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Fidelity Testing of Avionic Instruments in NAS 332 Super Puma Simulator Using FAA 14 CFR Part 60

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ABSTRAK

Simulation technology is increasingly vital in aviation, enhancing pilot training and reducing risks from human error. This study evaluates the fidelity of the NAS-332 Super Puma Helicopter Full Flight Simulator (FFS) Level-C, focusing on avionic instruments. The assessment aimed to determine how closely the simulator replicates the aircraft's avionic hardware, software, and operational performance. A black-box testing approach was applied in accordance with FAA 14 CFR Part 60 Advisory Circular standards. Avionic subsystems were examined for accuracy in display layouts, response functions, and system integration. Findings show that the simulator achieves a fidelity score of 89%, confirming its reliability in replicating real-world avionics. These findings confirm the simulator's suitability as a regulatory-compliant training tool that supports pilot proficiency and operational readiness. By highlighting avionics fidelity within the broader context of human-computer interaction and workload research, the study extends current simulation literature and contributes to improving the effectiveness of rotorcraft pilot training.

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1. INTRODUCTION

Simulation has become a central component of aviation training, offering pilots the ability to rehearse procedures, practice emergency scenarios, and develop situational awareness in a safe and controlled environment. Over the past two decades, flight simulators have evolved from basic procedural trainers into highly sophisticated systems capable of replicating real-world flight dynamics, cockpit instrumentation, and avionic responses. The effectiveness of these simulators is determined by their fidelity, the degree to which they accurately reproduce the operational characteristics of the actual aircraft. High fidelity is especially critical for rotorcraft, where operational environments are complex and accident risks remain disproportionately high compared to fixed-wing aviation (White & Padfield, 2021).

Rotorcraft operations such as offshore transport, emergency medical services, and search-and-rescue demand rapid decision-making in adverse conditions, making pilot proficiency essential. However, accident analyses consistently show that loss of control in-flight (LOC-I) continues to be a leading cause of helicopter mishaps (White & Padfield, 2021). These findings highlight the necessity of simulators that not only replicate flight dynamics but also provide accurate representations of avionics and system interactions, which are central to supporting realistic training transfer and effective decision-making.

Beyond physical fidelity, human-computer interaction (HCI) and cognitive workload have emerged as crucial dimensions in simulator effectiveness. Studies in neuroergonomics and cognitive science show that simulator performance depends not only on system accuracy but also on how pilots interact with the interface under varying cognitive demands. For instance, Shen et al. (2024) demonstrate that situation awareness–centered interface design can significantly enhance performance and reduce errors, while Hebbar et al. (2023) validate ocular metrics as reliable indicators of pilot workload in VR simulators. Similarly, neuroadaptive training approaches using fNIRS (functional near-infrared spectroscopy) have shown promise in adjusting task difficulty to real-time mental workload, improving learning efficiency (Mark et al., 2022). Recent evaluations of immersive simulators also underscore a trade-off between realism and workload. While VR increases engagement and ecological validity, it can elevate cognitive strain if HCI design is not carefully optimized (van Weelden et al., 2024). This aligns with Carroll and Dahlström's (2021) review of flight-deck HCI, which stresses that poor interface fidelity can compromise decision-making despite high mechanical accuracy.

Skill assessment research further reinforces the importance of workload-sensitive design (Awaludin & Gani, 2024). Eye-tracking studies indicate that gaze behavior can reliably differentiate expert and novice pilots (Harris, 2023), and validation studies of immersive simulators show that cost-effective designs can achieve meaningful training outcomes when workload and HCI factors are accounted for (Taylor et al., 2025). Collectively, these findings extend the concept of fidelity beyond hardware and motion systems toward integrated measures of human performance, cognitive adaptation, and interface usability.

Parallel to these human factors insights, regulatory bodies and research groups have advanced structured fidelity assessment frameworks. The NATO STO AVT-296 Task Group (2021), for instance, introduced systematic methods for quantifying fidelity, combining objective metrics with flight-test validation. Despite such advances, most fidelity studies continue to emphasize motion cueing, visual systems, and cockpit instrumentation, leaving avionics subsystems comparatively underexplored. This gap is significant: navigation, communication, and flight management systems constitute the operational backbone of modern rotorcraft and directly shape pilot workload and decision-making.

To address this gap, the present study evaluates the fidelity of avionic instruments in the NAS-332 Super Puma Full Flight Simulator (Level C). Developed collaboratively by DSL International Projects and Supplies Ltd (UK), PT Dirgantara Indonesia SU Engineering Services, and other partners, the simulator integrates advanced computer systems, avionics, visual displays, imported motion systems, and radar components (DSL, 2010). The Super Puma remains a critical platform in Southeast Asia for offshore oil and gas operations, search-and-rescue missions, and military transport. Ensuring that its simulators replicate avionics hardware, software, and functional behavior with high fidelity is therefore vital to sustaining pilot readiness and operational safety.

The evaluation framework for this study is grounded in the FAA 14 CFR Part 60 standards (FAA 2016), which provide regulatory criteria for simulator qualification. By applying black-box testing methods and comparing simulator outputs against reference aircraft data, the study aims to quantify the fidelity of avionic instruments and determine whether the simulator meets the regulatory thresholds required for effective training (Awaludin et al., 2024). This research seeks to fill that gap by delivering a comprehensive fidelity assessment of the NAS-332 Super Puma simulator's avionic instruments, thereby contributing to both academic understanding and practical improvements in helicopter pilot training. In doing so, this research positions avionics as a critical component of the broader pilot-interface system, bridging human factors considerations with hardware/software fidelity to advance both the science and practice of helicopter simulation training.

2. METHODOLOGY

This study adopted an experimental validation approach complemented by qualitative inputs to evaluate the fidelity of the NAS 332 Super Puma Full Flight Simulator (Level C) in accordance with FAA 14 CFR Part 60. The methodology integrates mathematical fidelity models proposed by Gross and Freeman (Schricker, 2001) and later extended by Liu (2004).

As illustrated in Figure 1 (Research Methodology), the research process consisted of three main stages: (1) authorization and security clearance, (2) data collection, and (3) testing and results phase.

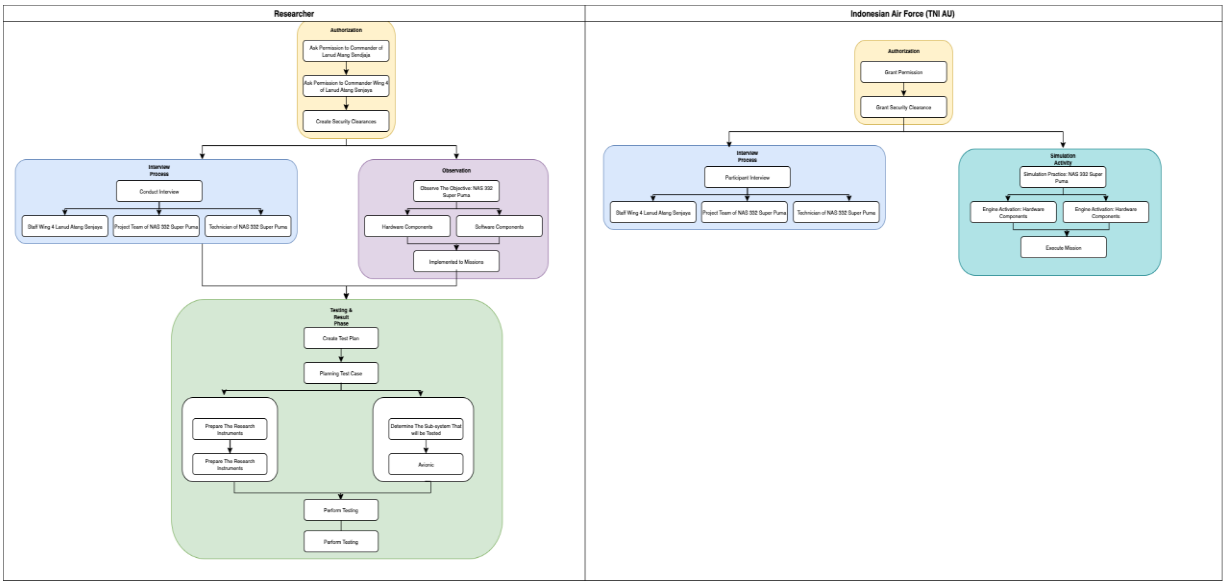

Figure 1. Research Methodology (Process Flow)

2.1. AUTHORIZATION AND SECURITY CLEARANCE

Before data collection, formal approval was obtained from the Commander of Lanud Atang Sendjaja and Wing 4. In addition, the Indonesian Air Force (TNI AU) issued security clearances to ensure that the research complied with institutional and operational protocols.

2.2. DATA COLLECTION PROCEDURE

Two complementary techniques were employed for data collection: interviews and direct observation.

2.2.1. INTERVIEW

Semi-structured interviews were conducted to gather qualitative insights regarding simulator operations and training procedures. Participants were purposively selected based on their expertise and direct involvement with the NAS 332 Super Puma. Three participant categories were included:

1. Staff of Wing 4 Lanud Atang Sendjaja,
2. The project team responsible for the NAS 332 Super Puma program, and
3. Technicians maintain and operate the simulator.

The interviews focused on simulator requirements, operational procedures, and training processes to provide contextual understanding of the system.

2.2.2. OBSERVATION

Direct observation was conducted on the NAS 332 Super Puma simulator to examine both hardware and software components. Special emphasis was placed on avionic subsystems and their integration into simulated mission scenario. The simulated mission was designed to reflect real-world rotorcraft training operations, incorporating standard flight procedures, system checks, and controlled malfunctions. The mission scenario began at Lanud Atang Sendjaja and concluded at Lanud Adi Sucipto, covering approximately 575 km, with specific malfunctions introduced mid-flight. The flow of the mission will be explained on Table 1.

Table 1. Mission NAS 332 Super Puma

No	User	Maneuver / Emergency Procedure	Procedure Detail and Result

1	Staff NAS 332	Engine ON	Staff initiated engine start-up and verified simulator readiness.
2	Instructor	Lesson Plan	Instructor created training plan, set route (Atang Sendjaja → Adi Sucipto, 575 km) and malfunctions.
3	Staff NAS 332	Instructor Operating System (IOS)	IOS staff configured motion, aural, and visual systems. Visual initialized at Atang Sendjaja.
4	Pilot	Start-Up Check	Pilot performed standard pre-flight checks, confirming instrument readiness.
5	Pilot	Taxiing, Hover & Low Work	Normal flight procedure
6	Staff NAS 332	Tail Rotor System Malfunction	IOS staff triggered Tail Rotor Drive Failure during cruise. Visual system displayed uncommanded yaw and vertical rotation.
7	Pilot	Control of Malfunction	Communication and emergency landing

Table 1 provides contextual background on how the simulator was operated during observation, including the roles of staff, instructors, and pilots, as well as the emergency procedures triggered in-flight. This scenario was not only a training simulation but also the framework through which avionic instruments were evaluated. For example, the Tail Rotor Drive Failure introduced in Step 6 allowed observation of the simulator's yaw control instruments and their fidelity under malfunction conditions. Similarly, start-up checks and IOS configurations (Steps 2–4) provided opportunities to validate flight indicators and navigation systems.

Simulator outputs throughout the mission were systematically observed and compared with reference data from the DSL Technical Description (DSL, 2010) and recorded Super Puma flight data simulation. This ensured that the avionic subsystems were assessed under realistic operational demands rather than in isolation.

2.3. TESTING AND RESULT PHASE

A structured test plan was designed in accordance with FAA Part 60 guidelines and fidelity measurement models.

2.3.1. PREPARATION OF INSTRUMENTS

Research instruments were prepared to ensure the systematic recording of simulator outputs in accordance with FAA Part 60 requirements. These instruments enabled consistent documentation and analysis of fidelity results.

To quantify simulator fidelity, this study employed the mathematical model proposed by Gross and Freeman (Schricker, 2001), later refined by Liu (2004). The overall fidelity formulation used in this research is illustrated in Figure 2.

1. The fidelity testing formula can be written as

$$F_s = \sum F_i . W_i$$

2. where F_s are the total fidelity of all the research objectives.
   (a) $F_i = \left\{ \frac{Totalnumberofsuccessfultestcases}{Totalnumberoftestcases} x100\% \right\}$ and
   (b) W_i is the relative weight level of the characteristics test objectives (D. Liu, 2004).

Figure 2. Algorithm Fidelity Formula

After calculating HSSP fidelity, the next step is to assess whether the simulation has outstanding, excellent, ordinary, bad, or very bad fidelity. To determine the fidelity, by comparing the results of the mathematical model with the indicators in the table 3.31. This indicator is based on the Guttman Scale (Garson, 2013). The classification can be seen on table

Table 2. Classification Fidelity

Indicator	Description
0% - 20%	Very Bad Fidelity
21% - 40%	Bad Fidelity
41% - 60%	Ordinary
61% - 80%	Excellent
81% - 100%	Outstanding

2.3.2. SUBSYSTEM DETERMINATION: AVIONIC

The fidelity assessment in this study was focused exclusively on the avionic instruments of the NAS 332 Super Puma simulator. Avionics were selected as the subject of evaluation because they constitute the most critical interface for navigation, situational awareness, and mission execution in rotorcraft operations. A total of 20 key components were examined, encompassing both simulated and real-aircraft instruments. These components are presented in Table 3. The classification of each instrument (simulated or real-aircraft based) along with its specific function is presented in Table 3.

Table 3. Avionic System

No	Instrument Name	Type	Function
1	Airspeed Indicator	Simulated	Measures the helicopter speed relative to the surrounding air.
2	Automatic Direction Finder	Simulated	Provides en-route navigation and holding pattern guidance.
3	Horizon Indicator	Simulated	Provides the pilot with vertical references (pitch and roll attitude), sideslip indication (ball-type level), approach signals from various navigation systems.
4	Horizontal Situation Indicator	Simulated	Displays heading, navigation, and instrument approach information
5	HSI Switching Controls Panels	Real A/C	Selects and displays the respective HSI indications on the pilot's and copilot's side.
6	Standby Gyroscopic Horizon	Simulated	Provides a stable pitch and roll reference in case of emergency.
7	Gyro Control Unit	Real A/C	Controls ON/OFF switching for the CC 130 gyromagnetic compasses and GV 76 vertical gyro platforms.
8	Directional Gyro Control Unit	Simulated	Controls the operating mode of the Directional Gyro.
9	Standby Magnetic Compass	Real A/C	Indicates the aircraft heading.
10	Radio Altitude System Indicator	Simulated	Provides the pilot with an accurate display of helicopter height above ground, regardless of weather conditions.
11	Transponder	Simulated	Enables ATC to identify and locate the helicopter by providing coded responses to radar interrogations.
12	Encoding Altimeter	Simulated	Transmits aircraft altitude to the radar of the attached radar beacon system
13	DME Control Unit	Real A/C	Controls frequency and mode of the DME system, which provides the slant-range distance between the helicopter and a VOR/DME station.
14	DME Indicator	Simulated	Displays distance, groundspeed, time to station, station identifier (2–4 letters), and diagnostic information.
15	VHF NAV Control Unit	Real A/C	Controls frequency and mode of the VHF navigation system, providing bearing to a VOR/DME station.
16	Marker Control Panel	Real A/C	Indicates passage over inner, middle, outer, or fan markers, and allows adjustment of marker sensitivity (High/Low).
17	Global Positioning System	Simulated	Provides positional data (longitude, latitude, altitude) to the NADIR navigation computer.
18	Doppler Radar	Simulated	Supplies speed data relative to the ground along the helicopter's axes.
19	Nadir	Simulated	Allows input of navigation data and monitors calculated parameters on the display.
20	Vertical speed indicator	Simulated	Rate the climb and descent of aircraft

2.3.3. EXECUTION OF TESTING

The avionic subsystem was evaluated using a black-box testing approach, in which simulator outputs were systematically compared against FAA Part 60, referenced research instruments to assess fidelity. Testing commenced after the development of a test plan and corresponding test cases, ensuring a structured and repeatable process. The fidelity assessment aimed to measure how accurately the simulator duplicated the physical characteristics and functional behaviors of the actual aircraft instruments.

Testing activities were performed collaboratively by pilots, co-pilots, flight instructors, and technicians. During the process, the researcher conducted direct observations of the test objects and recorded outcomes in a structured results table. Fidelity testing was carried out on both hardware and software components of the avionic subsystem. A sample of hardware fidelity results for avionic instruments is presented in Table 4.

Table 4. Sample Result of Hardware Fidelity Avionic Instruments

No	Instrument	Test Case	Indicator	Testing Result	Conclusion
1	Airspeed Indicator	Observe the numbers displayed on the Airspeed Indicator.	The Airspeed Indicator must display values from 0 to 220 knots.	The indicator displayed numbers correctly from 0 to 220 knots.	Succeed
2		Observe the components of the Airspeed Indicator.	The replica must be identical to the original, including Vs0, Vs1, and Vno markings.	All three components (Vs0, Vs1, Vno) were present.	Succeed
3	Encoding Altimeter	Observe the components of the Encoding Altimeter (long pointer, index, warning flag, short pointer, window & fixed index, hatched area, and setting knob).	The replica must be identical to the original, with all listed components.	The altimeter was not available.	Failed
4	Encoding Altimeter	Observe the numbers displayed on the Encoding Altimeter.	The number must be identical to the real encoding altimeter which is 0 to 9, 100	No number appears	Failed
5		Observed the number on hatched area	The hatched area must indicate 20,000 ft.	No number appears	Failed

A sample of software fidelity results is presented in Table 5.

Table 5. Sample Result of Software Fidelity Avionic Instruments

No	Instrument	Test Case	Indicator	Testing Result	Conclusion
1	Airspeed Indicator	Observe the numbers displayed on the Airspeed Indicator.	Observe the numbers displayed on the Airspeed Indicator.	The indicator displayed values correctly from 0 to 220 knots.	Succeed
2		Observe the numbers indicated by the long pointer.	The altimeter must display values corresponding to the long pointer (0–9, where 1 = 100 feet).	The long pointer displayed values correctly from 0 to 9.	Succeed
3	Encoding Altimeter	Observe the numbers indicated by the index pointer.	The index must be capable of selecting values in tens of feet.	Encoding was not available	Failed
4		Verify the function of the warning flag.	The altimeter must indicate instrument malfunctions and invalid signal outputs.	Encoding was not available	Failed
5		Observe the numbers displayed in the hatched area.	The hatched area must display values from 0 to 16,000 ft.	Encoding was not available	Failed

Following test execution, the next step was to analyze and quantify fidelity results. Prior to interpretation, the fidelity score for each instrument was calculated using the following formulation (Gross & Freeman, 2001; Liu, 2004):

$$Fi = \frac{Total\ number\ of\ successful\ test\ case}{Total\ number\ of\ test\ case}\ x\ 100\%$$

Where Fi denotes the fidelity score of the instrument. To account for the relative importance of hardware and software fidelity, weighting factors (W_i) were applied:

a. Hardware fidelity of avionic instruments: 0.5 (50%)
b. Software fidelity of avionic instruments: 0.5 (50%)

The overall subsystem fidelity (Fs) was then calculated as:

$$Fs = \Sigma(Fi \; x \; Wi)$$

This weighting approach reflects the principle that both hardware and software are equally critical in ensuring the realism and effectiveness of the NAS 332 Super Puma simulator.

3. RESULT

3.1. HARDWARE FIDELITY OF AVIONIC INSTRUMENTS

A total of 25 avionic hardware instrument test cases were conducted on the NAS 332 Super Puma simulator in compliance with FAA 14 CFR Part 60 requirements. Of these, 22 test cases (88%) passed the fidelity evaluation, while 3 test cases (12%) failed. The fidelity index was calculated as:

$$Fi = \frac{22}{25} \; x \; 100\% = 88\%.$$

The weighted hardware fidelity score was then computed as:

$$Fs = (\frac{22}{25} \; x \; 100\%) x 0.5 = 44\%$$

Figure 3 illustrates the overall distribution of successful versus failed test cases, while Figure 4 provides a detailed breakdown by instrument.

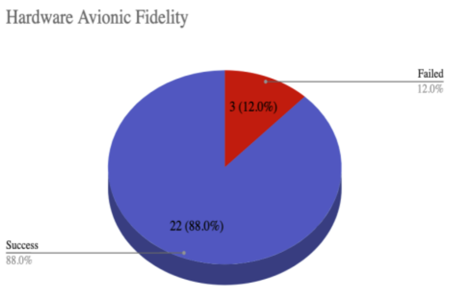

Figure 3. General Result of Hardware Instruments

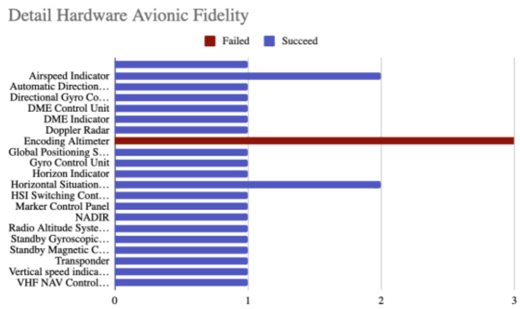

Figure 4. Detail Result of Hardware Instruments

Most hardware instruments, including the Horizontal Situation Indicator (HSI), Automatic Direction Finder (ADF), and Global Positioning System (GPS), performed consistently within the expected operational parameters. However, the Encoding Altimeter failed all 3/3 test cases, primarily due to the unit being inoperative at the time of testing. At the time of testing, the Encoding Altimeter unit itself was inoperative, which directly contributed to the failed outcomes. As this instrument is critical for altitude management across climb, cruise, and approach phases, its failure highlights how deficiencies in a single subsystem can disproportionately affect training fidelity and pilot readiness. Addressing this issue, through hardware repair, recalibration, or software validation, is therefore essential for ensuring that the simulator meets the fidelity standards required for high-stakes rotorcraft training.

3.2. SOFTWARE FIDELITY OF AVIONIC INSTRUMENTS

In addition to hardware testing, a total of 110 test cases were conducted across 20 avionic software instruments. Of these, 100 cases succeeded and 10 cases failed, yielding an overall fidelity index of:

$$Fi = \frac{100}{110} x\ 100\% = 90.9\%.$$

The weighted software fidelity score was calculated as:

$$Fs = (\frac{100}{110} x\ 100\%) x 0.5 = 45\%$$

Figure 5 shows the overall distribution of successful and failed test cases, while Figure 6 details performance per instrument. Failures were concentrated in a limited number of subsystems, while the majority of software instruments demonstrated high accuracy and responsiveness.

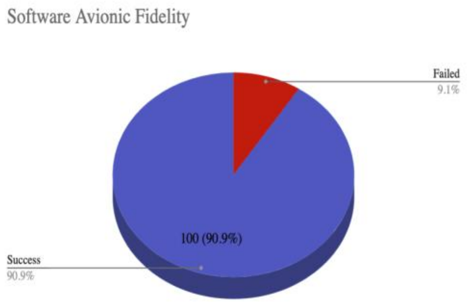

Figure 5. General Result of Software Instruments

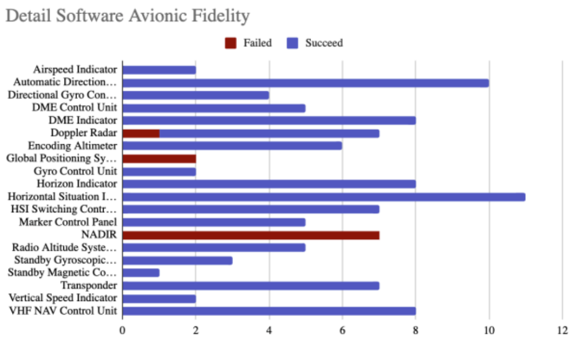

Figure 6. Detail Result of Software Instruments

3.3. OVERALL FIDELITY OF AVIONIC INSTRUMENTS

By combining the weighted hardware and software fidelity scores, the overall simulator fidelity was determined as:

$$Fs = \Sigma(44\% + 45\%) = 89\%$$

According to fidelity classification criteria, a score of 89% indicates outstanding fidelity, demonstrating that the NAS 332 Super Puma simulator provides a high level of realism, accuracy, and reliability in replicating operational helicopter avionics.

4. CONSLUSION

The results indicate that both hardware and software subsystems of the NAS 332 Super Puma simulator demonstrate high fidelity, with an overall score of 89%, which falls into the *outstanding* classification. A slight discrepancy was observed between the hardware fidelity (88%) and the software fidelity (90.9%). This gap is largely attributed to the Encoding Altimeter, which consistently failed across all three hardware test cases. Hardware discrepancies of this type are often linked to signal transmission delays, calibration errors, or integration issues between the simulator and its avionics software. Since the altimeter is a critical instrument for altitude awareness and flight safety, such failures must be prioritized for corrective action to ensure training reliability.

By contrast, the software subsystem performed more consistently, with only minor failures observed across a few instruments. These discrepancies are likely caused by data processing delays, coding errors, or simulation model limitations, which are generally easier to address through software updates. The results highlight the importance of maintaining a balanced fidelity assurance approach, where hardware calibration and software refinement work hand in hand to deliver seamless simulator performance.

From a training perspective, the overall fidelity score of 89% confirms that the NAS 332 Super Puma simulator provides a realistic and reliable platform for mission-oriented training, effectively replicating operational helicopter avionics. While the system already meets a high degree of fidelity, targeted improvements—particularly in the Encoding Altimeter—would further strengthen its compliance with FAA standards and enhance the safety, accuracy, and confidence of pilot training outcomes.

In conclusion, the study verifies that the simulator achieves outstanding fidelity, demonstrating its effectiveness as a training tool. However, attention to specific hardware weaknesses is necessary to sustain long-term reliability and to maximize its value for advanced helicopter training programs.

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