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# Risk Analysis of Operational Service Structure in Nigeria

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## Abstract

For the success of every operational service, there is the need to evaluate its risk performance. While risk assessment is important, it is not devoid of maintenance and other activities in service delivery of any institution. The views and reviews of organizational activities is what makes the system successful or otherwise in its operation bearing in mind adequate feedback mechanism for good productivity. Thus, the risk structure of air safety flight operations will be adopted to do the analysis and review as a mini- Risk –informed case model. Analysis of the air safety operational framework of the Nigeria air force with some recommendations were suggested based on the evaluation of the research work. Hence, this work conducted a safety and risk assessment of the Nigerian Air force Service between the year 2015 and 2023.

**Keywords***: Safety, Risk Analysis, Availability and Reliability*

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## Background to the Study

According to Office of Safety and Mission Assurance, National Aeronautics and Space Administration, Ames Research Center, NASA, System Safety is the application of engineering and management principles, criteria and techniques to achieve acceptable mishap risk within the constraints of operational effectiveness and suitability, time and cost throughout all phases of the system life cycle. Hence, it is a rational pursuit of acceptable mishap risk within a systems perspective; one in which the system is treated holistically, accounting for interactions among its constituent parts.

In addition, National Aeronautics and Space Administration, Ames Research Center explains that the factors that affect system safety are listed below. They are:

1. The high cost of testing, which limits the ability to rely on test-fail-fix strategies of safe and reliable system development and drives reliance on analytical results.
2. Increasing system complexity, which makes it necessary to leverage both traditional and modern hazard evaluation mechanisms in order to identify and analyze comprehensively the full set of credible mishap scenarios that have the potential to lead to adverse consequences, considering all hazard causes and propagation pathways through the system.
3. The development of systems that operate at the edge of engineering capability, requiring a high degree of discipline in system realization and system operation management and oversight.
4. The use of unproven technology, requiring engineering conservatism to protect against unknown mishap risks while at the same time requiring allowances for novel solutions.

According to ACQ notes, program management tool for aerospace, system safety in risk and safety management is the application of engineering and management principles, criteria, and techniques to achieve acceptable risk within the constraints of operational effectiveness and suitability, schedule, and cost throughout the system's lifecycle. It covers the entire spectrum of Environment, Safety, and Occupational Health (ESOH) considerations. It is an integral part of the Systems Engineering (SE) process and specific activities are required throughout the different phases of the acquisition lifecycle. While it went on to define System safety as a specialty within system engineering that supports program risk management, which optimizes safety.

It further went on to classify system safety into eight elements, namely:

1. Element 1, document the system safety approaches. Which is to be carried out by either the program manager or the contractor.
2. Element 2, Identify and document hazards through a systematic analysis process that includes system hardware and software, system interfaces (to include human interfaces), and the intended use or application and operational environment. This process shall consider the entire system life-cycle and potential impacts to personnel, infrastructure, defense systems, the public, and the environment.

3. Element 3, Assess and document risks.
4. Element 4, Identify and document risk mitigation measures. This is to be done using the Hazard Tracking System.
5. Element 5, Reduce risk. This is to be achieved using Systems Engineering Process and Integrated Product Teams process.
6. Element 6, Verify, validate and document risk reduction. This is to be achieved using Hazard Tracking System (HTS).
7. Element 7, Accept Risks and Document.
8. Element 8, Manage Life-cycle Risks, using HTS.

In addition, system safety engineering is an engineering discipline that employs specialized knowledge and skills in applying scientific and engineering principles, criteria, and techniques to identify hazards and then to eliminate the hazards or reduce the associated risks when the hazards cannot be eliminated.

Furthermore, Dezfuli (2014), discussed about a framework for system safety used by NASA known as the Risk-Informed Safety Case (RISC). Whereby an approach affords more flexibility to determine, on a system-specific basis, the means by which adequate safety is achieved and verified. It also focuses on system-level safety performance and serves to unify safety-related activities. Whereby flexibility promotes innovation, as a highly emphasized value in NASA's 2014 strategic plan. The new framework supports the need for System Safety personnel to function in both “safety insurance” mode to support the design, development and operation of a safe system (a systems engineering function) and in “safety assurance” mode to inform risk acceptance decisions (a technical authority function). It promotes technical rigor in safety assessments and safety arguments to enhance their credibility, thereby influencing decision makers' acceptance of safety information. While, it also promotes a “questioning attitude” in those who must critically review the validity of safety arguments (to identify flaws in the argument, rather than attempt to accept it without any reservations). Thus, it streamlines System Safety activities (e.g., safety analysis activities) in order to reduce redundancies and potential inconsistencies. While it increases the likelihood of programs and projects staying within budget.

However, sequel to RISC, NASA System Safety Steering Group in September 2013, identified areas for improvement. These areas include:

- i. Adequacy of the discussions of the substance of System Safety results in project forums.
- ii. Integration among System Safety-related disciplines, e.g., hazard analysis, reliability analysis, probabilistic risk assessment and risk management.
- iii. Early involvement of System Safety in life cycle activities.
- iv. Integration of System Safety across centers and projects.
- v. Differentiation between System Safety requirements for crewed versus uncrewed missions.
- vi. More effective analysis of cross-system interactions.

vii. Adequacy of time allotted to perform System Safety activities.
viii. Better reporting of System Safety results to higher levels of the organization.
ix. Better treatment of uncertainties.

In environmental Engineering, Han (2012) defined Risk as the expected outcome of an environmental hazard (human injury, disease, economic losses or damage to the ecosystem), these include death. This is expressed as a function of hazard and its exposure.

$$\boldsymbol{Risk} = \boldsymbol{f}(\ \boldsymbol{Hazard}, \boldsymbol{Exposure}) \quad \textit{known as Equation } (1)$$

Rucka and Tuhovcak (2007) defines used IEC 300 – 3 -9 definition for risk, which is "a combination of the frequency or probability of occurrence and the consequences of an undesired event". Mathematically expressed below as:

$$\boldsymbol{R} = \boldsymbol{P} \times \boldsymbol{C} \qquad \textit{known as Equation } (2)$$
$$\boldsymbol{Where\ R = Risk; P = Probability\ of\ occurence\ of\ an\ undesired\ event\ and\ C} \\ \boldsymbol{= Consequence\ of\ the\ event}$$

While they further defined Risk Analysis as a systematic application of available information about the hazard identification and estimation of risk, which individuals, society, assets and the environment are exposed to. Which comprises of the task definition and definition of validity extension, hazard identification and risk estimation. This was also based on IEC 300-3-9 specification.

It is meant to answer three principal questions stated below;

| | |
|---|---|
| What can go wrong? | (Undesired events and Hazard Identification) |
| How likely is it? | (Frequency Analysis) |
| What are the consequences? | (Consequence Analysis) |

Syed (2003), Risk is associated with decision making in stochastic environments. Where the stochastic environment is broadly classified as the external environments and internal environments. Also, risk could be established in qualitative aspect as well as in quantitative aspect.

In addition, Syed further explained Engineering Risk Analysis as the risk viewed by the observer in quantitative terms. Where the quantification of risk involves looking for answers for three basic questions:

i. What can happen?
ii. How often failure is expected?
iii. What are the likely consequences?

Gurjar and Mohan (2002) explains that, Environmental Risk Analysis (ERA), or simply "Risk Analysis," has emerged as a discipline to study allowing for the analyzation of those events or activities that can pose a threat to human health or the environment. Thus, the analysis of risk includes risk assessment, risk characterization, risk communication, risk management, and policy relating to risk. While risks to be analyzed include those to human health and the environment, both built and natural.

According to Perry and Green (1999), Government regulations require hazard and risk analysis as part of process safety management (PSM) programs. According to Lees (1996), on Loss Prevention in the Process Industries, process safety differs from the traditional approach to accident prevention in a number of ways. They include:

1. There is more concern with accidents that arise out of the technology.
2. There is more emphasis on foreseeing hazards and taking action before accidents occur.
3. There is more emphasis on a systematic rather than a trial-and-error approach, particularly on systematic methods of identifying hazards and of estimating the probability that they will occur, and their consequences.
4. There is concern with accidents that cause damage to plants and loss of profit but do not injure anyone, as well as those that do cause injury.
5. Traditional practices and standards are looked at more critically.
6. Process safety can be applied in any industry, but the term and the approach have been particularly widely used in the process industries, where it usually means the same as loss prevention.

According to Syed (2003), Risk differs from reliability in that it is the statement of the probabilities of occurrences of events and the impacts of those events, whereas reliability describes how a system responds or reacts to events. An important feature of risk is that the consequences of events may be described in quantitative or qualitative terms. According to The Association for Manufacturing Technology (AMT), asset availability is "the percentage of potential production time during which equipment is operable, that is, operation is not prevented by equipment malfunction." This states that, asset availability measures the amount of time equipment was running and producing goods compared to the time production was stopped due to repairs. This is expressed mathematically below as:

$$\boldsymbol{Asset\ Availabilty} = \frac{\boldsymbol{Production\ Time}}{\boldsymbol{Potential\ Production\ Time}} \times 100 \quad Known\ as\ Equation\ (3)$$

Furthermore, asset availability considers three factors:

I. Potential Production Time: the amount of time equipment was expected to run, not counting non-equipment-related delays.
II. Production Time: the amount of time equipment actually ran.
III. Repair Time: the amount of time equipment was not running due to an unexpected malfunction and its subsequent repair.

Although, according to The Association for Manufacturing Technology (AMT), Asset reliability measures how long equipment performs its intended function (i.e., how often it breaks down). Reliability can be calculated in multiple ways, using either Mean Time Between Failure (MTBF) or failure rate. Explained below as:

1. The **Mean Time Between Failures (MTBF)** metric is the most often used measure of asset reliability. It measures how long assets run, on average, before experiencing a malfunction. Expressed mathematically as:

$$\textbf{Mean Time Between Failures (MTBF)} = \frac{\textbf{\textit{Total Run Time of Asset}}}{\textbf{\textit{Number of Failures}}}$$

Known as equation (4)

2. Another way to calculate reliability is to use the failure rate, which is the frequency at which an asset fails. To calculate failure rate, divide the number of failures by the total run time. Expressed mathematically as:

$$\textbf{\textit{Failure Rate}} = \frac{\textbf{\textit{Number of failures}}}{\textbf{\textit{Total Run time of Asset}}} \quad \textit{Known as Equation } (5)$$

Thus, $\textbf{\textit{Failure Rate}} = \frac{1}{MTBF}$ known as Equation (6)

However, according to Optimal's Asset-Reliability-as-a-Service i.e., ARAS, (2023), in terms of plant reliability, asset reliability is essentially a measure of the asset's availability to perform its required functions. How often does a machine or piece of equipment fail to operate at full capacity, whether it's due to breakdowns or other sources of downtime?

Also, Aimee (2022), explained that Reliability engineering can be applied across the entire lifecycle of software development. Thus, it is designed to increase the dependability of a product by detecting potential reliability issues early in the software development cycle, and correcting causes of failure that do occur. This entails catching issues as early as possible, which helps organizations to create more reliable products and help teams to increase the mean time between failures (MTBF). Which will help organizations to produce better products and to improve their reputation.

Although, Davis (2021), reiterated that, reliability is "the probability that a component or system will perform a required function for a given time when used under stated operating conditions." Thus, for equipment reliability, it's the chance that a piece of equipment does what you want, when you want it to, in a specific way. While equipment reliability is simply the chance a piece of equipment is available when you need it.

An online group inspectioneering.com defined reliability as a special attribute that describes the dependability of a component. This means that the component consistently performs a desired function under certain conditions for a certain period of time in order to meet business goals and customer needs. It further went on to express it theoretically. That is shown below as:

$$\textbf{\textit{Reliability}} = \mathbf{1} - \textbf{\textit{Probability of Failure}} \quad \textit{Known as Equation } (7)$$

Thus, the lower the probability of failure, the greater the reliability of the system. However, there are many factors that can contribute to the uncertainty involved with any new design and capital project including variations in materials, manufacturing plants, shipping, storage, and use. However, it went on to explain that besides the engineering practices described above, there are three other essential components to equipment reliability: maintenance, inspection, and technology.

In addition, Glenford (1976), defines software reliability as the probability that the software will execute for a particular period of time without a failure, weighted by the cost to the user of each failure encountered. Industrial engineers applied reliability analysis techniques for product quality control more than half a century ago. Aeronautical engineering has applied it for aircraft and spacecraft design. Communication engineering incorporates it for reliability of communication systems. Nuclear engineering applies it for safety evaluation.

Thus, the more reliable an asset is, the better it is able to perform its function on demand. In industrial environments, assets such as machinery and electronics can be extremely expensive; keeping them available for use reduces costs in several ways. That is why, when it comes to risk management, asset reliability plays a huge role in mitigating potential losses. The most common measures of asset reliability include MTBF (mean time between failures) and MTTR (mean time to repair). These metrics allow you to compare similar pieces of equipment based on their level of reliability.

In addition, National Aeronautics and Space Administration, Ames Research Center's Human-Computer Interaction (HCI) Group developed Mission Assurance System (MAS) Platform at the International Space Station (ISS), by their safety engineers for an unanticipated situation. Whereby safety engineers on ground are responsible for gathering all of the relevant information, assessing the risk and providing a course of action. In this type of situation, timeliness, efficiency, and a correct and complete scope of available data are vital to ensure the safety of everyone onboard. This is to enhance and streamline safety, maintenance and reliability as well as efficiency at all times. Hence the benefits of MAS are accuracy, cost effectiveness and efficiency.

Prior to Mission Assurance System - MAS, NASA relied mainly on Problem Reporting and Corrective Action (PRACA) documents alone for quite some time. However, MAS now supports three systems for the International Space Station – ISS, Safety and Mission Assurance Office including Items for Investigation - IFI/ Problem Reporting and Corrective Action - PRACA, Failure Modes Effects Analyses (FMEAs) and Hazard Reports.

## Materials and Methods

**Table 1:** Break-Down of Risk Structure of Safety Air Flight Operations

| Air Operational Activities | Origin of Hazard | Consequences |
|---|---|---|
| Drills and Maintenance | Natural Hazards | Health |
| Training | Manmade Threads | Economic |
| Rehearsals | Technical and Technological Hazards | Socio-Economic |
| Combat Operations | | Environmental |

Basically, every operations have its own structure. Thus, for the purpose of this work, this risk structure of air safety flight operations will be adopted to do the analysis and review as a mini- Risk –informed case model. This segments flight operation activities into three categories namely:

i. Air operational activities
ii. Origin of hazard
iii. Consequences

## Results and Discussions

**Table 2:** Summary of Nigerian Air Force Operational Incidents Between 2015 and 2023

| Ref | Facility | Number of Causalities | Type of Hazard Witnessed |
|---|---|---|---|
| 3. 01 | Airport Emergency Landing at Lagos airport | None | One of their jets lost its tyre |
| 3. 02 | Airport crash shortly after take- off from the Nnamdi Azikwe International Airport | 7 NAF personnel | Death and Equipment wreckage |
| 3. 03 | Airport crash involving two pilots | Two pilots | Human disappearance and Equipment wreckage |
| 3. 04 | Military Beachcraft 350 aircraft crashed at the Kaduna, International airport. | Eleven people | Death and Equipment wreckage |
| 3. 05 | Alpha Jet Aircraft crashed in Zamfara | Unknown | Human disappearance and Equipment wreckage |
| 3. 06 | A trainer aircraft crashed in Kaduna | Two pilots | Death and Equipment wreckage |
| 3. 07 | Air force plane crash in Kaduna | Seven persons | Death and Equipment wreckage |
| 3. 08 | An F-7NI jet crashed | One person | Death and Equipment wreckage |
| 3. 09 | Augusta Westland 101 Helicopter crashed in Makurdi | Unknown | Equipment wreckage |
| 3. 10 | NAF Augusta 109 Light Utility Helicopter crashed in Borno River | None | Equipment wreckage |
| 3. 11 | Two F-7Ni aircraft crashed in Abuja | One person | Death and Equipment wreckage |
| 3. 12 | NAF Mi-35M crashed near Damasak, Borno State. | Five persons | Death and Equipment wreckage |
| 3. 13 | NAF helicopter crashed while landing in Katsina State | None | Equipment wreckage |
| 3. 14 | NAF aircraft RV-6A Air Beetle crashed near Kaduna | Two persons (Pilot and Instructor) | Death and Equipment wreckage |
| 3. 15 | A Helicopter of the NAF crashed at the Enugu NAF base | None | Equipment wreckage |

From the above, it clearly shows that between 2015 and 2023, the Nigerian air force witnessed fifteen key incidents. Whereby four incidents had no causality during occurrence. Five pilots were lost during this period in operational activities. While one instructor's life was claimed during the period under review. Seven personnel staff of the Nigerian air force lost their lives during this period. While fifteen people of different categories also lost their lives. Although, two operations are still under exhaustive review process with unknown number of causality. On the part of Asset and human management, the operations witnessed eight incidents of both human death and equipment wreckage. Though, with four incidents of equipment wreckage only. While it had two incidents of human disappearance and equipment wreckage, and one incident of tyre break-down and loss.

**Table 2:** Analytical Review of The Break-Down of Risk Structure Safety Air Operations

| S/N | Risk Structure Analysis | Number of Incidents |
|---|---|---|
| 1 | Drills and Maintenance | Four |
| 2 | Training | Three |
| 3 | Rehearsals | One |
| 4 | Combat Operations | Seven |
| | | |
| 1 | Natural Hazards | Two |
| 2 | Manmade Threads | Six |
| 3 | Technical and Technological Hazards | Seven |
| | | |
| 1 | Health | At least eight |
| 2 | Economic | Fifteen |
| 3 | Socio- Economic | Fifteen |
| 4 | Environmental | Fourteen |

From the method adopted earlier in materials and method, the risk structure analysis of Nigerian air force activities between 2015 and 2023 shows that during air safety operation, drills and maintenance recorded four safety hazardous incidents. Three safety hazardous incident were observed during training activities. Rehearsals witnessed one incident while combat operations recorded seven incidents. On the origin of the hazard incidents, natural hazards were responsible for two incidents. While manmade threads were responsible for six incidents. Just as Technical and technological hazards were responsible for seven incidents. On the consequence of the operational incidents, the health issues that were involved were in eight incidents of air flight operations. While economic concerns were in all fifteen incidents. Just as the socio-economic details were raised in all fifteen incidents. While environmental concerns were in fourteen incidents only.

## Conclusions

It is important to understand that the risk structure of air safety flight operations was adopted to do the analysis and review as a mini- Risk –informed case model. While this work conducted a safety and risk assessment of the Nigerian Air force Service between the year 2015 and 2023.

Thus, from the summary table on operational activities, it shows that between 2015 and 2023, 14 military air crashes took place. 15 Nigerian aircrafts were lost due to the incident. Under the period of review, 33 military personnel were killed and 2 unknown whereabouts. The operations recorded equipment wreckage on all incidents except on one occasion that resulted in emergency landing at Lagos International airport, where a jet aircraft lost one tyre. It also recorded unknown whereabouts of the victims or human disappearance on two incidents. Recall that, earlier in our materials and methods, the air operational safety risk structure breaks the operational risks into three sub-groups. They are:

i. Air operational activities.
ii. Origin of hazard.
iii. Consequences.

Based on the above, it is clear that with the analysis of break-down of air flight safety operations that Nigerian air force need to liaise and review the operational framework for system safety used by NASA known as the Risk-Informed Safety Case (RISC). Government and stakeholders should also consider Problem Reporting and Corrective Action (PRACA) as an operating mechanism in the industry. This will be used on areas of maintenance, reliability and asset management. The Federal government of Nigeria through its policy makers and top-level administrators should understudy the framework for adequate implementation at the air operational activities.

Government can also set up a steering group for this particular purpose. This will not only create jobs in line with the vision of the Nigerian Leadership model but, stimulate the economy of the country and in turn streamline the activities of various stakeholders, policy makers and leaders in the known sectors concerned. Hence a major boost for productivity, efficiency and reliability of the Nigeria air safety operations.

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