.
2	A system failure is present, but it remains within specification limits and is acceptable.	Has a very high probability of detecting the existence of a failure.
3	A system failure is present but has no operational impact; it remains within specification limits and is acceptable.	Has high effectiveness in failure detection.
4	A system failure is present, has no operational impact, and does not meet specifications; however, it is still accepted.	Has moderately high effectiveness in detecting failures.
5	A system failure is present and does not meet specifications; it is accepted but requires inspection.	Has moderate detection effectiveness.
6	The failure may affect the system, and partial maintenance can be performed.	Has moderately low detection effectiveness.
7	The failure may affect the system, and complete maintenance is required.	Has low detection effectiveness.
8	A failure has occurred causing the system to become inoperative; however, the aircraft remains airworthy.	Has the lowest effectiveness among the applicable categories.
9	A failure has occurred causing the system to become inoperative, and the aircraft is not airworthy.	Has a very low probability of detecting defects.
10	The system cannot be restored to operational condition.	Almost certainly will not detect defects.

RESULT

Based on the results of the research conducted, a recapitulation of failure data that occurred on the A330-300 aircraft autoflight servo was obtained as follows:

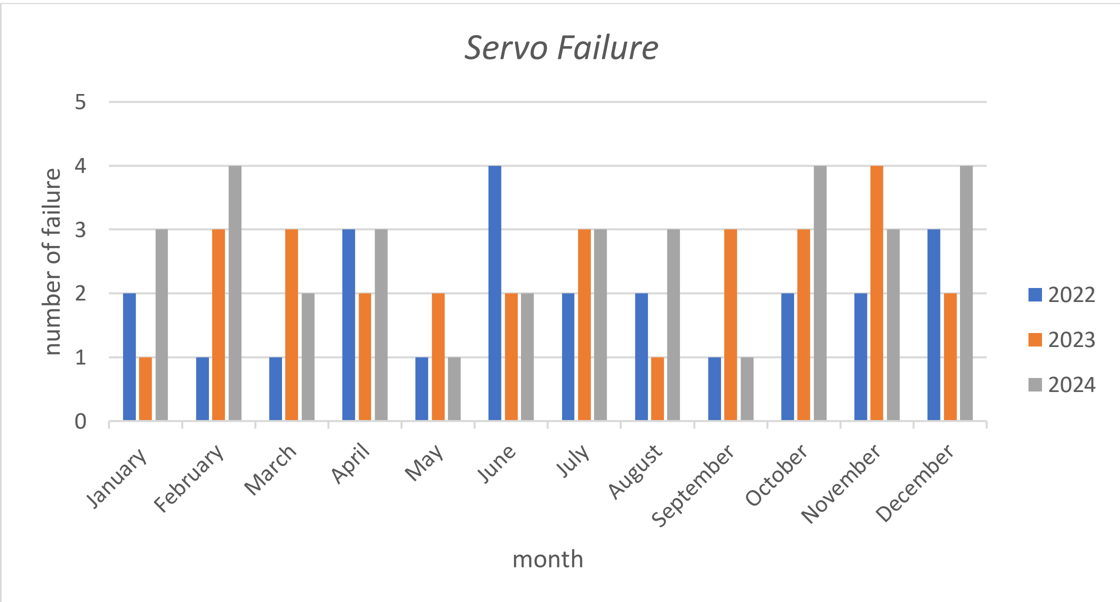

Figure 1 Failure of the Autoflight Servo of an A330-300 Aircraft

The figure explains the failure graph of the A330-300 aircraft autoflight servo at international airline X in each month from 2022 to 2024. The total number of failures in the A330-300 aircraft autoflight servo that occurred in 2022 was 24 incidents, in 2023 it was 29 and in 2024 was 33 incidents with a total of 86 incidents. From 2022 to 2024 there was an average increase in 2-time intervals of 2.21. The increasing problems shown need investigation and root cause analysis. **Table 2** shows that external factor, mechanical failure, and electrical failure as the dominant root causes of autoflight servo problems.

Table 2 Number of Failure on the Autoflight servo A330-300 Aircraft

No	Remark	Total	Percentage (%)
1	*Mechanical failure*	18	20,93
2	*Electrical failure*	24	27,91
3	*Hydraulic system*	15	17,44
4	*Human error*	6	6,98
5	*External factor*	23	26,74

Table 3 presents the total flight hours of the Airbus A330-300 fleet associated with autoflight servo failures at International Airline X. The flight hour data were calculated by summing the daily aircraft utilization and aggregating them across the fleet. A total of 57 autoflight servo component replacements were recorded during the observation period. Of these, 18 replacements occurred in 2022, 20 in 2023, and 19 in 2024.

Table 3 Total Flight Hours of A330-300 Aircraft Utilization

No.	Month	Total *Flight Hours*		
		2022	2023	2024
1	January	2434	2300	2456
2	February	2232	2908	2283
3	March	2393	3033	2820
4	April	2721	3005	2629
5	May	2245	2766	2685
6	June	3027	2643	2214
7	July	2261	2293	2203
8	August	2108	2957	2322
9	September	2259	2967	3005
10	October	3008	3058	2616
11	November	2545	2846	2179
12	December	3029	2766	2628

Based on utilization and failure data, Mean Time Between Unscheduled Removal (MTBUR) could be calculated as total operational time divided by Number of replacements. MTBUR for 2022, 2023, and 2024 are 1681.22 FH, 1677.10 FH, and 1581.05 FH respectively. Decreasing MTBUR value means decreasing reliability in autoflight servo components.

In this study, the cause of failure analysis was conducted using a fishbone diagram approach. Based on data obtained from documentation and interviews, the following diagram was obtained:

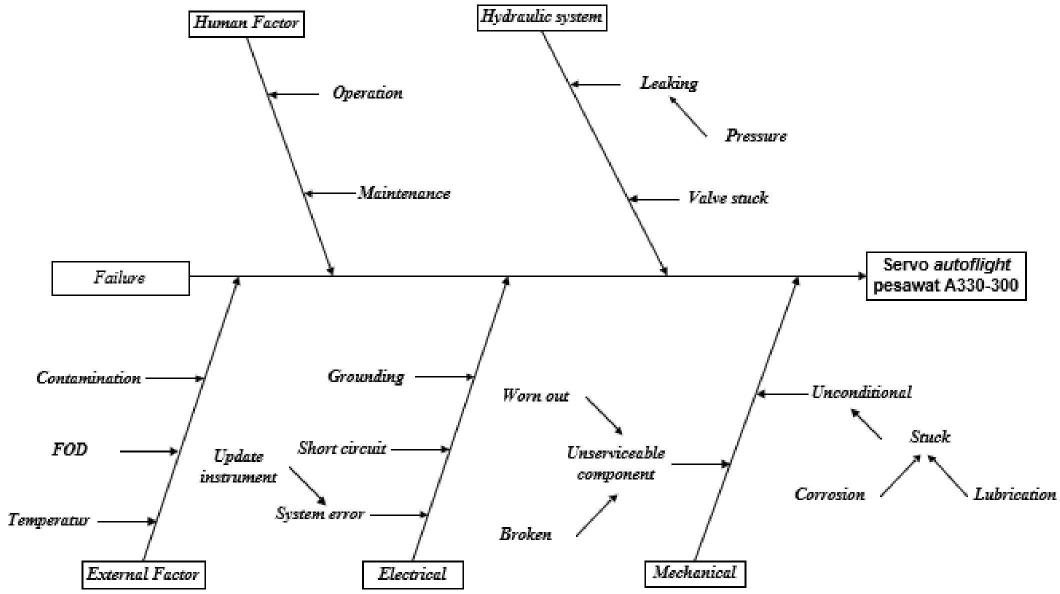

Figure 2 Fishbone Diagram of Failure in the Autoflight Servo of an A330-300 Aircraft

The first section of the diagram explains human factors, which consist of two main subcategories: operation and maintenance. Human errors, both during operation and maintenance, can be a major trigger for system failure. For example, technician inaccuracy in connecting connectors, incorrect component installation, or negligence during inspections can cause signal interference or even direct damage to the servo system. Meanwhile, from an operational perspective, pilot errors can lead to system failure.

The second section is the hydraulic system, which is the primary power source for servo actuators. Hydraulic system failures can be caused by leaks, pressure drops, and stuck valves. These three factors contribute to the decreased performance of aileron actuators, which are highly dependent on stable hydraulic pressure. If pressure is insufficient, the actuator will not be able to produce the required movement, which can disrupt aircraft control.The electrical category mentions cause such as grounding, short circuits, system errors, and instrument update failures. Electrical failures can occur due to poor current connections, signal interference from the flight control computer (FCC/PRIM), or even an unsuccessful system update. Errors in the electrical system can be crucial because they disrupt the transmission of command signals to the servo actuators. These failures include electrical system problems such as broken cables, short circuits, poor grounding, and damage to the LVDT sensor. These problems are often not physically visible, so early detection can only be done through the diagnostic system or alerts on the EICAS (Electronic Centralized Aircraft Monitor).

Mechanical factors describe causes such as worn-out, broken or damaged components, and unserviceable components. These factors are further broken down into unconditional failure, corrosion, stuck components, and lubrication failure. Physical damage to servo components includes worn bearings, jammed linkages, and damaged spool valves. Servo components that are not regularly maintained can experience wear, jamming due to lack of lubrication, or even rust due to exposure to humid environments. This can cause the servo to respond slowly or stop working altogether.

External factors are also an important part of this diagram. These factors represent events that can occur beyond human control. External factors such as fluid contamination, FOD (Foreign Object Damage), temperature changes, or outdated measuring instruments contribute significantly to servo system failure. Fluid contamination, for example, can damage seals and valves, while extreme temperatures can affect fluid viscosity or interfere with the operation of electronic sensors.

Table 4 Summary Results of SOD Values

Failure	Effect	Cause	Control	S	O	D	(RPN)	Total
Mechanical	Control surface is stuck or jammed	Binding or jamming linkage	Visual inspection of linkage, routine lubrication, replacement of worn parts	5.33	6.00	4.67	149.35	398.26
	Vibration and decreased precision of control movements	Bearing wear	Preventive maintenance and bearing wear monitoring	5.33	4.67	4.33	107.78	
	Control surface malfunction	Damage to the control surface structure	Routine inspection of control structures and NDT (Non-Destructive Test)	4.67	5.33	5.67	141.13	
Electrical	Servo position data is inaccurate	Position feedback sensor error (LVDT)	Recalibrate and check LVDT output signal	7.00	3.67	5.00	128.45	374.95
	autoflight system failed to provide correct control commands.	Input/output signals do not match	Electrical Interface System) signal testing and built-in test	4.33	4.00	5.00	86.60	
	Intermittent signal loss, servo does not respond	Damaged wiring harness or loose connector	Periodic connector inspection and cable continuity testing	6.00	5.33	5.00	159.90	
Hydraulic System	Control movements become slow or unresponsive	Low hydraulic pressure	Monitoring of pressure system and pressure switch, inspection of reservoir system	6.00	4.67	5.33	149.35	343.71
	Decreased actuator performance and leakage	Hydraulic fluid contamination	Periodic fluid replacement, filter inspection and flushing system	4.33	5.33	4.33	99.93	
	Actuator overheating, decreased efficiency	Overheating of the hydraulic system	Monitoring hydraulic temperature and heat exchanger function	4.67	4.33	4.67	94.43	
Human Factor	Connection is unstable, actuator failed to receive signal	unlocked connector	Installation supervision, torque and lock checklist, technician cross-check	6.00	5.33	5.00	159.90	341.89
	Servo feedback error, control movement does not match system instructions	imprecise feedback sensor installation,	Technician training and accurate measurements (tooling according to Airbus standards)	5.33	4.67	4.33	107.78	
	The system is tested in an unprepared condition, the risk of control errors	Passed the whole system test	Mandatory final test SOP, use of QRH/MEL and QC audit	4.33	3.67	4.67	74.21	

DISCUSSION

The servo is part of the primary flight control system, which regulates the aircraft's movements. On the Airbus A330-300, this servo is driven using a hydraulic system electronically controlled by the flight computer (PRIM/SEC). When a servo fails, the system is unable to move the flight controls properly, whether controlled automatically (autopilot) or manually.

This failure is highly risky because it has the potential to disrupt aircraft stability, especially when flying in turbulent conditions or during critical maneuvers such as approach and landing. If the servo is unresponsive, input commands from the sidestick or autopilot cannot change the flight control position, which can cause the aircraft to tilt to one side or be unable to return to a level position. This forces the pilot to immediately disengage the autopilot and take over control manually during flight.

In real-world situations, the first indication often appears as a warning on the ECAM system or an imbalance on the Flight Control Synoptic Page, where one flight control does not move or move asymmetrically with the other. This incident generally indicates that the servo actuator is not providing the expected motion output even though the signal input has been sent which leads to the need for in-depth investigation of the servo components and their supporting systems.

CONCLUSIONS

Failures in the A330-300 autoflight servo on the international airline X include mechanical failures of 20.93%, electrical failures of 27.91%, hydraulic system failures of 17.44%, and human error of 6.98%. This means that the highest potential source of failure is electrical failure.

Mitigation of A330-300 autoflight servo failures involves automatically switching to SEC (Secondary Flight Control Computer) or alternate law mode. In manual mode, the pilot can use the sidestick to provide input to the functioning system. Although maneuverability is not as optimal as under normal conditions, the aircraft can still be safely controlled for return-to-base or emergency landings. Recommended maintenance includes cleaning and protection of the connector pins at least once every one to two years. Another aspect to consider is the condition of the actuator seals. Oil analysis can quantitatively detect residual seal wear particles in the hydraulic fluid. This research only using data from one Airline and need to compare with reliability of same component from other airlines.

ACKNOWLEDGMENTS

The author would like to express his sincere gratitude to all parties who have provided support and contributions during the preparation and editing of this journal. He extends his deepest gratitude to his supervisors, lecturers, and colleagues for their guidance, constructive feedback, and valuable encouragement throughout the writing process. Finally, he extends his deepest gratitude for the continued moral support and prayers from his family and other parties not mentioned individually. He hopes this journal will provide significant benefits and make a positive contribution to the advancement of aviation safety.

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