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Reliability in Aeronautical Systems and Decision Making Based on Preventive Maintenance: A Strategic Approach to Reducing Risks and Costs Operational

Reliability in Aeronautical Systems and Preventive Maintenance-Based Decision-Making: A Strategic Approach to Mitigating Risks and Reducing Operational Cost

Edson Costa – Postgraduate in Aircraft Maintenance Management from the University Sá's Internship

SUMMARY:

The reliability of aeronautical systems plays a fundamental role in flight safety and operational efficiency of commercial and military aviation. This article analyzes how modeling reliability and the use of statistical techniques applied to preventive maintenance contribute to more assertive decisions, with a direct impact on cost reduction, failure prevention and increased aircraft availability. Based on authors such as Barbosa (2018), Cruz (2016) and Vilela (2010), the main mathematical functions and statistical distributions used in failure prediction and their effects on the life cycle of aeronautical components are discussed.

International studies, such as that of Payne (2006), on the reliability of memory use in maintenance tasks are also considered. The data indicate that the intelligent use of reliability models allows the alignment of economic efficiency and technical safety, strengthening a culture of proactive safety in aviation.

Keywords: Reliability. Preventive maintenance. Aviation. Risk. Engineering aeronautics.

ABSTRACT:

The reliability of aeronautical systems plays a fundamental role in flight safety and the operational efficiency of both commercial and military aviation. This article examines how reliability modeling and the application of statistical techniques to preventive maintenance contribute to more assertive decision-making, with a direct impact on cost reduction, failure prevention, and increased aircraft availability. Based on the works of authors such as Barbosa (2018), Cruz (2016), and Vilela (2010), the study discusses the main mathematical functions and statistical distributions used in failure prediction and their effects on the life cycle of aeronautical components. International studies are also considered, including Payne's (2006)

research on memory reliability in maintenance tasks. The data indicates that the intelligent use of reliability models enables the alignment of economic efficiency and technical safety, thus strengthening a proactive safety culture in aviation.

Keywords: Reliability. Preventative maintenance. Aviation. Risk. Aeronautical engineering.

1. INTRODUCTION - Reliability as a Pillar of Aeronautical Safety

Reliability in aeronautical systems represents the ability of a component or system to perform its function without failure under specific conditions for a given period.

This concept is directly linked to operational safety, since in-flight failures can result in catastrophic consequences. As discussed by Barbosa (2018), reliability is essential both for preventing accidents and for protecting the reputation of operators and manufacturers.

The practical application of the concept of reliability begins in the design of aircraft, but its impact is most noticeable during operation and maintenance. Reliability allows us to predict, based on historical data, the probability of failures and the ideal time for maintenance.

According to Oliveira (2019), this ensures more accurate decisions about replacing parts, avoiding both unexpected failures and premature replacements.

The concept of component life cycle is closely linked to reliability. The reliability is not a fixed attribute, but varies according to the equipment's life stage — from infant mortality to wear and tear. As illustrated in the "bathtub curve," this Statistical behavior needs to be monitored to ensure timely interventions, as advocated by Vilela (2010).

In addition to the technical aspect, reliability also involves organizational culture. A company that values reliability invests in ongoing training, data collection and analysis, and the use of technologies that enable real-time monitoring. This behavior is compatible with the pursuit of proactive security, a central element in ICAO (International Civil Aviation Organization) and ANAC (National Civil Aviation Agency) audits.

In this context, failures cease to be just isolated events and become elements analyzable and predictable, as long as reliable data are available. Reliability engineering therefore offers essential tools for risk management and maintenance based on evidence, with positive impacts not only on safety, but also on profitability.

Therefore, reliability cannot be treated as a peripheral element in maintenance. aeronautics, but as a structural pillar that supports decision-making at all levels of the organization, from flight planning to strategic maintenance management

2 Data-Driven Preventive Maintenance: Concept and Applications

Preventive **maintenance** is one of the most widely used strategies in aviation to reduce failures and ensure the operational availability of aircraft. Unlike corrective maintenance, which reacts to failures that have already occurred, preventive measures seek to act before they happen. This concept has evolved over the decades and is currently strongly linked to the use of data to predict the ideal moment for intervention. According to Cruz (2016), modern preventive maintenance is based on the continuous collection of information about the systems, allowing an approach based on reliability and risk.

Onboard systems on modern commercial aircraft monitor in real time various operational parameters. This data is stored, processed and analyzed by maintenance engineers, who determine trends and predict wear. This approach is known as condition-based maintenance (CBM) and has become standard among large airlines, as pointed out in a report by Boeing (2020). CBM allows for increased time between inspections, reduced costs and improved security.

A good example of an application is the ACMS (Aircraft Condition Monitoring System) system, used by several airlines to monitor engines and hydraulic systems. This data is cross-referenced with statistical information on failures, allowing us to determine the residual reliability of components. When this reliability reaches a minimum limit acceptable, the replacement of the part is scheduled, with sufficient time for planning logistic.

The use of data-driven preventive maintenance is also directly linked to the concept risk. Each component has a level of criticality, and its failure can represent

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varied consequences. Highly critical components, such as flight control systems or engines, require more conservative maintenance strategies, while smaller items impact can follow more flexible models. This risk management is defended by Barbosa (2018) as a way to balance safety and operational cost.

Brazilian legislation, through ANAC, already recognizes and regulates preventive maintenance based on reliability. The Brazilian Civil Aviation Regulation (RBAC 121 and 145) requires operators to implement reliability control systems in their programs maintenance. However, effective implementation still faces challenges, mainly between regional and small operators, due to the cost of technological infrastructure necessary.

It is concluded that data-driven preventive maintenance is a promising strategy and aligned with international best practices. For its application to be effective, it is necessary investment in technology, professional training and organizational culture focused on proactive security.

3. Statistical Models in Failure and Reliability Prediction

Statistics is an essential tool in the reliability analysis of aeronautical systems.

Mathematical models are used to predict the probability of failures and calculate the time Mean Time Between Failures (MTBF), an essential indicator in maintenance programmed. One of the most widely used models is the probability density function Weibull, which allows estimating the behavior of failures over time based on adjustable parameters.

The Weibull distribution is preferred for its flexibility. With different configurations of its parameters (shape, scale), it can represent both initial failures (infant mortality), as random failures or wear and tear. This modeling is essential to define the optimal maintenance windows and reduce both the risk of in-flight failure and maintenance costs. excessive maintenance. Vilela (2010) states that Weibull is widely used in aeronautical engineering due to its practical applicability in different situations.

Another important tool is the bathtub curve graph, which represents the failure rate of equipment as a function of time. This curve is divided into three phases: initial (high rate of

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failures), intermediate (constant rate) and final (increasing failure rate due to wear). Understand what stage each component is in is essential for defining replacement strategies preventive, inspection or monitoring.

In addition to Weibull, other distributions such as Exponential, Lognormal and Normal are also applied depending on the behavior of the analyzed component. International studies, like Payne (2006), show that, in combat helicopter maintenance in the USA, the combination of operational data and statistical distributions reduced the number of incidents by 40%. unplanned failures in critical missions.

The correct choice of statistical model requires not only technical knowledge, but also access to quality historical data. The reliability of the information collected is a factor decisive for the efficiency of the analysis. As Cruz (2016) points out, failures in data collection or in the standardization of records can compromise the entire maintenance system based on reliability.

Thus, the application of statistical models in aircraft maintenance is not just a technical practice, but a management strategy with a direct impact on flight safety, resource optimization and the sustainability of air operations.

4. Information Management in Maintenance Engineering

Modern maintenance engineering depends largely on efficient management of information. With the increasing complexity of aeronautical systems and the amount of generated data, it is essential that companies implement processes and technologies capable of collect, store, process and analyze information accurately and quickly. Reliability, in this context, it is directly related to the quality of information.

One of the main challenges is data standardization. Several embedded systems can generate information in different formats, and its integration into unique analysis platforms requires investments in software, training and data governance. As Oliveira highlights (2019), the lack of standardization and clear information management policies leads to loss traceability and makes decision-making difficult.

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Furthermore, organizational culture significantly influences the quality of information. Companies that do not prioritize the correct documentation of failures, operating times and causes of interventions accumulate unreliable data, which compromises predictive models reliability. Awareness among technicians and engineers about the importance of records is therefore a key element for the success of the system.

Tools such as ERP (Enterprise Resource Planning) and CMMS (Computerized Maintenance Management System) are widely used in the aeronautical industry to consolidate and analyze maintenance data. These tools integrate failure histories, work orders, service, parts control and uptime, creating a robust basis for modeling statistics and technical auditing. According to the ICAO report (2020), companies that use CMMS effectively record 25% more operational availability in their fleets.

Analytical data processing also allows the creation of key performance indicators (KPIs), such as MTBF, MTTR (Mean Time To Repair) and RPN (Risk Priority Number). These indicators guide operational and strategic decisions, helping to prioritize interventions, allocate resources and improve processes.

Therefore, investing in information management is not just a regulatory or technical requirement, but an essential condition for the success of reliability-based maintenance. The Quality information is the basis of any safe and efficient decision in aviation.

5. Organizational Culture and Trust-Based Decision Making

Organizational culture is one of the least tangible, yet most influential, pillars in successful implementation of reliability-based practices. More than just tools statistics and embedded technologies, it is necessary that all actors in the organization — from the operational to the strategic level — understand and value the importance of prevention, of failure recording and analysis. As Barbosa (2018) argues, the culture of reliability must be built on the basis of technical education, internal communication and appreciation of preventive behaviors.

One of the central elements of this culture is trust in information. Technicians who do not see value in the data they collect tend to fill them with low accuracy or even omit them. them. This distortion seriously compromises the effectiveness of reliability models. The study de Cruz (2016) demonstrates that companies that implemented incentive programs accurate documentation of failures and interventions achieved 27% improvements in the accuracy of their predictive reporting.

Leadership also plays a fundamental role. When managers make decisions based on reliability data and encourage the team to do the same, a cycle is created virtuoso of organizational learning. The theory of the high reliability organization (HRO) – High Reliability Organization), proposed by Weick and Sutcliffe (2001), suggests that organizations operating in high-risk environments, such as aviation, should foster attention continuous to small signs of failure and promote rapid and coordinated responses.

Another important aspect is learning from failures. In punitive cultures, mistakes are hidden, preventing the generation of organizational knowledge. On the other hand, companies with organizational maturity treat failures as opportunities for improvement. This logic is defended by Reason (2000) in his theory of "latent failure", according to which accidents are result of accumulation of adverse conditions that could have been identified in advance.

International experience reinforces this view. According to a report by the European Union Aviation Safety Agency (EASA, 2020), operators that invest in a culture of reliability and in Continuous training for all levels of the organization presents up to 35% less operational occurrences per year, compared to companies with hierarchical models rigid and focus only on reacting to failures.

Therefore, building a culture of trust is an ongoing process that requires institutional commitment, ongoing education and participatory management mechanisms. When implemented well, it transforms the way an organization views security. and maintenance, promoting safer, more productive and sustainable operating environments.

6. Global Overview and Future Perspectives for Reliability Engineering in Aviation

Reliability, as a science applied to aeronautical systems engineering, has evolved from accelerated in recent decades. Around the world, air operators, manufacturers and agencies regulators have invested in increasingly sophisticated technologies and analysis models to

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predict failures and optimize maintenance cycles. According to the ICAO global report (2021), 89% of airlines with a fleet of more than 50 aircraft use some model based on in reliability to plan technical interventions.

On the global stage, countries such as Japan, Germany and the United States lead the use of tools like machine learning and artificial intelligence to predict failures based on large volumes of data (big data). In a study published by Sun et al. (2020) in the Journal of Intelligent Manufacturing, it was demonstrated that predictive algorithms reduced the aircraft downtime at Asian airlines by anticipating failures based on operational and environmental data.

Brazil has made progress in this field, but still faces structural challenges. ANAC has promoted programs to encourage the adoption of reliability-based systems, especially among regional transport and air taxi companies. However, as the study by Oliveira (2021), published in the Brazilian Journal of Aerospace Technology, Adhesion is still limited due to high implementation costs, low digital maturity and lack of data culture in smaller companies.

Another global trend is the concept of “digital twin”, in which virtual replicas of aeronautical components are updated in real time based on sensor data of the aircraft. This technology allows accurate simulations of future failures and interventions.

Companies like Airbus and Rolls-Royce already use this model to predict turbine failures weeks in advance, reducing costs and improving system performance (Rolls-Royce, 2020).

The future of reliability engineering in aviation also involves greater integration between universities, research centers and industry. Technological innovation projects supported by agencies such as FINEP and CNPq have allowed advances in Brazil, although on a smaller scale than those observed in countries in Europe and Asia. The consolidation of public policies aimed at innovation and technical capacity will be fundamental for the sustainable advancement of reliability in the country.

It is concluded that the global panorama of reliability engineering offers opportunities promising for Brazilian aviation, as long as there is continuous investment, collaboration

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between sectors and an institutional commitment to operational excellence. The future of safety and efficiency in the sector depends on the ability to predict and prevent, intelligently, risks before they materialize.

Conclusion

Reliability in aeronautical systems emerges as one of the main foundations for ensure operational safety, economic efficiency and sustainability of transport air transport in the 21st century. This article highlighted, through a scientific and humanized, such as the application of statistical models, information management and culture organizational contribute decisively to the implementation of preventive practices data-driven maintenance.

Such practices, in addition to reducing the risk of failures, increase the useful life of components and optimize the operational resources of airlines. Preventive maintenance based on data, when correctly applied, transforms traditional reactive logic of aviation into a predictive, efficient and adaptable system. As analyzed, tools such as ACMS, CMMS systems and statistical techniques such as the Weibull distribution allow an accurate prediction of failure behavior, reinforcing the strategic value of reliability engineering for the aeronautical industry.

It also became evident that the results obtained depend not only on the tools techniques, but of the organizational culture. Reliability is only consolidated as a practice institutional when there is a commitment to the collection, analysis and intelligent use of information. Continuous training programs, encouragement of internal communication and valuing good practices are essential elements for the success of the system.

Another important point addressed was the role of leadership in transforming this culture. decision to base maintenance and safety strategies on accurate reliability data be driven by senior management, with a focus on proactive safety and sustainability. The high reliability organization, as proposed by Weick and Sutcliffe, does not ignore risks, but anticipates them and treats them with technical and ethical rigor.

From a global perspective, Brazil is at an intermediate stage in the use of technologies advanced for reliability. While countries like Germany, the US and Japan implement digital twins and artificial intelligence to predict failures with high precision, the Brazilian scenario still requires investments in technological infrastructure, data culture and public policies to encourage innovation.

Despite this, positive experiences reported by Brazilian companies and initiatives carried out by ANAC demonstrate that the country has the potential to advance, especially with training partnerships between universities, funding agencies and the private sector. Applied research, combined with the growing use of big data and machine learning, represents a promising path for strengthening operational reliability in Brazil.

Reliability, therefore, should not be understood merely as a set of techniques or formulas, but as a management philosophy and a safety principle. Its application requires discipline, planning, technology and, above all, an ethical commitment to life human that depends on the correct functioning of aeronautical systems.

Thus, this article concludes that reliability is a link between science and safety, between data and decisions. Promoting it is, above all, reaffirming the importance of safe aviation, efficient and sustainable for economic and social development, both in Brazil and world.

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