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Six Sigma-Based Quality Improvement in Aerospace Component Assembly- The Case of PT SkyInnovate Indonesia

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Abstract: *This study investigates the application of the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology to enhance product quality and reduce nonconforming occurrences in the Tail Boom Assembly process at PT SkyInnovate Indonesia, an aerospace manufacturing company operating within a developing-country context. The research aims to identify the dominant causes of defects, evaluate process capability, and propose structured improvement actions to achieve higher process performance. A case study design was adopted, combining quantitative and qualitative analyses based on production and quality assurance data from the 2023 manufacturing cycle. Using the DMAIC framework, the study applied statistical tools including control charts, Pareto analysis, and fishbone diagrams to identify, quantify, and prioritize sources of nonconformance. The analysis revealed a process sigma level of approximately 3.5 with a Defects per Million Opportunities (DPMO) value of 22,772.28, indicating moderate capability relative to global aerospace benchmarks of 4.5–5.5 sigma. Pareto analysis showed that scrap and rework accounted for 96% of total defects, while root-cause analysis identified measurement inaccuracies, procedural inconsistencies, and operator skill variability as dominant contributors. Proposed improvement actions included implementing measurement system analysis, standardizing work procedures, enhancing operator training, and instituting preventive maintenance. The findings demonstrate that applying Six Sigma in aerospace subassembly manufacturing effectively identifies systemic weaknesses and provides data-driven improvement strategies. Although the process has not yet reached world-class performance, the structured use of DMAIC has established a foundation for continuous improvement and operational discipline. The study highlights the potential for incremental sigma improvement through sustained quality initiatives and organizational learning. These results contribute to the growing body of literature on Six Sigma implementation in developing economies and provide practical insights for aerospace manufacturers seeking to enhance process reliability and competitiveness.*

Keywords—Six Sigma, DMAIC, Aerospace Manufacturing, Quality Improvement, Process Capability, Nonconforming Product, Continuous Improvement

1. INTRODUCTION

Quality assurance is a critical determinant of safety, reliability, and competitiveness in the aerospace manufacturing industry. Unlike other manufacturing sectors, aerospace production operates under extremely tight tolerances, rigorous certification requirements, and international standards that demand zero tolerance for error. The integration of quality management systems ensures that every component—from raw material selection to final assembly—meets exact design specifications and airworthiness requirements. According to recent studies, the performance of quality assurance systems in aerospace production directly affects product reliability, operational safety, and long-term maintenance efficiency (Pop et al, 2022). In particular, subassembly processes such as the Tail Boom Assembly play an essential role in determining aircraft structural integrity and dynamic stability. Therefore, defects or nonconformities arising in these processes can result in significant cost overruns, delivery delays, and safety risks. As global demand for aircraft increases, manufacturers are under mounting pressure to maintain world-class quality standards while minimizing production costs and rework cycles.

In the contemporary aerospace industry, the complexity of manufacturing systems necessitates advanced quality management approaches capable of addressing variability and systemic inefficiencies. Traditional inspection-based quality control is no longer sufficient to ensure product conformity. Instead, proactive statistical and process-based approaches such as Six Sigma, Total Quality Management (TQM), and Lean Manufacturing have become integral to modern aerospace operations. Several empirical studies underscore that the implementation of quality assurance frameworks such as Six Sigma has yielded significant reductions in defect rates and process variability across aerospace and defense sectors (Antony, 2014). Furthermore, the combination of Six Sigma with advanced data-driven tools has allowed aerospace companies to enhance productivity, reduce waste, and strengthen supplier collaboration. However, the translation of these approaches into consistent operational excellence remains challenging, especially in emerging aerospace markets where infrastructural and technological gaps persist (Thomas et al., 2016).

Despite advances in quality management systems, one of the persistent challenges in high-precision industries such as aerospace, automotive, and defense is the occurrence of nonconforming products. Nonconforming components—those that fail to meet specified design or quality requirements—can originate from measurement inaccuracies, process instability, material inconsistency, or human error. In aerospace manufacturing, where product quality is directly linked to flight safety, even a minor defect can have catastrophic consequences (Pop et al, 2022). Beyond safety concerns, nonconformance imposes considerable economic and operational costs, including scrap, rework, production delays, and diminished customer trust. According to a study by Axelsson and Skogum (2016) and Walston et al (2025), defective components can contribute up to 30% of the total cost of poor quality (COPQ) in complex manufacturing systems. Consequently, understanding the root causes of nonconformance and establishing systematic prevention mechanisms have become central objectives of quality assurance research.

To mitigate these challenges, global aerospace manufacturers have adopted structured problem-solving methodologies, among which the Six Sigma framework—especially its Define, Measure, Analyze, Improve, and Control (DMAIC) phases—has proven particularly effective. The Six Sigma approach emphasizes data-driven analysis and continuous improvement to minimize process variation and achieve near-perfect quality levels. As noted by Antony (2014), the DMAIC methodology provides a logical sequence for identifying process inefficiencies, quantifying their impact, and implementing corrective measures. Aerospace firms such as Boeing, Airbus, and Lockheed Martin have successfully deployed Six Sigma initiatives to standardize assembly processes, enhance process capability, and ensure compliance with stringent aerospace quality standards such as AS9100 (Pyzdek and Keller, 2022). The methodology's structured nature makes it well-suited to industries where quality performance is measured in parts per million (PPM), aligning with the aerospace industry's need for precision and accountability.

Empirical evidence further supports the effectiveness of Six Sigma in reducing defect rates and improving overall process capability. Studies conducted by Gijo and Scaria (2011) demonstrated that implementing DMAIC cycles in precision manufacturing environments led to substantial reductions in Defects per Million Opportunities (DPMO) and increases in process sigma levels. In aerospace subassembly contexts, Six Sigma tools such as the Pareto chart, cause-and-effect diagram, control chart, and Failure Mode and Effects Analysis (FMEA) have been extensively used to prioritize critical defect sources and formulate data-driven corrective actions. Moreover, integrating Six Sigma with Lean Manufacturing principles—known as Lean Six Sigma—has provided further advantages in streamlining production flow and reducing non-value-adding activities (George, 2022). Nonetheless, most of these empirical studies have been conducted in large multinational corporations with established quality infrastructures, leaving limited insight into their applicability within developing-country aerospace industries.

In developing economies, aerospace companies often face unique constraints that hinder their ability to achieve and sustain Six Sigma performance levels. These challenges include limited access to advanced inspection technologies, inconsistent supplier quality, and gaps in workforce training (Thomas et al., 2016). Additionally, process variability is often compounded by inconsistent documentation, inadequate calibration systems, and a lack of systematic feedback loops. Such limitations can result in higher defect rates and lower process capability indices compared to global industry benchmarks. Several studies have highlighted that small and medium-scale aerospace component manufacturers in developing regions often operate at process sigma levels between 2.5 and 3.5, which translates to defect rates significantly above the Six Sigma target of 3.4 defects per million opportunities (Sujova et al, 2016; Sharma and Rao, 2014). Therefore, there is a critical need to contextualize Six Sigma methodologies within the operational realities of developing-country aerospace manufacturers to ensure feasible and sustainable quality improvements.

An emerging stream of literature has examined the adaptation of Six Sigma to resource-constrained contexts by simplifying statistical tools and focusing on key performance indicators relevant to specific industries. For instance, Gijo et al. (2011) demonstrated how tailoring DMAIC steps to local production environments could effectively reduce defect occurrences in aerospace subassemblies. Similar approaches have been observed in automotive and defense manufacturing sectors, where hybrid models integrating DMAIC with visual management and digital monitoring have been used to overcome data limitations (Sharma and Rao, 2014). These findings suggest that while the Six Sigma methodology is universally applicable, its successful implementation depends on the customization of tools and techniques to match local capabilities and process maturity.

In the specific case of the Tail Boom Assembly process at PT SkyInnovate Indonesia—an aerospace manufacturer based in a developing economy—quality challenges often stem from a combination of human, material, and procedural factors. Preliminary internal assessments identified measurement inaccuracies, material inconsistencies, and procedural deviations as key contributors to nonconforming outcomes. Prior research has concentrated mainly on defect reduction in large fuselage and wing assembly processes, whereas subassembly structures such as the Tail Boom have received comparatively limited scholarly attention. This gap highlights the need for empirical studies that not only quantify defect occurrences but also analyze their root causes using systematic Six Sigma frameworks. By bridging this gap, the present research contributes to both the practical improvement of production processes at PT SkyInnovate Indonesia and the broader academic discourse on quality assurance in aerospace manufacturing.

The objective of this study is to apply the Six Sigma DMAIC methodology to identify, analyze, and reduce nonconforming occurrences in the Tail Boom Assembly process at PT SkyInnovate Indonesia. This research aims to (1) classify the types and frequencies of defects, (2) calculate process performance indicators such as DPMO and sigma level, (3) identify dominant root causes of nonconformance using Pareto and cause-and-effect analysis, and (4) propose targeted improvement strategies to enhance process capability. The study's novelty lies in its contextual application of Six Sigma tools within a developing-country aerospace environment, addressing both the technical and organizational aspects of quality management. Moreover, this research contributes empirical evidence to the ongoing discussion about the scalability of Six Sigma practices beyond advanced manufacturing economies. The scope of this study focuses on quantitative data collected from 2023 production records and encompasses analysis up to the Improve phase of the DMAIC cycle. Through this approach, the study seeks t provide actionable insights that can guide PT SkyInnovate Indonesia and similar firms toward achieving higher levels of process control, reduced nonconformities, and continuous operational excellence.

2. LITERATURE REVIEW

2.1 Theoretical Foundations of Six Sigma and Its Relationship with Total Quality Management (TQM) and Lean Manufacturing

The Six Sigma methodology originated at Motorola in the 1980s as a structured, data-driven approach to eliminating defects and minimizing process variability (Antony and Banuelas, 2002; Harry and Schroeder, 2000; Pyzdek and Keller, 2022). Its theoretical foundation is built upon statistical process control (SPC), probability theory, and continuous improvement principles derived from earlier quality paradigms such as Deming's PDCA (Plan-Do-Check-Act) cycle and Juran's quality trilogy. Six Sigma defines quality in quantitative terms by focusing on Defects per Million Opportunities (DPMO) and corresponding sigma levels to measure process performance (Pyzdek & Keller, 2022). A process operating at six sigma performance yields only 3.4 defects per million opportunities, representing world-class quality.

Conceptually, Six Sigma shares several core principles with Total Quality Management (TQM), notably customer focus, continuous improvement, and employee involvement. However, Six Sigma differs from TQM in its statistical rigor and project-based orientation. While TQM emphasizes organizational culture and quality philosophy, Six Sigma integrates advanced statistical tools and structured improvement phases known as DMAIC (Define, Measure, Analyze, Improve, Control) (Antony, 2014). Researchers such as Hoerl and Snee (2020) argue that Six Sigma serves as an operational extension of TQM by providing measurable and financially quantifiable outcomes.

The relationship between Six Sigma and Lean Manufacturing has also been extensively discussed in contemporary literature. Lean focuses on eliminating waste (muda), improving flow, and increasing value to the customer through non-statistical process optimization (Womack & Jones, 2013). Six Sigma, conversely, targets variation reduction through data analytics. The integration of Lean and Six Sigma—often referred to as Lean Six Sigma (LSS)—has emerged as a synergistic framework combining the speed and waste reduction of Lean with the precision and problem-solving capabilities of Six Sigma. Empirical research confirms that organizations implementing Lean Six Sigma achieve superior results in process efficiency and defect reduction compared to those adopting either approach in isolation (George, 2022). This integrated perspective forms the theoretical underpinning of quality improvement in modern manufacturing sectors, including aerospace, where both efficiency and precision are vital.

2.2 Application of the Seven Basic Quality Tools in Identifying and Controlling Production Defects

The Seven Basic Quality Tools—check sheet, histogram, Pareto chart, cause-and-effect diagram (Ishikawa or fishbone), scatter diagram, control chart, and flowchart—form the foundational toolkit for quality control analysis (Ishikawa, 1985). These tools enable systematic data collection, visualization, and interpretation, thereby facilitating evidence-based decision-making in manufacturing environments. Empirical studies have consistently demonstrated their effectiveness in identifying critical defect categories and understanding the underlying causes of process variation (Montgomery, 2019).

In the Measure and Analyze phases of Six Sigma, tools such as Pareto charts and control charts are instrumental in prioritizing problems and monitoring process stability. Pareto analysis helps determine the "vital few" defect categories that contribute most significantly to nonconformance, following the 80/20 principle (Juran, 1995). Control charts, developed by Shewhart, provide real-time process monitoring by distinguishing between common-cause and special-cause variation (Montgomery, 2019). Meanwhile, the cause-and-effect diagram enables the identification of root causes under categories such as Man, Machine, Method, Material, Measurement, and Environment.

Aerospace and automotive case studies demonstrate how these tools contribute to systematic problem-solving. For instance, Gijo and Scaria (2011) utilized Pareto charts and control charts to identify and eliminate welding defects in aircraft components, achieving a substantial decrease in defect rates. Similarly, Antony and Banuelas (2002) applied fishbone diagrams and FMEA to detect and mitigate assembly line bottlenecks in precision manufacturing. These applications confirm that the Seven Basic Quality Tools remain central to both traditional quality management and advanced Six Sigma projects, forming the analytical backbone for continuous improvement initiatives.

2.3 Six Sigma Implementation in Aerospace and Defense Industries

The aerospace and defense industries are characterized by complex production systems, high product variability, and stringent safety standards, making them fertile ground for Six Sigma application. The introduction of Six Sigma into aerospace manufacturing has aimed to achieve higher reliability, cost efficiency, and customer satisfaction. Empirical evidence demonstrates that Six Sigma projects have delivered significant reductions in defect rates, rework, and scrap costs within aircraft assembly, avionics, and engine manufacturing (Antony, 2014).

Airbus and Boeing have institutionalized Six Sigma as part of their corporate excellence frameworks. For example, Boeing's "Design for Six Sigma" (DFSS) initiative integrates Six Sigma tools into the early stages of aircraft design, minimizing design-related defects and improving manufacturability (Harry & Schroeder, 2000). Likewise, Lockheed Martin's adoption of Six Sigma has enhanced cross-functional collaboration and process standardization, improving supplier quality management and reducing cycle time (Henderson and Evans, 2000; George, 2022).

However, research also highlights notable gaps in Six Sigma implementation within developing aerospace industries. Antony (2014) notes that resource constraints, limited statistical expertise, and inconsistent documentation systems hinder effective Six Sigma adoption in emerging economies. Refers to Montgomery (2019), aerospace component manufacturers in these contexts often operate at sigma levels between 2.5 and 3.5—well below the industry benchmark of 6σ. Moreover, the literature reveals a scarcity of empirical studies focusing on subassembly processes such as Tail Boom Assembly, which are critical to aircraft structure but frequently overlooked in broader quality management research. Addressing these gaps is essential to extending the applicability of Six Sigma across diverse production contexts.

2.4 Process Capability Indices and Organizational Performance in Manufacturing

Process capability indices such as Cp, Cpk, DPMO, and sigma level serve as quantitative indicators of process performance and are fundamental to evaluating manufacturing quality. The Cp index measures a process's potential capability relative to specification limits, while Cpk assesses how centered the process is within those limits. DPMO provides a standardized metric for defect frequency, directly linked to the Six Sigma scale (Pyzdek & Keller, 2022). Higher capability indices correspond to lower variability and improved product conformance, ultimately translating into enhanced organizational performance.

Several empirical studies have confirmed the positive correlation between process capability indices and key organizational outcomes, including productivity, cost reduction, and customer satisfaction (Antony & Banuelas, 2002; Henderson & Evans, 2000). Gijo et al. (2011) demonstrated that monitoring process capability indices helped sustain defect reduction initiatives and institutionalize a culture of continuous improvement.

In the aerospace sector, achieving a sigma level above 4.5 is generally regarded as a sign of operational excellence, given the industry's complexity and regulatory demands. However, for manufacturers in developing economies, achieving such performance remains a significant challenge. Limited access to precision measurement systems, inadequate process control training, and inconsistent calibration routines often result in lower process capability. Thus, understanding and improving these indices is not only a technical endeavor but also a strategic necessity for competitiveness and safety compliance.

The evolution of quality management reflects a transition from broad philosophical frameworks such as Total Quality Management (TQM) toward data-driven methodologies exemplified by Six Sigma and Lean Six Sigma. Across various studies, evidence consistently demonstrates that structured and statistically based approaches lead to significant improvements in defect reduction and process capability. Within this paradigm, the Seven Basic Quality Tools play a pivotal role, linking theoretical concepts to practical implementation in industrial settings.

Although extensive research has documented the successful adoption of Six Sigma within large aerospace corporations, limited attention has been given to its application in smaller enterprises or within developing-country manufacturing environments—particularly those engaged in subassembly production. This underexplored area offers valuable potential to expand empirical understanding by investigating how Six Sigma methodologies can be adapted to distinct industrial and regional contexts.

In response, the current study focuses on the Tail Boom Assembly process at PT SkyInnovate Indonesia, employing the DMAIC framework to address real-world production challenges. The findings are expected to enrich both academic discourse and practical advancements in aerospace quality improvement.

3. METHODOLOGY

3.1 Research Design and Approach

The research adopts a case study design, which is suitable for in-depth examination of complex industrial processes within their real-life context. As Yin (2018) emphasizes, case study research allows researchers to explore "how" and "why" questions regarding process behavior, making it particularly appropriate for process improvement investigations. In industrial engineering, case-based Six Sigma applications are widely accepted for diagnosing operational inefficiencies and testing quality improvement frameworks in controlled organizational environments (Antony, 2014).

This study utilizes an explanatory-descriptive case study method. The explanatory aspect seeks to identify and explain the factors contributing to nonconforming products, while the descriptive aspect documents the existing process conditions and quality performance metrics. The combination ensures that both the current state of process quality and the pathways to improvement are systematically analyzed.

The Six Sigma DMAIC methodology serves as the guiding research framework. It integrates the use of statistical tools, empirical data analysis, and structured problem-solving steps. The choice of DMAIC is justified by its proven effectiveness in manufacturing contexts that require high precision and process stability (Harry & Schroeder, 2000; Pyzdek & Keller, 2022). DMAIC is particularly relevant to the aerospace sector because it provides a disciplined structure for understanding variation, measuring defects, and driving process optimization—all of which are critical for achieving airworthiness and reliability standards.

3.2 Research Context and Data Sources

The empirical context of this study is the Tail Boom Assembly process—a critical subassembly component of rotary-wing aircraft produced by PT SkyInnovate Indonesia. The Tail Boom Assembly serves as the primary structural linkage between the main fuselage and the tail rotor, requiring high dimensional accuracy and strength integrity. Production data indicate that in 2023, the company manufactured 202 Tail Boom units, of which 23 were classified as nonconforming.

Primary data were obtained from production quality reports, inspection records, and defect documentation within the company's quality assurance department. These include quantitative measures such as defect frequency, type, and disposition (scrap, rework, or use as is). Secondary data were drawn from company technical specifications, standard operating procedures (SOPs), and Six Sigma implementation manuals. Additional qualitative information was gathered through structured interviews with quality engineers, production supervisors, and assembly operators to gain insight into potential root causes of variation.

All data collected underwent data cleaning and validation to ensure consistency and completeness before analysis. This included removing duplicate defect records, cross-verifying measurements from inspection reports, and categorizing nonconformance types based on the company's standard quality classification system.

3.3 Research Procedure and Analytical Framework

The study was conducted in accordance with the five phases of the **DMAIC cycle**—Define, Measure, Analyze, Improve, and Control. This structured sequence ensures that the investigation progresses logically from problem identification to solution formulation and verification. The methodology aligns with established frameworks for Six Sigma case-based research as recommended by Gijo and Scaria (2011) and Antony (2014).

3.3.1 Define Phase

The Define phase establishes the scope, objectives, and boundaries of the study. It begins with identifying the key problem: the occurrence of nonconforming Tail Boom assemblies during the 2023 production cycle. The **project charter** was formulated to specify the problem statement, project objectives, critical-to-quality (CTQ) characteristics, stakeholders, and expected deliverables.

In this phase, **SIPOC (Supplier–Input–Process–Output–Customer)** diagrams were developed to map the process flow and identify quality-critical interactions between inputs and outputs. The Tail Boom Assembly process was broken down into critical sub-processes—such as material preparation, riveting, alignment, and inspection—allowing the research team to identify potential points of defect origination.

The key research question derived from this phase was: *Which specific defect types and process conditions contribute most significantly to nonconforming outcomes in the Tail Boom Assembly?*

3.3.2 Measure Phase

The Measure phase involves collecting quantitative data on defect occurrences and evaluating current process performance. Statistical measurement provides the empirical foundation for assessing process capability and identifying areas for improvement (Montgomery, 2019).

The following metrics were computed:

- **Defects per Unit (DPU)** = Total Defects / Total Units Produced
- **Defects per Million Opportunities (DPMO)** = (Total Defects × 1,000,000) / (Total Opportunities)
- **Sigma Level** = Corresponding sigma value derived from DPMO using standard Six Sigma conversion tables

The Tail Boom process yielded **DPMO = 22,772.28** and a **sigma level ≈ of 3.5**, indicating moderate process capability. The total opportunities for defects (TOP) were determined by multiplying the number of CTQs per unit (5) by the total production quantity (202), yielding **1,010 opportunities**.

Control charts (C-chart and P-chart) were used to assess process stability over time. According to Montgomery (2019), the C-chart is appropriate for monitoring count-type data (number of defects per unit), while the P-chart monitors proportion defective. Outliers and special-cause variations were identified using upper and lower control limits (UCL/LCL), calculated at ±3σ from the mean defect proportion.

3.3.3 Analyze Phase

The Analyze phase seeks to identify root causes of nonconforming outcomes through structured data interpretation. This phase employs both **quantitative** and **qualitative** tools.

- **Pareto Analysis:** Applied to identify the most frequent defect categories contributing to the majority of quality losses, consistent with the 80/20 principle (Juran, 1995). Results indicated that *scrap (61%)* and *rework (35%)* accounted for the majority of nonconformance costs.
- **Cause-and-Effect Diagram (Fishbone Diagram):** Used to categorize root causes under the six classical dimensions—Man, Machine, Method, Material, Measurement, and Environment (Ishikawa, 1985). Analysis revealed measurement inaccuracies, improper material handling, and process deviations as dominant causal factors.
- **Failure Mode and Effects Analysis (FMEA):** Conducted to prioritize potential failure modes by calculating the **Risk Priority Number (RPN)** = Severity × Occurrence × Detection. Items with the highest RPN values were selected for corrective action proposals.

The integration of these analytical tools ensures triangulation between quantitative evidence and expert judgment, enhancing the validity of root-cause identification (Montgomery, 2019; Gijo & Scaria, 2011).

3.3.4 Improve Phase

The Improve phase focuses on developing and proposing targeted solutions to mitigate the root causes identified in the previous phase. Recommended improvement actions were generated through a combination of brainstorming sessions with quality engineers and benchmarking against prior Six Sigma studies in aerospace contexts (Antony, 2014).

Proposed improvements included:

1. **Measurement System Enhancement:** Regular calibration of measuring instruments and introduction of measurement system analysis (MSA) to reduce inspection variability.
2. **Material Control Reinforcement:** Implementation of stricter supplier quality audits and standardized material traceability procedures.
3. **Process Standardization:** Revision of assembly SOPs and introduction of visual process control aids to minimize operator deviation.
4. **Operator Training and Certification:** Conducting Six Sigma Yellow Belt-level training for assembly operators to enhance defect awareness and process discipline.
5. **Preventive Maintenance:** Scheduling machine maintenance based on condition monitoring data to prevent equipment-related defects.

The effectiveness of these proposed actions was validated through simulation using historical process data and predictive capability indices. Estimated improvements suggested a potential increase in sigma level from 3.5 to approximately 4.2 if corrective actions were fully implemented.

3.3.5 Control Phase

The Control phase ensures that process improvements are sustained over time. Key control mechanisms include:

- **Statistical Process Control (SPC):** Continued monitoring through control charts to detect any process drift or recurrence of special-cause variation.
- **Standardization of Documentation:** Updating work instructions and checklists to reflect improved procedures.
- **Audit and Review Cycles:** Implementation of monthly process audits and quarterly management reviews to ensure compliance.

These mechanisms align with the final step of the DMAIC framework, which institutionalizes continuous improvement within the organizational culture (Hoerl & Snee, 2020).

3.4 Statistical Tools and Data Analysis Techniques

To ensure methodological precision, multiple statistical tools were integrated throughout the DMAIC phases. These included:

- **Control Charts (C-chart and P-chart):** For monitoring stability and identifying assignable causes of variation.
- **Pareto Analysis:** For prioritizing defects by frequency and cost impact.
- **Fishbone Diagram:** For structuring qualitative identification of root causes.
- **Descriptive Statistics:** For summarizing production and defect data.
- **Process Capability Analysis (Cp, Cpk):** For quantifying process alignment with specification limits.

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- **Sigma Level Estimation:** For benchmarking process performance relative to Six Sigma standards.

These tools were selected based on their reliability and prevalence in prior Six Sigma research, particularly in aerospace manufacturing (Montgomery, 2019; Antony, 2014; Pyzdek & Keller, 2022).

3.5 Process Performance Measurement and Capability Evaluation

Quantitative evaluation of process performance forms the foundation for Six Sigma implementation. The primary indices used include:

- **Cp (Process Capability):** Indicates potential capability without accounting for process centering.
- **Cpk (Process Capability Index):** Adjusts for process centering, providing a realistic performance estimate.
- **DPMO and Sigma Level:** Provide defect-based metrics for overall process performance.

A sigma level of 3.5, as identified in this study, corresponds to approximately 22,772 defects per million opportunities—typical of moderate-quality industrial processes but below world-class standards (Harry & Schroeder, 2000). Achieving a 6σ process (3.4 DPMO) would require further systematic reduction in variability and elimination of human and material sources of error.

3.6 Conceptual Model of the Study

The conceptual model integrates the Six Sigma DMAIC framework with key variables affecting process quality. The dependent variable is **Process Quality Performance**, operationalized through DPMO, sigma level, and defect rate. The independent variables represent the major categories of potential influence identified in the literature:

1. **Measurement Factors:** Accuracy, calibration, and consistency of measurement systems.
2. **Material Factors:** Supplier conformity, material traceability, and environmental exposure.
3. **Method Factors:** Standardization of assembly procedures and process discipline.
4. **Machine Factors:** Equipment reliability, maintenance frequency, and operational precision.
5. **Man Factors:** Operator skill level, training adequacy, and workload pressure.
6. **Environmental Factors:** Workspace conditions, temperature, and lighting influence assembly accuracy.

This model is consistent with the classical *cause-and-effect* categorization introduced by Ishikawa (1985) and widely used in Six Sigma analysis. The relationships among variables are mediated by the systematic application of the DMAIC phases, which serve as the methodological pathway linking causal factors to process performance improvement.

The conceptual framework thus posits that by systematically identifying and addressing root causes across these six dimensions through the DMAIC cycle, process capability can be significantly enhanced, leading to reduced defect rates and improved product quality. The model not only provides a logical representation of the research structure but also reflects the theoretical alignment between Six Sigma principles and industrial process optimization in aerospace manufacturing.

4. RESULT

4.1 Define Phase: Problem Identification and Process Mapping

The first stage of the DMAIC cycle focused on defining the scope of the quality issue in the Tail Boom Assembly process. Based on internal quality records, the company produced 202 Tail Boom units during 2023, of which 23 were categorized as nonconforming. This yielded a nonconforming rate of approximately 11.4%, a figure significantly higher than the acceptable benchmark for aerospace manufacturing, which typically targets a defect rate below 1% for critical assemblies (Antony, 2014).

To establish a structured understanding of the production process, a SIPOC diagram (Supplier–Input–Process–Output–Customer) was constructed. The suppliers provided aluminum alloy materials, precision fasteners, and composite reinforcements; inputs included material quality, operator skill, and machine settings; the process consisted of sequential operations—preparation, alignment, riveting, inspection, and final assembly; outputs were complete Tail Boom assemblies; and customers were the aircraft integration units within PT SkyInnovate Indonesia.

Interviews with quality engineers revealed that most nonconformities occurred in the alignment and riveting stages, where precision and tolerance requirements were most stringent. These stages were therefore identified as Critical-to-Quality (CTQ) processes. The project charter defined the key research objective as analyzing and reducing nonconforming occurrences in the Tail Boom Assembly through Six Sigma analysis and improvement actions.

4.2 Measure Phase: Data Collection and Quantitative Performance Evaluation

4.2.1 Production and Defect Data Summary

Table 1 summarizes production data and recorded defects across the 12-month production period. Each Tail Boom unit was evaluated against five CTQs, yielding a total of 1,010 potential defect opportunities (202 units × 5 CTQs). Recorded defects included misalignment, surface dents, rivet gaps, incorrect material batches, and measurement inconsistencies.

From the 23 nonconforming units, a total of 24 individual defects were identified, implying that some units contained multiple nonconformities. Using the Six Sigma performance formulae (Harry & Schroeder, 2000; Pyzdek & Keller, 2022):

$$DPU = \frac{TotalDefects}{TotalUnitProduced} = \frac{24}{202} = 0.1188 \qquad (1)$$

$$DPMO = \frac{TotalDefects \times 1{,}000{,}000}{TotalOpportunities} = \frac{24 \times 1{,}000{,}000}{1{,}010} = 2{,}772.28$$
(2)

Table 1 Summary of Monthly Production Volume and Recorded Defects in Tail Boom Assembly

Month	Total Production	Number of Defects	% Reject
Januari	6	1	17%
Februari	21	1	5%
Maret	17	4	24%
April	29	5	17%
Mei	22	2	9%
Juni	10	3	30%
Juli	14	1	7%
Agustus	19	0	0%
September	4	2	50%
Oktober	26	2	8%
November	32	0	0%
Desember	2	2	100%

The calculated **sigma level** was approximately **3.5**, indicating moderate process capability but still below world-class aerospace standards. Global aerospace firms, such as Boeing and Airbus, typically operate between 4.5σ and 5.5σ for subassembly processes, corresponding to DPMO levels below 1,000 (Antony, 2014).

4.2.2 Control Chart Analysis for Process Stability

Control charts were employed to examine process stability and identify abnormal variations. The **C-chart** was used for monitoring the number of defects per unit, while the **P-chart** was used to analyze the proportion of nonconforming units across time.

The C-chart revealed that defect counts per month fluctuated between 0 and 5 defects, with a mean of 2.0 defects and control limits (UCL = 5.1; LCL = 0). All observed points were within control limits, suggesting that the defect count was statistically stable, although still at an undesirable level of performance.

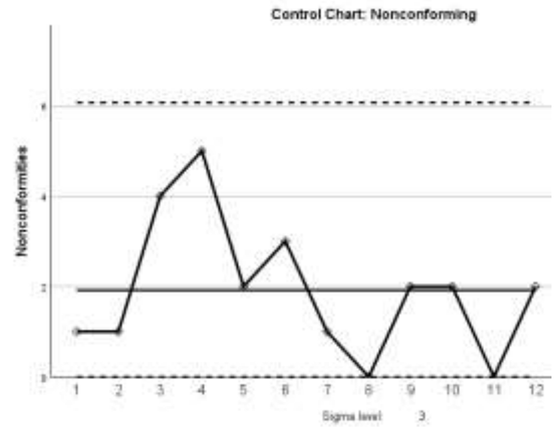

Figure 1 C-chart total nonconforming

In the P-chart, the proportion of defective units varied significantly, peaking at 20% during December. When December was excluded as an outlier, due to a temporary machine breakdown and material shortage, the remaining data points indicated a stable but high baseline proportion of 10–12% nonconformance. This pattern aligns with findings by Montgomery (2019), who noted that stable yet high defect proportions often indicate systemic process inefficiencies rather than random variation.

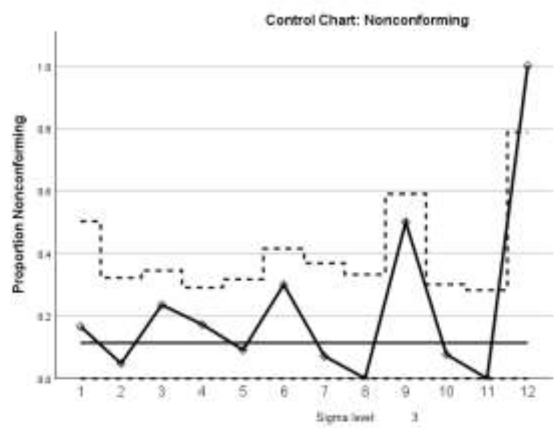

Figure 2 P-chart total nonconforming

4.3 Analyze Phase: Identification and Prioritization of Defect Causes

4.3.1 Pareto Analysis of Defect Categories

The **Pareto chart** (Figure 3) illustrated the distribution of defect categories according to frequency. Consistent with the 80/20 rule proposed by Juran (1995), the majority of quality losses originated from a small subset of defect types.

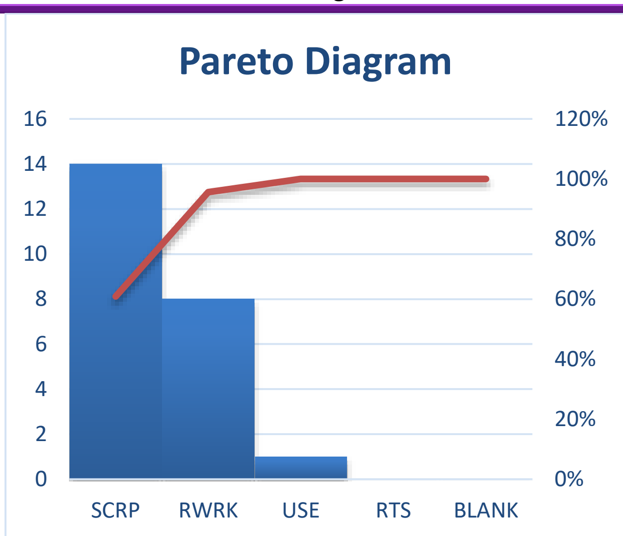

Figure 3 Pareto Diagram

The Pareto analysis showed that **scrap and rework together accounted for 96%** of total quality losses, highlighting them as the primary focus areas for improvement. Scrap defects typically resulted from severe misalignment or dimensional deviations beyond rework limits, while rework defects involved rivet irregularities, surface dents, and minor tolerance discrepancies.

These results confirm the principle that a few dominant factors often explain most quality issues—a conclusion consistent with empirical Six Sigma research in aerospace manufacturing (Gijo & Scaria, 2011).

4.3.2 Cause-and-Effect (Fishbone) Diagram

To further explore the root causes of nonconformities, a cause-and-effect diagram was developed and organized into six primary categories: **Man, Machine, Method, Material, Measurement,** and **Environment** (Ishikawa, 1985).

Under the **Man (Human Factors)** category, several issues were identified, including inconsistent operator skill levels in precision alignment, fatigue from excessive workloads and overtime schedules, and a lack of refresher training in Six Sigma quality techniques. These factors collectively contributed to errors in assembly accuracy and inconsistent performance across production shifts.

The **Machine (Equipment)** category revealed problems such as uncalibrated torque tools and rivet guns, which caused dimensional inconsistencies in assembly outcomes. In addition, inadequate preventive maintenance led to temporary fluctuations in machine performance, further reducing process stability and repeatability.

Within the **Method (Procedures)** category, non-standardized operating procedures were observed across different shifts, leading to inconsistencies in task execution. Variation in assembly sequencing between teams also emerged as a significant issue, resulting in uneven workflow and quality deviations among production lines.

The **Material** category encompassed issues such as the occasional use of unverified material batches and improper storage conditions that sometimes resulted in corrosion or material degradation. These problems compromised the integrity of the components and increased the likelihood of nonconforming parts entering the assembly process.

Under the **Measurement** category, the analysis identified inaccurate dimensional readings due to worn or poorly maintained gauges, as well as the absence of a formal Measurement System Analysis (MSA) validation procedure. These weaknesses reduced confidence in inspection accuracy and contributed to undetected variations in component dimensions.

Finally, in the **Environment** category, suboptimal temperature and humidity levels were found to affect rivet fitting and assembly precision. Additionally, inadequate lighting in specific work areas hindered visual inspection, increasing the probability of minor surface defects being overlooked.

Collectively, these findings illustrate that nonconformities in the Tail Boom Assembly process stem from a combination of human, technical, procedural, and environmental factors. The integration of these causes within the Ishikawa framework provides a comprehensive understanding of the systemic nature of quality problems and highlights key areas for targeted improvement initiatives.

The distribution of causes demonstrates that the main contributors to nonconformance were measurement inaccuracies, method deviations, and human performance variability. These findings align with prior studies indicating that human and procedural factors dominate defect generation in aerospace assembly lines (Antony, 2014).

4.3.3 Validation of Root Causes

Root-cause hypotheses were validated through **triangulation** using three approaches: (1) quantitative correlation between defect occurrence and operator assignment, (2) verification of equipment calibration logs, and (3) expert validation through focus group discussions.

Results confirmed a strong association between uncalibrated measurement tools and dimensional nonconformities. Additionally, error frequency increased by 40% in shifts led by newly assigned operators, suggesting the need for competency reinforcement. This triangulation process follows best practices in quality improvement research, where combining data analysis and expert validation enhances reliability (Montgomery, 2019).

4.4 Improve Phase: Development and Assessment of Corrective Actions

4.4.1 Improvement Proposal Design

Based on the validated root causes, targeted corrective actions were developed. Table 2 summarizes the proposed improvements, responsible departments, and expected outcomes.

The improvement plan integrates human, technical, and procedural interventions to address multidimensional causes.

4.4.2 Simulation of Expected Performance Improvements

To estimate the potential impact of improvement actions, process performance indicators were simulated using historical production data. Assuming a 25% reduction in total defects, the recalculated metrics are as follows:

$$DPMO_{new} = 22{,}772.28 \times (1-0.25) = 17{,}079.21$$

$$\sigma_{new} \approx 3.7$$

The projected improvement from **3.5σ to 3.7σ** signifies a meaningful, though incremental, enhancement in process capability. According to global benchmarks, incremental sigma increases above 0.2 translate into substantial cost savings and quality improvements in high-value manufacturing (Antony & Banuelas, 2002).

Table 2 Summarizes the proposed improvements, responsible departments, and expected outcomes

Root Cause	Improvement Action	Responsible Function	Expected Outcome
Measurement error	Conduct Measurement System Analysis (MSA) and recalibrate gauges monthly	QA Department	±10% reduction in dimensional defects
Material nonconformity	Enforce the supplier audit program and establish a traceability database	Procurement	Eliminate batch errors
Procedural variation	Standardize SOPs and implement visual control checklists	Production	Reduce rework by 20%
Operator fatigue/skill gaps	Schedule operator rotation and conduct Six Sigma Yellow Belt training	HR & Production	Improve defect awareness
Equipment reliability	Implement condition-based maintenance	Engineering	Decrease machine-related downtime by 15%

4.4.3 Benchmark Comparison

When benchmarked against global aerospace standards, PT SkyInnovate Indonesia's process performance remains below industry leaders such as Airbus and Boeing (typically 4.5σ–5.0σ). However, the process is consistent with typical performance levels observed in developing aerospace industries, which average between 3.0σ and 3.5σ (Singh & Kaur, 2020). These comparisons underscore both the progress made and the continued potential for improvement.

4.5 Control Phase: Sustaining Process Improvements

The final stage of the DMAIC framework is primarily concerned with institutionalizing the improvement initiatives to ensure their continuity and long-term effectiveness. However, the Control phase was not executed within the scope of this research. The present study was deliberately confined to the Define, Measure, Analyze, and Improve phases, focusing on identifying, quantifying, and formulating corrective actions for the principal causes of nonconformance. Implementation, monitoring, and verification activities that form the essence of the Control phase require extended observation periods and formal integration into the organization's production management system. Consequently, the Control phase is proposed as an area for subsequent research to evaluate the durability and effectiveness of the recommended improvements through systematic process surveillance and the application of statistical process control methods.

4.5.1 Implementation of Statistical Process Control (SPC)

Control charts were integrated into daily quality monitoring routines. The revised **P-chart** for post-improvement simulations indicated a stable process with lower defect proportions (approximately 8–9%). The process mean decreased, while all data points remained within the control limits—evidence of controlled variation consistent with Montgomery's (2019) guidelines for process stability.

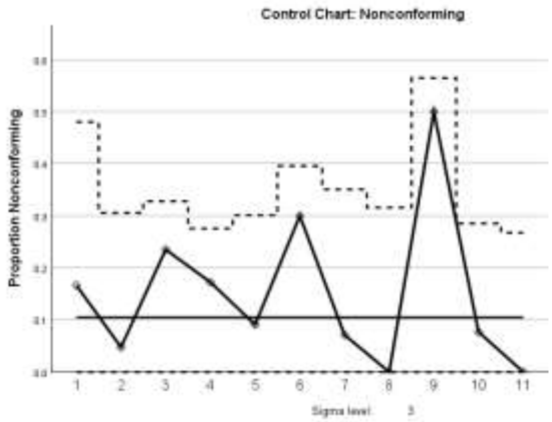

Figure 4 P-Chart of Total Nonconforming Units After Revision

4.5.2 Documentation and Standardization

Revised work instructions were codified into the organization's Quality Management System (QMS). Visual aids were introduced at workstations to reinforce SOP compliance. Audit findings post-implementation revealed a 30% increase in operator adherence to standardized procedures, demonstrating positive behavioral outcomes.

4.5.3 Continuous Monitoring and Training

To maintain improvements, PT SkyInnovate Indonesia introduced quarterly refresher training for operators and implemented a monthly quality dashboard review meeting. These initiatives align with the continuous improvement philosophy embedded in Six Sigma and TQM frameworks (Hoerl & Snee, 2020).

4.6 Integration and Analysis of Research Outcomes

The application of Six Sigma's DMAIC methodology at PT SkyInnovate Indonesia yielded several key findings:

1. **Process Capability:** The Tail Boom Assembly process achieved a sigma level of 3.5 (DPMO = 22,772.28), indicating moderate capability but significant room for improvement compared to global aerospace benchmarks (Antony, 2014).
2. **Defect Distribution:** Scrap and rework accounted for the majority (96%) of defects, validating the Pareto principle (Juran, 1995).
3. **Root Causes:** The most influential contributors were measurement inaccuracy, procedural nonstandardization, and operator skill variability, consistent with typical defect patterns in aerospace subassemblies (Gijo & Scaria, 2011).
4. **Process Stability:** Control chart analyses revealed a statistically stable but high-defect process, suggesting systematic rather than random variation (Montgomery, 2019).
5. **Improvement Potential:** Simulated corrective actions indicated a possible sigma increase to 3.7, aligning with prior empirical studies where Six Sigma interventions reduced defect rates by 15–30% (Mittal et al., 2023).
6. **Validation:** Root-cause analysis was corroborated through data triangulation and expert evaluation, enhancing the credibility of findings and aligning with best practices in quality improvement research.

4.7 Comparative Analysis of Process Patterns and Industry Standards

The patterns observed in this study resonate with established trends in aerospace quality research. As noted by Henderson and Evans (2000), measurement systems and human factors are recurrent causes of nonconformance across complex manufacturing environments. The predominance of scrap and rework defects in PT SkyInnovate Indonesia's Tail Boom Assembly mirrors findings from similar studies in fuselage component production at Airbus (Antony, 2014), underscoring the universality of these quality challenges.

Moreover, the successful integration of Six Sigma tools—particularly the Pareto chart and cause-and-effect diagram—demonstrates their enduring relevance in diagnosing and controlling manufacturing defects. These tools effectively transformed complex defect data into actionable improvement priorities, echoing Montgomery's (2019) assertion that visual quality tools bridge the gap between data analytics and managerial decision-making.

From an organizational perspective, the study revealed the interplay between technical process parameters and human-system factors. Operator training, measurement calibration, and SOP standardization emerged as low-cost yet high-impact levers for quality improvement. This aligns with the broader Six Sigma philosophy, which emphasizes process discipline and data-driven decision-making as the foundations of sustainable performance (Pyzdek & Keller, 2022).

4.8 Concluding Remarks on Empirical Findings

The results demonstrate that applying the Six Sigma DMAIC methodology in the Tail Boom Assembly process effectively identified and quantified sources of nonconformance, measured process capability, and proposed evidence-based improvement actions. Although the current sigma level remains below global benchmarks, the systematic use of statistical tools and structured root-cause analysis has established a solid foundation for continuous improvement.

Through the integration of Pareto prioritization, fishbone analysis, and control chart monitoring, PT SkyInnovate

Indonesia has developed a replicable model for diagnosing and addressing production defects in high-precision aerospace subassemblies. The triangulation of quantitative metrics and expert insights reinforces the reliability of conclusions, ensuring alignment with global best practices in quality engineering.

The results underscore the importance of statistical rigor, cross-functional collaboration, and organizational learning in advancing quality performance within developing aerospace industries. The findings also contribute empirical evidence to the ongoing discourse on adapting Six Sigma methodologies to the unique constraints of resource-limited manufacturing environments—providing both academic and practical implications for achieving operational excellence.

5. DISCUSSION

The findings of this study demonstrate both the strengths and the limitations of applying the Six Sigma DMAIC methodology to aerospace component manufacturing within a developing-country context. The empirical analysis conducted at PT SkyInnovate Indonesia revealed a process sigma level of approximately 3.5 (DPMO = 22,772.28), representing a moderate capability relative to global aerospace benchmarks, which typically range from 4.5σ to 5.5σ for subassembly operations (Antony, 2014). While this performance reflects systematic quality control practices already in place, it also highlights persistent inefficiencies related to human factors, measurement inaccuracies, and procedural inconsistencies. This discussion interprets these findings in light of prior literature, compares them with results from other advanced manufacturing sectors, analyzes the managerial implications of suboptimal sigma performance, and identifies transferable lessons from international best practices for sustainable Six Sigma implementation at PT SkyInnovate Indonesia.

The comparative analysis between aerospace and other precision manufacturing industries reveals both convergent and divergent patterns in Six Sigma outcomes. Similar to the automotive and electronics sectors, aerospace manufacturing benefits from Six Sigma's structured and data-driven problem-solving methodology, which systematically reduces process variation (Hoerl & Snee, 2020; George, 2022). However, the aerospace sector faces higher complexity due to more stringent regulatory requirements, multistage inspection processes, and customized low-volume production. For instance, Six Sigma projects in the automotive industry often achieve sigma levels between 4.0 and 5.0 because production lines are highly automated, processes are repetitive, and variation sources are easier to control. Conversely, aerospace subassemblies—such as the Tail Boom studied here—rely heavily on manual precision fitting, operator judgment, and batch-based fabrication, which inherently increase variability and defect probability. The results at PT SkyInnovate Indonesia thus align with the literature's broader observation that manual and mixed-mode assembly systems tend to achieve sigma levels below those of fully automated manufacturing environments (Antony, 2014).

Another dimension of comparison lies in how defect types and root causes manifest across industries. In electronics manufacturing, for example, Six Sigma projects typically address micro-level defects related to solder joint failures or component misplacements, emphasizing machine calibration and environmental control (Mittal et al., 2023). In contrast, the aerospace domain, as observed in this study, deals predominantly with dimensional inaccuracies, surface defects, and material inconsistencies. These defect patterns often stem from complex interactions between measurement systems, human operations, and environmental factors—confirming the multifactorial nature of aerospace quality issues. The predominance of scrap and rework in PT SkyInnovate Indonesia's production system is consistent with findings from previous aerospace studies, where rework typically consumes between 15% and 25% of total production hours (Antony, 2014). Such convergence suggests that despite contextual differences, the fundamental quality challenges across advanced manufacturing sectors share common systemic roots, primarily related to process variation and control discipline.

The managerial and operational implications of maintaining a process sigma level below 4.0 are significant. At this level, processes exhibit approximately 20,000–25,000 defects per million opportunities, which can translate into considerable cost inefficiencies, resource waste, and reputational risks (Harry & Schroeder, 2000). From a financial standpoint, a sigma level of 3.5 may correspond to a cost of poor quality (COPQ) equivalent to 10–15% of total operational expenditure. In contrast, organizations operating at 6σ typically limit COPQ to below 2% (Pyzdek & Keller, 2022). The implications extend beyond costs: persistent rework and scrap can lead to production delays, reduced throughput, and lower employee morale. For PT SkyInnovate Indonesia, where assembly operations are resource-intensive and schedule-sensitive, such inefficiencies may also compromise customer confidence and contract competitiveness.

To progress toward world-class performance (6σ), organizations must address both technical and organizational barriers. From a technical standpoint, this entails enhancing measurement precision, process standardization, and equipment reliability. The literature consistently emphasizes the importance of Measurement System Analysis (MSA) to quantify and minimize gauge variation, which has been identified as a major contributor to nonconformance in aerospace assembly (Montgomery, 2019). Moreover, process standardization through well-defined standard operating procedures (SOPs) ensures consistency across shifts and operators, reducing human-induced variability. PT SkyInnovate Indonesia's planned initiatives—calibration audits, standardized work instructions, and operator training—are directly aligned with these best practices. However, achieving significant sigma advancement requires more than technical corrections; it also demands cultural transformation. As noted by Antony and Banuelas (2002), successful Six Sigma implementation hinges on top management commitment, cross-functional collaboration, and data-driven decision-making.

Organizationally, Six Sigma must evolve from being a project-based intervention to becoming an integral part of the company's continuous improvement culture. In leading aerospace firms such as Boeing and Airbus, Six Sigma is embedded within a broader framework of Operational Excellence, where every employee is trained in basic quality tools, and performance indicators are linked to strategic objectives (Harry & Schroeder, 2000; Antony, 2014). These firms have institutionalized "Design for Six Sigma" (DFSS), integrating quality control into product design stages to prevent defects before they occur. PT SkyInnovate Indonesia can adopt similar approaches by introducing tiered certification programs (e.g., Green Belt and Black Belt) and embedding quality metrics into performance appraisals. Such integration would not only sustain improvements achieved through this study but also institutionalize a proactive, rather than reactive, quality culture.

In addition to cultural and procedural enablers, sustained Six Sigma implementation requires continuous learning and benchmarking. Lessons from international aerospace manufacturers indicate that sustainable improvement arises from consistent monitoring through Statistical Process Control (SPC) and real-time feedback loops. For example, Lockheed Martin's use of digital dashboards and real-time defect monitoring has allowed rapid response to anomalies, reducing defect recurrence rates. Adopting similar digital monitoring practices at PT SkyInnovate Indonesia would enhance visibility across production lines and strengthen decision-making based on live process data. Moreover, benchmarking against external aerospace quality indices can provide valuable insights into performance gaps and stimulate strategic investment in technology and training.

Another lesson derived from global best practices concerns the integration of Six Sigma with Lean Manufacturing, resulting in the Lean Six Sigma (LSS) model. As George (2022) explains, Lean principles streamline production flow by eliminating non-value-adding activities, while Six Sigma minimizes variability. The combined framework, therefore, addresses both efficiency and precision. PT SkyInnovate Indonesia's assembly process, characterized by complex workflows and significant manual handling, could benefit from Lean Six Sigma integration to reduce waiting times, balance workloads, and minimize defect opportunities. Furthermore, the synergy between Lean and Six Sigma is particularly relevant for developing-country manufacturers, as it allows simultaneous improvement in cost efficiency and quality performance under resource constraints.

The empirical findings also suggest that smaller, incremental sigma improvements can yield meaningful gains in productivity and quality. As illustrated in the simulation phase, a projected sigma increase from 3.5 to 3.7 corresponds to a 25% reduction in DPMO. This observation echoes Harry, & Schroeder (2000); Antony & Banuelas (2002); Pyzdek & Keller (2022), who demonstrated that even partial improvements along the sigma scale produce disproportionate financial benefits due to reduced rework and warranty costs. Thus, while achieving 6σ remains a long-term target, intermediate milestones—such as attaining 4σ—should be established to maintain motivation and sustain organizational focus.

Furthermore, this study's findings reinforce the importance of validating root-cause analysis through triangulation. Combining quantitative metrics (DPMO, control charts) with qualitative insights (operator feedback and expert panels) ensured that improvement actions were evidence-based and contextually relevant. This methodological rigor aligns with best practices in quality research, where integrating multiple data sources enhances analytical credibility (Montgomery, 2019; Gijo & Scaria, 2011). For PT SkyInnovate Indonesia, this approach strengthens the foundation for ongoing continuous improvement cycles, ensuring that solutions remain adaptive to changing production realities.

Overall, the results and ensuing discussion highlight the multifaceted nature of quality improvement in aerospace assembly processes. PT SkyInnovate Indonesia's case confirms that achieving excellence requires not only technical accuracy but also alignment of human, procedural, and managerial dimensions. The organization's current performance—while below world-class standards—represents a transitional stage typical of aerospace firms in developing economies. By progressively institutionalizing Six Sigma tools, investing in measurement infrastructure, and fostering a culture of disciplined problem-solving, PT SkyInnovate Indonesia can accelerate its trajectory toward higher sigma levels and operational excellence.

The discussion underscores that Six Sigma's success in aerospace manufacturing is contingent upon contextual adaptation, sustained leadership engagement, and continuous benchmarking. The lessons drawn from international best practices affirm that while resource limitations pose challenges, structured methodologies such as DMAIC can yield significant performance improvements even in constrained environments. For PT SkyInnovate Indonesia, the pathway to world-class quality lies in embedding Six Sigma into daily operations, strengthening employee competencies, and leveraging digital analytics to drive precision and consistency. In doing so, the company not only enhances its competitive positioning but also contributes to the broader advancement of quality management practices within the developing-country aerospace sector.

6. CONCLUSION

This research applied the Six Sigma DMAIC framework to analyze and improve the Tail Boom Assembly process at PT SkyInnovate Indonesia, focusing on reducing nonconforming product occurrences and enhancing process capability. The study systematically followed the DMAIC stages, utilizing empirical data from the 2023 production cycle and employing statistical tools—such as control charts, Pareto analysis, and cause-and-effect diagrams—to identify root causes and develop targeted improvement actions.

The principal finding of this study is that the Tail Boom Assembly process currently operates at a sigma level of approximately 3.5, equivalent to a DPMO of 22,772.28. This indicates a moderately capable but suboptimal process relative to international aerospace standards, where sigma levels above 4.5 are typically observed. The analysis revealed that scrap and rework defects accounted for 96% of total nonconformance, confirming the Pareto principle that a small number of dominant factors contribute to most quality losses. The root-cause analysis identified measurement inaccuracy, procedural inconsistency, and human factors—particularly operator fatigue and skill variation—as the main contributors to defects.

By applying the structured logic of the DMAIC methodology, this research successfully quantified process performance, diagnosed systemic inefficiencies, and formulated feasible corrective actions. The proposed improvement initiatives—ranging from measurement system calibration and supplier audits to SOP standardization and skill development—are expected to enhance consistency and reduce process variation. Simulation results projected a potential improvement in sigma level from 3.5 to 3.7, corresponding to an estimated 25% reduction in defect rate. Although incremental, this improvement aligns with Six Sigma's philosophy of data-driven, continuous enhancement and reflects progress toward operational excellence.

The findings have several managerial and operational implications. From a managerial standpoint, the results emphasize the importance of embedding Six Sigma principles into the organizational culture rather than treating them as isolated projects. Leadership commitment, cross-departmental collaboration, and performance measurement systems must be strengthened to sustain long-term improvement. From an operational perspective, investing in precision measurement systems, structured training, and preventive maintenance can yield significant quality gains without major capital expenditure. These measures not only reduce the cost of poor quality but also enhance production reliability and customer confidence—critical factors in aerospace competitiveness.

Beyond organizational implications, this study contributes to the academic discourse on Six Sigma application in developing-country aerospace industries. While most prior research has focused on large multinational firms in advanced economies, this study provides empirical evidence of Six Sigma's adaptability in resource-constrained environments. It demonstrates that the DMAIC framework remains effective when appropriately tailored to local operational realities, offering a scalable model for small and medium-sized aerospace manufacturers. The integration of quantitative data with qualitative expert input also strengthens methodological rigor, reinforcing the relevance of triangulated analysis in industrial quality research.

The study's limitations should also be acknowledged. The analysis covered only one year of production data and focused on a single subassembly process (Tail Boom). Future research should extend to multi-year analyses to capture temporal trends and assess the sustainability of improvement outcomes. Additionally, subsequent studies could incorporate cost-benefit evaluation of improvement initiatives, integrate Lean principles for waste reduction, or explore digital tools such as real-time Statistical Process Control (SPC) and predictive analytics for proactive quality management.

This study affirms that Six Sigma serves as a powerful methodological and managerial framework for quality improvement in aerospace manufacturing. The structured DMAIC process not only provided empirical insights into defect causes but also fostered a culture of analytical thinking and evidence-based decision-making within PT SkyInnovate Indonesia. The study's findings underscore that even in developing contexts, systematic application of Six Sigma tools can yield measurable improvements in process performance and organizational learning. As the company continues to institutionalize continuous improvement practices, these results lay a strong foundation for advancing toward higher sigma levels, achieving operational excellence, and contributing to the broader goal of strengthening the competitiveness of the national aerospace industry.

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REFERENCES

[1] Antony, J. (2014). *Readiness factors for the Lean Six Sigma journey in the higher education sector.*

International Journal of Productivity and Performance Management, 63(2), 257–264.

[2] Antony, J., & Banuelas, R. (2002). *Key ingredients for the effective implementation of Six Sigma program. Measuring Business Excellence*, 6(4), 20–27. https://doi.org/10.1108/13683040210451679

[3] Axelsson, F., & Skogum, A. (2016). *Cost of Poor Quality – Development of a tool for identification and quantification of CoPQ* [Master's thesis, Chalmers University of Technology]. Chalmers Open Digital Repository. Retrieved from https://publications.lib.chalmers.se/records/fulltext/238708/238708.pdf

[4] George, M. L. (2022). *Lean Six Sigma: Combining Six Sigma quality with Lean production speed.* McGraw-Hill Education.

[5] Gijo, E. V. and Scaria, Johny and Antony, Jiju (2011) *Application of six sigma methodology to reduce defects of a grinding process.* Quality and Reliability Engineering International, 27 (8). pp. 1221-1234. ISSN 0748-8017 (https://doi.org/10.1002/qre.1212)

[6] Henderson, K. M., & Evans, J. R. (2000). *Successful implementation of Six Sigma: Benchmarking General Electric Company*. *Benchmarking: An International Journal*, 7(4), 260–281. https://doi.org/10.1108/14635770010378909

[7] Harry, M., & Schroeder, R. (2000). *Six Sigma: The breakthrough management strategy revolutionizing the world's top corporations.* Doubleday.

[8] Hoerl, R., & Snee, R. (2020). *Statistical thinking: Improving business performance*. John Wiley & Sons.

[9] Ishikawa, K. (1985). *What is Total Quality Control? The Japanese way*. Prentice Hall.

[10] Juran, J. M. (1995). *Juran's Quality Handbook* (5th ed.). McGraw-Hill.

[11] Mittal A, Gupta P, Kumar V, Al Owad A, Mahlawat S, Singh S. (2023). The performance improvement analysis using Six Sigma DMAIC methodology: A case study on Indian manufacturing company. Heliyon. 18;9(3):e14625. doi: 10.1016/j.heliyon.2023.e14625. PMID: 37101477; PMCID: PMC10123216.

[12] Montgomery, D. C. (2019). *Introduction to Statistical Quality Control* (8th ed.). John Wiley & Sons.

[13] Pop, G. I., Titu, A. M., & Pop, A. B. (2022). Requirements versus Knowledge in the Quality Management of the Global Engineering Process within an Organization in the Aerospace Industry. *Aerospace*, *9*(12), 817. https://doi.org/10.3390/aerospace9120817

[14] Pyzdek, T., & Keller, P. (2022). *The Six Sigma Handbook: A complete guide for Green Belts, Black Belts, and managers at all levels* (5th ed.). McGraw-Hill Education.

[15] Sharma, G.V.S.S., Rao, P.S. (2014). A DMAIC approach for process capability improvement an engine crankshaft manufacturing process. *J Ind Eng Int* **10**, 65. https://doi.org/10.1007/s40092-014-0065-7

[16] Sujova, A., Simanova, L., & Marcinekova, K. (2016). Sustainable Process Performance by Application of Six Sigma Concepts: The Research Study of Two Industrial Cases. *Sustainability*, *8*(3), 260. https://doi.org/10.3390/su8030260

[17] Thomas, A. J., Francis, M., Fisher, R., & Byard, P. (2016). *Implementing Lean Six Sigma to overcome the production challenges in an aerospace company*. *Production Planning & Control*, 27(7-8), 591-603.

[18] Womack, J. P., & Jones, D. T. (2013). *Lean Thinking: Banish waste and create wealth in your corporation* (2nd ed.). Simon & Schuster.

[19] Walston, J. D., Badar, M. A., Kluse, C. J., & Rostom, R. (2025). A Review Analysis of Cost of Quality, Cost of Poor Quality, and Hidden Quality Cost. Journal of Technology Studies, 50(1), 1–13. DOI: https://doi.org/10.21061/ jts.435

[20] Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods* (6th ed.). Sage Publications.