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RESONANCE OF FAILURE: THE TAM FLIGHT JJ3054 ACCIDENT

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ABSTRACT

The TAM Flight JJ3054 accident, which occurred on July 17, 2007, at Congonhas's Airport in São Paulo, is examined as a case study in the emergence of failures within complex sociotechnical systems. Using the Functional Resonance Analysis Method (FRAM), this research models how normal performance variability and unanticipated interactions among system functions contributed to the accident. Moving beyond linear causality, the FRAM approach enabled the functional reconstruction of key system behaviors, including thrust lever management, braking system activation, degraded runway surface management, time-constrained decision-making, and the influence of organizational and regulatory structures. The analysis reveals how minor, routine performance variations (individually acceptable) can combine non-linearly to generate conditions conducive to systemic failure. Contributing factors such as the dispatch of the aircraft with one thrust reverser inoperative, the lack of runway grooving under wet conditions, and the persistence of outdated standard operating procedures illustrate how latent conditions and real-time adjustments interact dynamically. Rather than resulting from a single failure or human error, the accident emerged from the resonance of functional variabilities across technical, human, environmental, and organizational dimensions. By adopting a systems-oriented perspective, this study reinforces the need for operational models that capture real-world complexity and performance variability. It also highlights the value of FRAM as a methodological tool for anticipating emergent risks in aviation, supporting the development of resilience-informed safety strategies that go beyond compliance and error prevention.

Keywords: FRAM, Complex Sociotechnical Systems, Minimum Equipment List, Aviation.

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If applicable, insert here the acknowledgements. In the next pages any information that could potentially uncover the authors identity may be provided. Before uploading the PDF file of the article, please remove all the properties (metadata) of the file as names, etc.

GENERATIVE AI USAGE STATEMENT

This research did not use generative AI.

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1 INTRODUCTION

Civil aviation is widely recognized as a complex sociotechnical system, in which multiple elements (human, technological, and organizational) are interconnected and interact dynamically (Belmonte et al, 2011). In general, complex systems comprise different groups of people, technologies, and organizations that interact non-linearly with each other across various industrial domains (Tian & Caponecchia, 2020). These systems are composed of numerous components that, although performing specific functions, depend on one another to ensure the safe and efficient operation of the whole. As pointed out by (Righi & Saurin, 2015), complexity is not merely defined by the number of elements involved, but rather by the way in which these elements connect, vary over time, and respond to unforeseen situations.

In the context of aviation, this complexity is evident. The flight of an aircraft involves a wide network of interactions: pilots operate advanced systems, following procedures defined by the airline and the aircraft manufacturer; these procedures are based on regulations established by authorities such as ANAC, FAA, and EASA; Air traffic control, in turn, provides authorizations and weather information that are essential for flight safety. Aircraft maintenance, airport infrastructure, and even passengers are part of this network of mutual dependencies. Any failure, delay, or adaptation in one of these elements can directly affect the performance of the system.

In addition, such interactions do not occur in a linear fashion. Small changes in one part of the system can generate unexpected effects in other parts, making event predictions and control a challenging task (Macchi, 2010). This is why specific methods, such as the Functional Resonance Analysis Method (FRAM), have been applied to model complex systems such as aviation. FRAM allows visualizing how system functions connect and how variations in performance can lead to undesirable consequences, without relying on direct cause-and-effect logic (Hollnagel, 2012).

This paper aims to explore this complexity by modeling the TAM JJ3054 accident using the FRAM. Through this approach, it seeks to demonstrate that civil aviation should not be analyzed solely based on its isolated technical components but rather understood as an integrated system in which the interactions among people, technology, and organizational structures determine its behavior and associated risks.

2 THE FUNCTIONAL RESONANCE ANALYSIS METHOD

The FRAM derived from a need to understand and describe how performance in the complex dynamic socio-technical systems unfolds and how the “mechanisms” behind everyday performance variability may be modelled (Patriarca et al., 2020). It is a method-sine-model, which focuses on the system functioning rather than the structure of its components (Tian & Caponecchia, 2020). Its purpose is to build a model of how things happen rather than to interpret what happens in the terms of a model.

FRAM is built over the following four principles (Patriarca et al, 2017). First, failures and successes are equivalent in the sense that they have the same origin. In other words, things go right and go wrong for the same reasons. Second, the everyday performance of socio-technical systems, including humans individually and collectively, is always adjusted to match the conditions. Third, many of the outcomes we notice – as well as many that we do not – must be described as emergent rather than resultant. Fourth, the relations and dependencies among the functions of a system must be described as they develop in a specific situation rather than as predetermined cause–effect links. This is done by using functional resonance (Hollnagel, 2012).

The modelling process consists of four steps. First, the complex sociotechnical system is deconstructed into "functions", that represent a task, or an activity, required to produce a certain outcome. This step identifies these functions that are needed for everyday work to succeed, characterizing them by six different aspects as shows in Figure 1. Aspects are traditionally placed at the corners of a hexagon, which represents the function itself.

Figure 1: A Hexagon Representing a Function.

Second, the variability of the functions that constitute the FRAM model are characterized. Here, it is necessary to assess how performance variability will show itself – either in the sense of how it can be observed or detected – or in the sense of how it may affect downstream functions. Third, specific instantiations of the model are examined to understand how the potential variability of each function can become resonant, leading to unexpected results. Fourth, performance variability is monitored and managed.

2.1 Case Study: TAM Flight JJ3054

The accident of TAM Flight JJ3054, which occurred on July 17, 2007, at São Paulo/Congonhas's Airport (ICAO Code: SBSP), highlighted significant gaps in operational procedures related to landings with one thrust reverser inoperative, as well as a broader set of contextual and organizational contributing factors. According to the Final Report issued by the Aeronautical Accidents Investigation and Prevention Center (CENIPA, 2011), the Airbus A320-233 (registration PR-MBK) was operating with the right thrust reverser deactivated, a condition allowed by the Minimum Equipment List (MEL), provided that specific operational precautions were followed.

At the time of the accident, MEL procedures permitted dispatch with one inoperative reverser under the condition that the associated thrust lever be placed at IDLE during landing. However, the MEL did not require a physical constraint or a checklist item to ensure this configuration, making it possible for the thrust lever to remain inadvertently in the CLIMB position as it did in the case of Flight JJ3054 (Carvalho, 2011). This incorrect lever position prevented the automatic activation of the ground spoilers, autobrake, and the reverse thrust on the operational engine, resulting in a significant loss of deceleration capability (Silva, 2023).

Following the accident, Airbus issued a Service Bulletin (SB) recommending physical or procedural safeguards to prevent thrust levers from being set incorrectly during landing when operating with an inoperative reverser. Among the new measures introduced were procedures to physically block or remove the reverser-inoperative thrust lever from the reverse range, and the requirement to ensure both levers are in IDLE at touchdown. These revisions aimed to eliminate the possibility of asymmetric thrust lever positions during the landing roll.

This change was especially critical because operating with one inoperative reverser substantially increases the required landing distance. According to the investigation, the absence of one reverser may increase the landing distance by approximately 28% on a dry runway, and up to 40% or more on a wet surface (CENIPA, 2011). At the time of the accident, Runway 35L was wet from recent rainfall and, critically, lacked grooving longitudinal cuts on the runway surface that significantly improve water drainage and braking friction. The lack of grooving increased the likelihood of hydroplaning and degraded the effectiveness of the braking systems (Salehi et al, 2021).

Adding to the risk, a runway overrun had already occurred the day before the accident under similar weather conditions, yet no new restrictions or operational adjustments were imposed. Despite the adverse environmental conditions, the existing operational framework did not prohibit the use of an aircraft with an inoperative thrust reverser on that runway. This underscores a gap in safety oversight from both the operator and regulatory authorities.

It is important to note that while the Service Bulletin (SB) issued by Airbus provided critical guidance to mitigate such risks, SBs are not mandatory unless enforced through an Airworthiness Directive (AD) by aviation authorities. In this case, implementation of the SB remained optional, depending on the operator’s initiative. The lack of mandatory enforcement delayed systemic improvements, even though previous incidents such as one involving the TAM aircraft PT-MRE in early 2007 had already signaled the vulnerabilities of the existing procedures.

The case of TAM JJ3054 illustrates how the combination of technical misconfiguration, inadequate procedural safeguards, and adverse environmental conditions, particularly a wet, ungrooved runway can converge to produce a catastrophic outcome, even within the bounds of regulatory compliance. It also highlights the limitations of MEL-based permissions in the absence of contextual risk assessments and regulatory adaptation.

2.2 Investigational Outcomes

The investigation outcomes emphasize that the accident resulted from the interplay of multiple contributing factors across technical, environmental, human, and organizational domains.

Technical outcomes: highlighted that the thrust lever for engine #2 remained in the CLIMB detent at touchdown, while engine #1 was placed correctly at IDLE. This misconfiguration prevented the automatic deployment of ground spoilers and inhibited the autobrake system, significantly reducing braking capacity leading to continued forward thrust despite landing (CENIPA, 2011).

Environmental outcomes: note that Runway 35L was wet and slippery, having recently been resurfaced but lacking grooving. The report does not confirm hydroplaning nor brake system inefficiency per se. Instead, it identifies that the pilot’s awareness of slippery conditions influenced procedural decisions—specifically, opting for an older throttle procedure—rather than the surface itself causing physical brake failure (CENIPA, 2011).

Human factors outcomes: underscore that the flight crew failed to recognize and correct the asymmetric thrust lever configuration, an error amplified by anxiety and stress. Despite audible “RETARD” callouts, there were no cockpit warnings specific to asymmetric lever positioning, and autobrake activation was suppressed because spoilers did not deploy (CENIPA, 2011).

Organizational outcomes: revealed that while regulatory requirements, including MEL permissions for operation with one inoperative thrust reverser—were formally observed, risk mitigation measures were insufficient. Moreover, the report highlights a lack of standardized training, inconsistent procedure usage among crews, and inadequate oversight of runway conditions and procedural compliance (CENIPA, 2011).

Based on these findings, the investigation recommended:

- Revising operational policy on flying with inoperative equipment under adverse runway conditions, including ensuring thrust levers are correctly positioned at idle during approach and touchdown;
- Implementing a warning system to alert crews to incorrect thrust lever settings (Recommendation 172/A/07);
- Standardizing pilot training and procedures regarding asymmetric thrust, spoiler/autobrake deployment logic, and handling of deferred reversers;
- Requiring runway grooving on short, wet, and high-traffic runways like Congonhas to improve drainage and braking performance (CENIPA, 2011);
- Strengthening safety culture within airlines to reduce tolerance for procedural deviations;
- Enhancing regulatory oversight of both operational practices and airport infrastructure conditions.

These outcomes reflect systemic safety deficiencies, not merely individual actions (Alboghobeish & Shirali, 2022). However, the report did not employ a systemic tool (e.g. FRAM) to generate these findings; it identified latent and active failures through data analysis, crew behavior, and environmental context, highlighting the complex interactions that led to the accident.

2.3 Applying the FRAM

The methodology described in Section 2 was applied to TAM Flight JJ3054 accident. Figure 2 shows a diagram with the functions considered relevant to explain how the system was expected to work. The diagram was drawn using the FRAM Model Visualiser. Note that the component responsible for the execution of each function is represented through the color as follows. Mustard denotes the airline, green the flight crew, blue the aircraft and turquoise the aircraft manufacturer. Pink is related to the airport infrastructure, red indicates the official investigation body, and grey characterizes the certification authority.

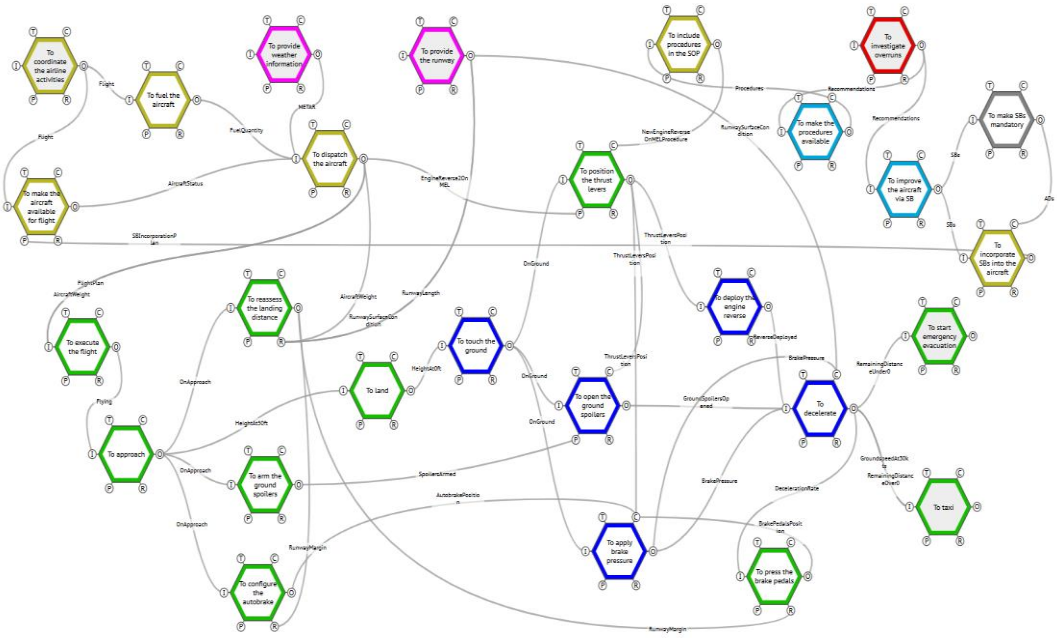

Figure 2: FRAM Diagram for the TAM Flight JJ3054 Analysis – System as Expected.

Each commercial flight belongs to an airline that is responsible for the crew training and schedule; the aircraft maintenance, fueling and catering; and so on. In the current analysis, the functions “To make the aircraft available for flight” and “To fuel the aircraft” were considered pertinent as the aircraft was released with an engine thrust reverse on MEL and filled with extra fuel due to the fuel price at the destination airport. This information is compiled by the dispatcher, responsible for the flight plan as well as for communication between the maintenance/ground services with the pilots.

The flight crew executes the flight as prescribed by the airline. During approach, they usually reassess the landing distance, arm the ground spoilers and configure the autobrake. The former has the runway margins as an output, that is a comparison between the runway length and the distance that the aircraft needs to land and brake to a complete stop. Among other factors, this distance depends on the aircraft’s weight and the runway surface condition. A heavy aircraft as well as a wet and/or contaminated runway requires more field to stop. Ground spoilers are panels mounted on the upper surface of the wing. When extended, they dump the lift raising the load on the wheels and thus improving the wheel-brake efficiency. They also increase aerodynamic drag contributing to aircraft deceleration. The spoilers usually deploy automatically (if armed) upon touchdown or upon thrust reverser’s activation. Autobrake systems provide automatic braking at maximum deceleration rates, which varies according to runway surface conditions and its mode selection (e.g., Low, Medium, High) (Reiser et al., 2024).

The landing starts at 50-feet Above Ground Level (AGL) and the aircraft touches the ground at 0-feet AGL. The pilots position the thrust levers in order to deploy the engine reversers. To accomplish that, they should follow a new operational procedure for at least one engine on MEL (Minimum Equipment List). This procedure was established a few months prior to the accident due to further overruns. The overruns had initiated investigations, whose recommendations resulted in corrective actions that were made available by the aircraft manufacturer (i.e., the new operational procedure and the inclusion of the “ENG THR LEVER ABV IDLE” warning via Service Bulletin (SB)). The procedure was provided to the pilots, and the SB was not incorporated into the aircraft. There was no Airworthiness Directive (AD) over this SB. Note that these corrective actions aim to minimize the impact of a questionable influence of the thrust lever position on the ground spoilers and the wheel brake action. At touchdown, ground spoilers should automatically deploy, and brake pressure should automatically be applied in accordance with the autobrake settings.

The aircraft decelerate, which is monitored by the pilots together with the distance to the runway end. If necessary, the crew takes control of the brake pressure employment through pedal application. At a groundspeed of approximately 30 knots, the pilots start taxiing when the aircraft is within the runway. If the aircraft surpassed the runway limits, they start the emergency evacuation procedure.

Figure 2 already confirms the complexity of the aviation system. Even being a simplified and targeted version of the system, it is composed of many components that interact with each other in non-linear ways. In addition, the TAM Flight JJ3054 accident revealed some unpredictable functions and connections among the components, as illustrates Figure 3.

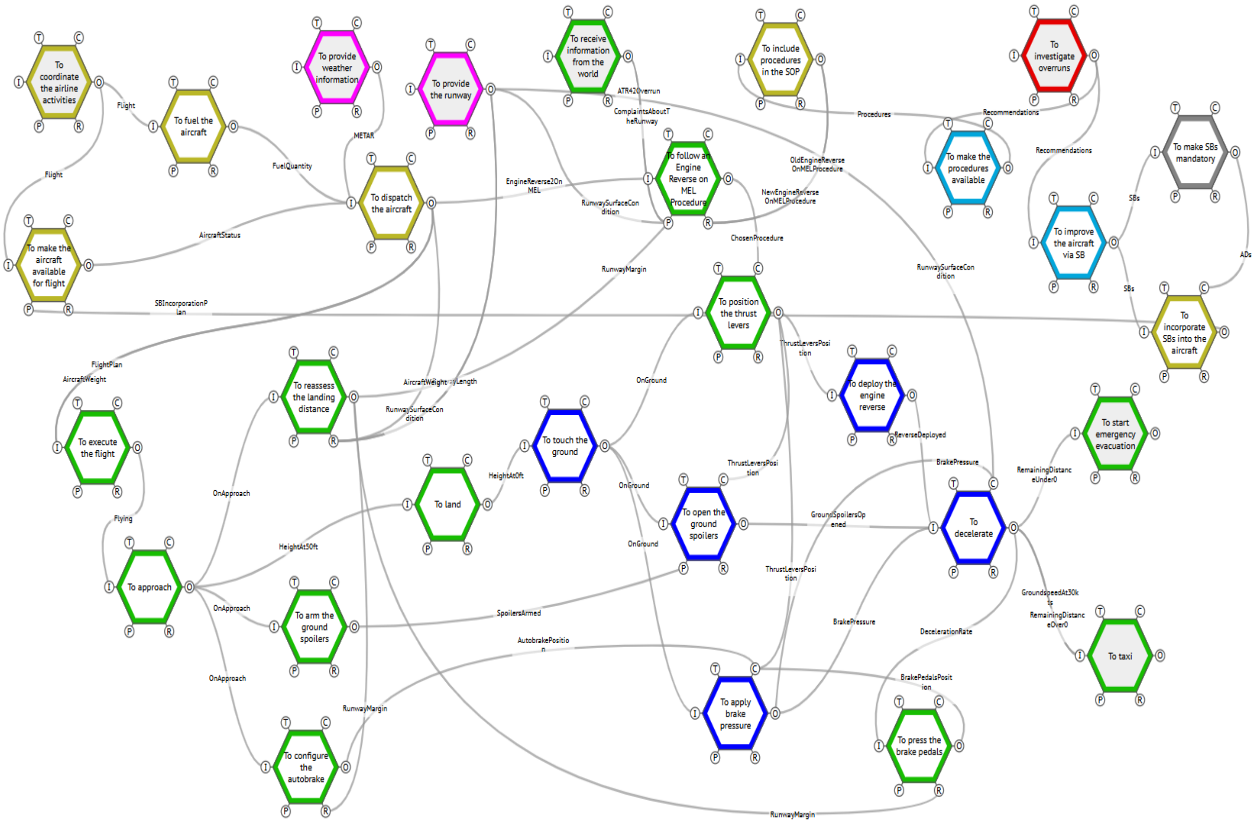

Figure 3: FRAM Diagram for the TAM Flight JJ3054 Analysis – System as Worked.

To summarize, the flight crew does not strictly follow a new procedure because the airline substitutes the old one in the Standard Operating Procedures (SOP). The old procedure resides in their mind and may be used whenever it seems more appropriate. The new procedure imposed an increase of up to 55 meters in the calculations of runway distance required for landing. A distance that the pilot decided to regain because of a low margin in a wet and maybe contaminated runway. A runway that had just been reopened without the grooving prescribed in the project and where many pilots presented problems related to operations in rainy conditions. In addition, an ATR 42 aquaplaned the runway one day before the crash. Therefore, two functions were added to the model: "To receive information from the world", exemplifying the contextual conditions of the world in the fateful flight, and "To follow an engine reverse on MEL procedure", representing the pilot decision-making process.

As a lesson learned, it is recommended the monitoring of new procedures execution, mainly when the modification is related to safety. The use of the old procedure due to the additional distance required for landing could be present in further flights, prior to the JJ3054 one. Programs such as the Flight Data Monitoring (FDM) are available, being this one designed to enhance safety by identifying airlines' operational safety risks through the routine analysis of flight data during revenue flights (Delhom, 2014).

3 CONCLUSIONS

The analysis of the TAM Flight JJ3054 accident using the FRAM method highlighted the intrinsic complexity of sociotechnical systems. The study showed that, rather than isolated causes or individual failures, the accident resulted from the dynamic and non-linear interaction among multiple system functions, whose performance variations, normally acceptable in daily operations, combined unexpectedly under specific contextual conditions. Factors such as operating with an inoperative thrust reverser, adverse runway conditions, operational pressure, and organizational limitations proved to be interdependent in shaping the scenario that culminated in the tragic outcome.

The application of FRAM enabled a broader understanding of how the different layers of the system (i.e., human, technical, and organizational) interact and influence operational safety. This approach reinforces the importance of adopting systemic models both in accident investigations and risk management, recognizing that performance variability is inherent to operations and that its management is fundamental to enhancing system resilience. Thus, the study contributes to advancing aviation safety by demonstrating the usefulness of analytical tools like FRAM to identify latent vulnerabilities and strengthen protective barriers, preventing small variations from escalating and resulting in future accidents (Ghasemi, Zarei & Salehi, 2024).

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