Measurement of the Variability of Flight Test Instruction Organizational Processes

Thiago Fontes Macêdo[1]

Instituto de Pesquisas e Ensaios em Voo (IPEV)

Moacyr Machado Cardoso Júnior[2]

Instituto Tecnológico da Aeronáutica (ITA)

Mário Henrique de Oliveira Coutinho da Silva[3]

Comando de Aviação do Exército (CAVEx)

ABSTRACT

Flight test instruction is an overwhelmed activity by risk factors, ranging from the student's inexperience to the work overload imposed on flight instructors, as they become directly responsible for ensuring, in addition to quality of instruction, setting deadlines and meeting minimum safety levels. The article aimed to develop ways to map and quantify the stages of an instructional organizational process, and, thus, ensure better flight safety conditions in activities, based on the use of relatively new and little explored concepts and methods in the flight test environment. For this, Functional Resonance Analysis Method (FRAM) was selected to graphically depict the complexity of socio-technical systems, and the Monte Carlo Simulation, for quantifying the variability of the functions described from the use of FRAM, allowing the semi-quantification and measurement of variability in the execution of a sub-phase of the Fixed Wing Flight Test Course. Thus, the integrated application of the tools resulted in an objective way to manage the organization risk of flight test instruction activities, as it generated the identification and quantification of processes variability, as well as the activities with the greatest potential for resonance.

1. INTRODUCTION

Flight instructions are in themselves an activity fraught with risk factors, ranging from the student's inexperience to the work overload imposed on flight instructors, as they become solely responsible for ensuring safety during the flights. From the instructor perspective, the current state of the aircraft, the traffic, the weather, the airspace, the flight area, and certainly, the student progress and attitude require a notable level of situation awareness [1]. Furthermore, when the flight instruction environment is combined with the flight test activity, an escalation of hazards is clearly observed, since the flight test normally implies to explore areas and capabilities not experienced before, many times, pushing beyond the limits during aircraft development and upgrading [2].

In the Brazilian Air Force, the flight test organization responsible for training the specialized flight test professionals such as pilots, engineers, and instrumentations technicians is the *Esquadrão de Formação em Ensaios em Voo* (EFEV), located at the city of São José dos Campos, Brazil. Considering this demanding role assigned to EFEV, it is necessary to maintain a high level of safety during its routine flight activities. The legislation that supports flight safety through flight test instruction is the Flight Test Safety Program, or in Portuguese, *Programa de Segurança de Voo em Ensaios* (PSVE), which aims to prevent incidents and accidents during its activity. It establishes processes and guidelines for flight test risk management based on the classical test hazards analysis method to manage the hazards that could occur in a flight test program or test flight [3]. Aviation regulatory institutions, such as, the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO) rely on the same methods to map and survey the hazards involved in flight activity [4,5], concentrating most of the effort in identifying the root causes of the unwanted

1 M.Sc., Aeronautic Sciences – ITA post graduate student
2 PhD, Engineer - ITA professor
3 M.Sc., Military Sciences – ITA post graduate student

outcomes, based on chain events theories, to know the Reason's Swiss Cheese approach [6]. However, those theories tackle the events through the knowledge obtained mostly when something undesired or dangerous happens, implementing barriers to avoid a reiteration of the undesired outcomes. Honnagel [7] endeavors a new view to complement the traditional "cause-effect" mechanism theories stated for a long time in academic risk assessment. He proposes to look to the risk as a result of a systematic and complex interactions of events and players, aiming on picturing of how the activity is actually performed, tracking the synergy among the components of the activity.

To understand the flight test synergy, it is necessary to know that it aims to explore the limits of the aircraft to investigate and verify the expected behavior of the airplane requirements. Frequently, a flight test project takes months, from the test plan production, which is the document that describes all the aspects of the flight test execution, to the last report, the product of any test campaign. The flight test instruction follows the same concept, but with a shorter schedule. The syllabus for a fixed wing experimental test pilot normally covers four wide areas, performance, handling and flying qualities, systems, and aircraft qualitative evaluation. Each of these areas are guided by a test plan which is remarkably similar to which is executed in a test project, however, with the addition of the instruction labor happening over it. To carry out this complex task, several actors have to come into play. Figure 1 shows a diagram of the *Instituto de Pesquisas e Ensaios em Voo* (IPEV) organization structure, which provides the support to EFEV execute the courses.

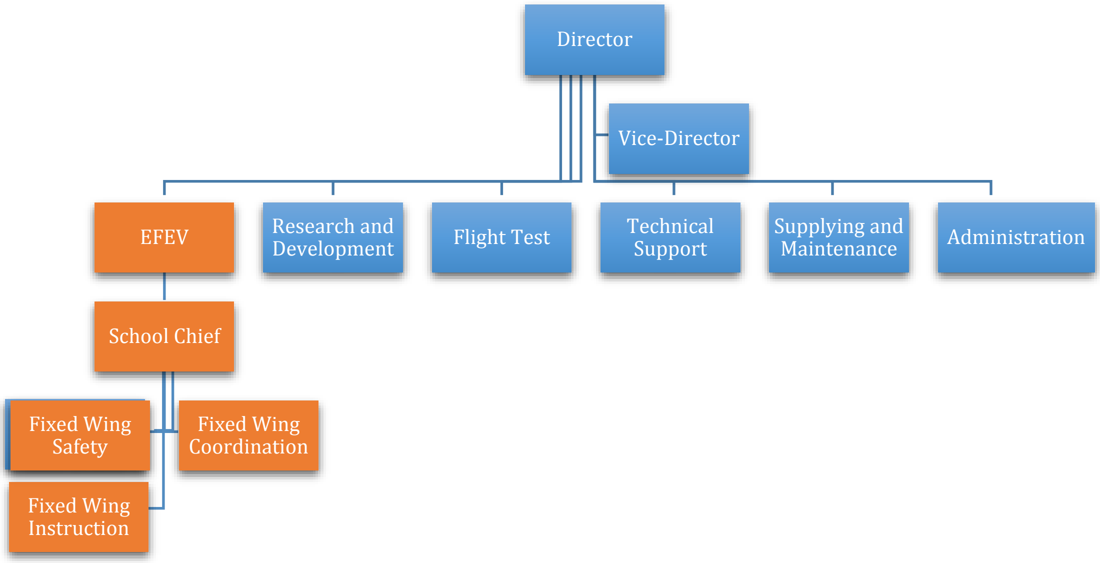

Figure 1 - IPEV organogram
Source: www.ipev.cta.br

As an example, the supplying and maintenance area is responsible for providing the aircraft ready and up for the flights, as long as, the technical support is responsible for the instrumentation of the airplanes allowing the students to gather the data from the flight and processing to theirs reports. Inside the EFEV, another structure is built to support the safety and instructional aspects of the school. This structure will be important to understand how work is planned to be done and how work is actually done. From Figure 1, we can infer that many actors are involved in the process. Besides EFEV roles, the IPEV accomplishes other activities, such as, all flight test required by Brazilian Air Force, research and developmental of new products, and so on. However, most of the times, it uses the same human and material resources that is used by the school, which increases the interest conflicts inside the organization on sharing those resources.

According Rosenhead [8], when a situation has several actors, points of views and interests, mainly embedded in uncertainties, it is classified as a “wicked problem”. The safety management of flight test instruction involves various sectors of the organization, ranging from the fatigue control of the flight personnel to the hazards analysis of flight events. Furthermore, the instructional environment brings an even greater challenge in how to manage the organization's risk to teach an inherently dangerous activity. Since hazard analysis is a well-known and quite common tool for flight test, and mostly used as a safety management process specifically for the test events, as stated in documents from FAA and IPEV [3, 9], this article will concentrate on how the organization synergy could have an impact on the flight activity.

Thus, the objective of this article is to map and quantify the variability of the organizational process in the flight test instructional activity, seeking for better conditions of safety from the use of relatively new concepts and methods in the environment of flight test risk management. For this, the Functional Resonance Analysis Method (FRAM) [10] was selected to portray in graphical form the socio-technical system of this case study facilitating the visualization of all the stages and actions actually developed in the process, and Monte Carlo Simulation (MCS) to quantify the function interactions described from FRAM, allowing to survey system variability.

In this study, a brief description of the methods used will be addressed in the next section, followed by their application in a case study with the analysis of the results and a proposal for future studies.

2. DESCRIPTION OF THE METHOD

2.1 Functional Resonance Analysis Method (FRAM)

FRAM is a method developed by Erik Hollnagel [10] for mapping and systemic visualization of processes and activities, allowing the identification of the risks and variability involved. The method represents socio-technical systems in the form of technical, human, or organizational functions, with the objective of understanding how systems actually work and how variability propagates among their functions, aiming to develop more resilient systems [11]. The main purpose is to represent the dynamics of systems rather than calculating the probability of failure. He states that the focus of the method is on understanding how something is being executed, how it is affected by the upstream functions, and how the outputs of the functions are affected by the interactions of these functions, whether they are planned or not. The method is based on four principles:

- Equivalence of successes and failures: successes and failures are equivalent in the sense that they have the same origins, that is, the activities go right or wrong for the same reason.
- Approximate adjustments: the daily performance of sociotechnical systems, including people individually and collectively, is always adjusted to achieve working conditions.
- Appearance: all results that we perceive or not should be described as emergent and not as resultant which means that something may have happened simply by the appearance of specific space and time conditions, without a trace and not prevenient from a latent cause.
- Functional resonance: the relationships and dependencies among system functions should be described as whether they are actually developed for a specific situation and not as cause-and-effect links. It represents the detectable emerging signal generated by an undesirable interaction from the variability of multiple daily signals.

Based on these principles, four steps are necessary to represent the socio-technical system: identify and describe the functions, identify the variability of the system, aggregate the variability of the system, and analyze the consequences of variability.

2.1.1 Identify and describe the functions

This phase maps the activities as they are routinely performed. Hollnagel [10] states that the best source of information about the activities of interest are the people who actually perform them. The functions are defined by six dimensions:

- Inputs (I) - is what the function processes or transforms. It can also be something that triggers the start of operation of the function.
- Outputs (O) - Output is the product of a function. It could be something or just a change of state.
- Resources (R) - This is what the function needs to function or is simply what is consumed during to produce the output.
- Controls (C) - Controls serve to supervise, or restrict, the function so that it is adjusted in case of deviations. Controls can be both active functions and procedures, plans, or guidance.
- Preconditions (P) - Necessary but not sufficient preconditions for activation of the function. These are steps or conditions that must be met before the function processes the entry.
- Time (T) - Time constraints that affect function and may be related to the beginning, during and end of the activity described by the function.

The functions are represented in hexagon form and in each of these six aspects should be described, as shown in Figure 2.

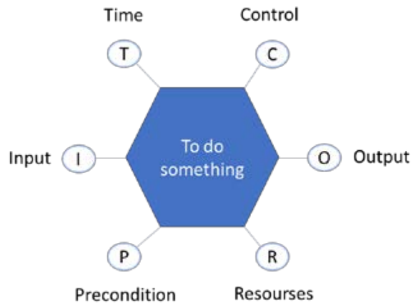

Figure 2 - FRAM Hexagon
Source: Hollnagel (2012)

2.1.2 Variability Identification

As previously mentioned, since FRAM does not have the purpose of obtaining numerical results, after the identification and development of the existing couplings in the case under study, the simple alternative for the analysis of variability was adopted in terms of time and precision [12] using for each coupling a Monte Carlo Simulation. MCS was initially applied to financial theory in 1964, but nowadays its uses encompass several project risk analyses [13]. It is commonly used to perform probabilistic analyses involving uncertainties, reliability, and risk assessments [14], characteristics inherent to the organizational process of flight instruction, where the uncertainty of the test activities outcomes, the search for reliability in the process, and the necessary assertive risk assessment are observed. The simulation uses a sequence of random numbers to generate a simulation [15]. Thus, through successive scenario simulations, also known as interactions, it calculates heuristic probabilities, translated into numerical approximations that allow a quantification of a problem. It is interesting to note that, despite appearing a certain complexity, the mathematical concepts applied to the MCS are, in fact, quite simple, and many are the software available to perform the calculations in an automated way, thus facilitating the use of this method.

Figure 3 shows in a schematic way of how from frequency distributions and the definition of their interrelationships, it is possible to perform interactions, store the data and adapt it to the distribution, or to select the distribution and adjust its parameters in case of data unavailability [16].

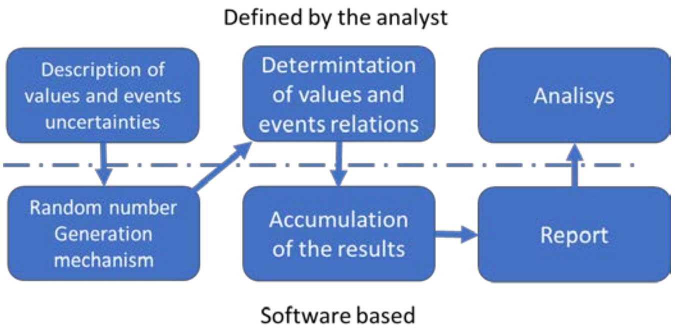

Figure 3 - Schematic MCS illustration.
Source: GREY (1995)

In this study, the phases defined by the analyst, referring to the description of uncertainties, were carried out through the application of the FRAM method, looking for an approximation with the reality of the variability of the organizational process under analysis. For the phases supported by the software, the software R Studio version 1.2.5033 was used.

2.1.3 Aggregating the variability of the socio-technical systems

The aggregation of variability was based on the Efficiency Thoroughness Trade-Off (ETTO) principle, which establishes that human activities, at all levels, from the individual to the organizational, are carried out seeking a relationship of commitment between efficiency and completeness. Sometimes this behavior is purposeful and sometimes usual, in the latter case, occurring often unnoticed. These adjustments should be considered as normal system behavior [12].

In this study, this aggregation was performed in such a way that the output of a given function considered the effects of all the couplings that are downstream in the FRAM network, and so on, until the specific coupling that is desired to be analyzed is reached. Figure 4 graphically illustrates this approach.

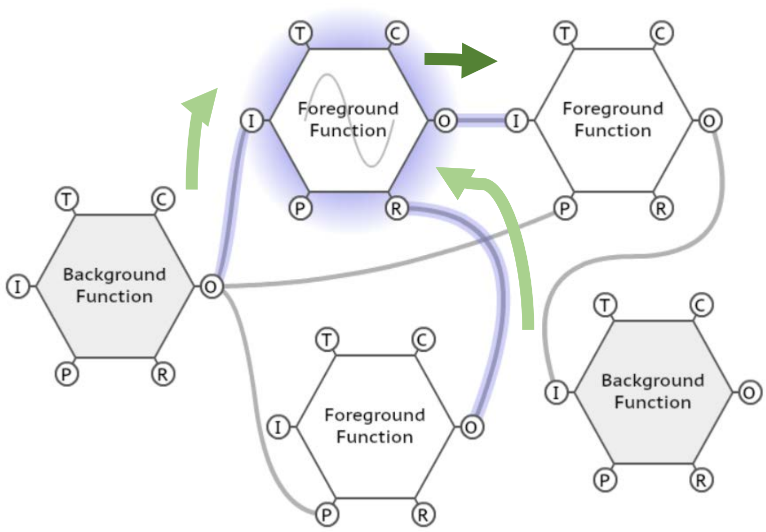

Figure 4 - Schematic FRAM aggregation.

2.1.4 Analyzing the consequences of variability

In this step, the limits of the variability of the system were defined, because the FRAM is focused on the performance of the variability rather than worrying about whether it is positive or negative [12]. In this sense, it was sought, through the opinion of the specialist, to determine what would be the acceptable behavior of the system for the organization in terms of time, that is, the moment when the upstream activity or function activates the downstream function, and accuracy, that is, the quality of the output of the upstream function.

Falegnami [17] applied multilayer network representation to define the boundaries of the variability, using centrality indices to stand-out the limits of the system. Using similar approach, the current behavior of the system was verified to identify which couplings should be amplified or degraded to increase the variability of the system, seeking efficiency, if it was working below the established limit, or degraded, if it was working above the established limit, seeking safety.

3. CASE STUDY AND DISCUSSION

For the case study, four subject matter specialists (SME) were interviewed, current EFEV instructors, to report how the activities of the first performance subphase of the Fixed Wing Flight Test Course, from the date stipulated for its planning (Weekly Working Table - WWT), until the delivery of the product of the last activity performed by the students (report of the execution flight). Expert opinion was especially important since there was no historical data suitable for the application of FRAM analysis [18]. This questioning was based on the premise that the description of a socio-technical system should reflect how activities are performed on a day-to-day basis, work-as-done rather than work-as-imagined [10].

The SMEs were selected based on their experience time in lecturing a flight test course. They were divided in two groups, being the first group the most experienced professionals and the second, formed by recently integrated instructors. To build the FRAM model, the experienced SMEs were individually interviewed. The interviewer executed a briefing defining the meaning of the FRAM functions and the dimension to provide a minimum training [19]. These data were used to build graphically a FRAM model which was confirmed by each one separated after the facilitator had had aggregated all the results. Figure 5 graphically shows the resulted model representing the organizational synergy of the flight test instructional activity.

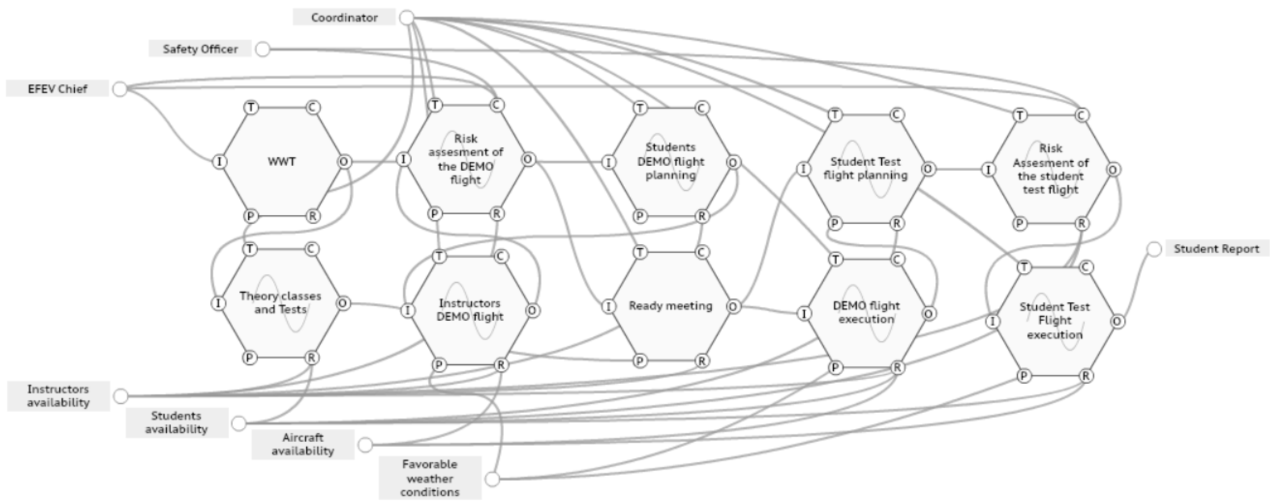

Figure 5 - Fixed wing EFEV instruction activity.

Seven background functions were identified, since they do not need to have defined inputs, working in the background and out of scope of the analysis, being classified according to their coupling (time, control, resources, and prerequisites) in the functions of "foreground", which are the functions inserted within the socio-technical system [10]. Table 1 and 2 shows the background functions with their outputs and the foreground functions respectively.

Table 1 - Background functions

Background Functions	Output
EFEV Chief	Control/Input
Coordinator	Time
Safety Officer	Control
Instructor availability	Resources
Student availability	Resources
Aircraft availability	Resources
Favorable weather conditions	Precondition

Table 2 - Foreground functions

Foreground functions
WWT
Theory classes and Tests
Risk assessment of DEMO flights
Instructor DEMO flight
Student DEMO flight planning
Ready meeting
DEMO flight execution
Student test flight planning
Risk assessment of student test flight
Student test flight execution
Student report

After the FRAM model was established, the second step of the process consisted in identifying the variability of the performance of the socio-technical system was initiated. For this, the most experienced SMEs were asked to determine scores for each level of variability of the output of the functions in relation to the dimensions of time and precision, as well as to define discrete probability distributions for each score [20]. Tables 3 and 4 respectively shows scores for the linguistic variables and definitions and the related discrete probability distribution. Linguistic variable seems to be a good practice when the data source is the human opinion [21].

Table 3 - Function outputs to time and precision dimensions

	Linguistic variables	Meaning	Score
Time	Early	Before the week provided on WWT	1
	On time	On the week provided on WWT	2
	Late	One week after the provided on WWT	3
	Very late	After one week after the provided on WWT	4
Precision	Precise	Adding new knowledge comparing to the previous course	1
	Acceptable	Repetition of the previous course with documentary and risk review	2
	Unsatisfactory	Repetition of the previous course, but without documentary review	3
	Unacceptable	Repetition of the previous course, without documentary and risk review	4

Table 4 - Discrete probability distribution associated to each score.

#	Score	Time			
VT_a	1	0,70	0,15	0,10	0,05
VT_b	2	0,15	0,70	0,10	0,05
VT_c	3	0,15	0,05	0,70	0,10
VT_d	4	0,10	0,05	0,15	0,70
#	**Score**	**Precision**			
VP_a	1	0,7	0,2	0,05	0,05
VP_b	2	0,05	0,7	0,2	0,05
VP_c	3	0,05	0,2	0,7	0,05
VP_d	4	0,1	0,1	0,1	0,7

For each coupling between the background and the foreground functions and among the foreground functions, a MCS with 1001 interactions was performed. Initially, a vector of random numbers was generated for each coupling considering the probability distribution related to each degree stipulated by the specialist, according to the equation 1 [20].

$$V_{(x)} = VT_{(a,\, b\,,c \text{ ou } d)} \text{ x } VP_{(a,\, b,\, c \text{ ou } d)} \qquad (1)$$

In this article, to consider the effect of the propagation of variability within the socio-technical system throughout the functions, it was performed the sum of the results of the simulations of each function coupled upstream, replicating this process to the downstream functions up to the last background function. Equation 2 represents the MCS sampling of the six dimensions of the FRAM hexagon (input, control, time, precondition, and resources) and accounts the variability of the function itself, since its own functioning could affect the total variability.

$$\text{Propagation} = mcV_i + mcV_c + mcV_t + mcV_p + mcV_r + mcV_f \qquad (2)$$

For example, considering the graphical illustration on Figure 6, we define $V_{(i)} = VT_a$ x VP_b (input coupling), $V_{(k)} = VT_c$ x VP_d (resources coupling), $V_{(l)} = VT_b$ x VP_c (function variability), and $V_{(m)} = V_{(i)} + V_{(k)} + V_{(l)}$. Using the VT and VP scores from Table 4 and applying MCS, the results end up being the distribution shown on Figure 7.

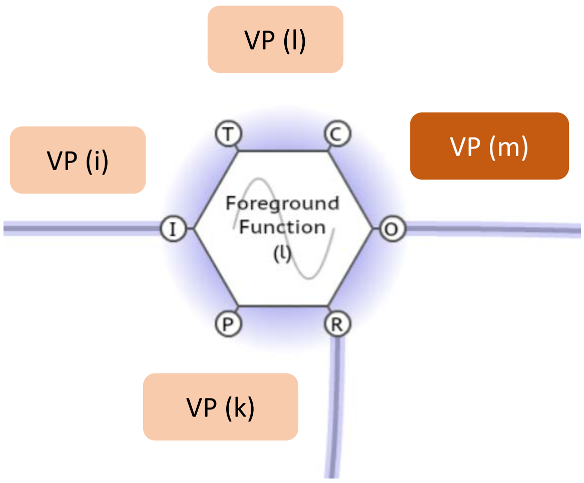

Figure 6 - FRAM propagation illustration.

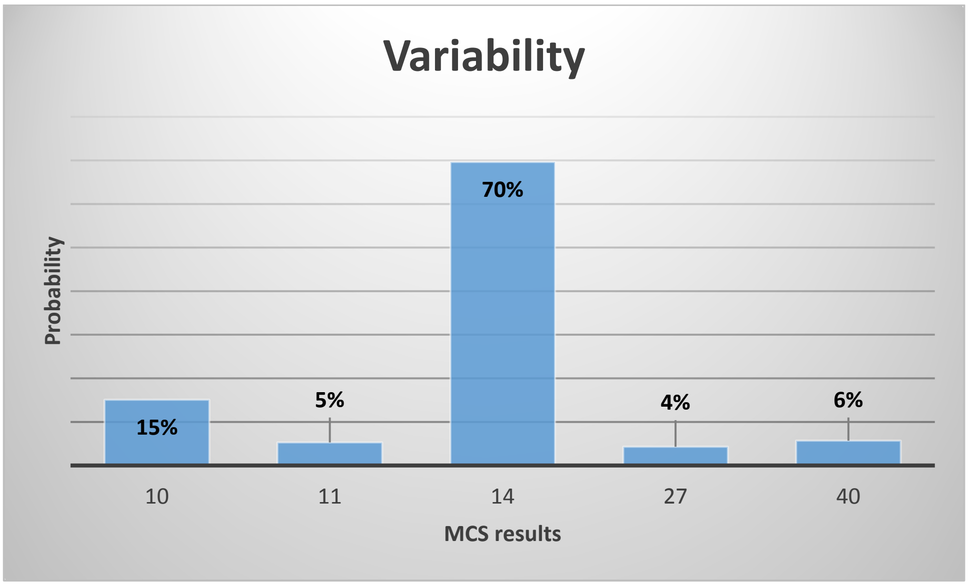

Figure 7 - FRAM propagation variability.

To define the variability limit or boundary, the experienced SMEs were asked about what the maximum VT and VP in terms of time and accuracy for an acceptable system functioning for the organization would be. They returned a score of 2 for both dimensions. Considering this, a first propagation was performed by inserting the score 2 in all couplings. The coupling "Student test flight execution (O) – Student Report (I)" was chosen for measurement and instantiation of the FRAM system. This coupling was chosen for measurement, since it is the last coupling of the organizational process, aiming a successful execution of the course phase. For that, the number of interactions with 94% confidence level in 1001 interactions was used to set an acceptable level for a safe operation of the system. The MCS returned maximum score of 660, since represents the maximum acceptable variability, as shown in Figure 8.

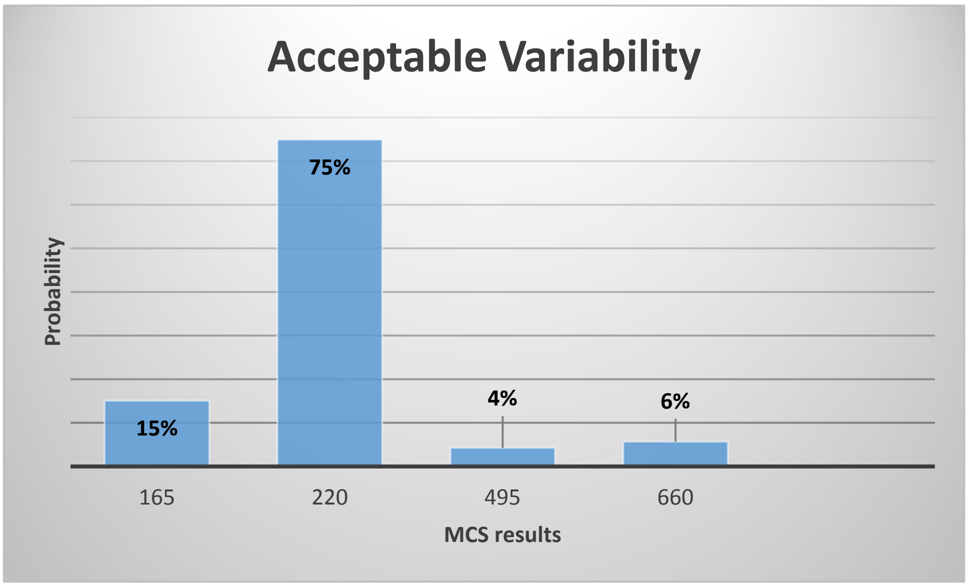

Figure 8 - EFEV Acceptable variability

From now on, any scenarios simulated which returns a score higher than 660 with confidence level of higher than 94% will be considered with a variability higher than acceptable, in other words, above the variability limit. Thereby, with the vision of the system's ideal variability, the third stage of FRAM method was implemented, the variability monitoring of the system. For this, a new propagation was carried out, consulting the second group, less experienced, about the scores of each coupling, as shown in Table 5. The propagation result is shown in Figure 9.

Table 5 - Current variability coupling scores.

Couplings	VT(a, b ,c ou d)	VP(a, b ,c ou d)
#1 EFEV Chief (O)	2	2
#2 Coordinator (O)	3	2
#3 Safety Officer (O)	2	2
#4 Instructors availability (O)	2	3
#5 Student availability (O)	1	3
#6 Aircraft availability (O)	3	3
#7 Favorable weather conditions (O)	2	2
#8 WWT (O) – Theory classes and Tests (I)	2	2
#9 Theory classes and Tests (O) - Ready meeting (P)	2	3
#10 WWT (O) - Student DEMO flight planning (I)	2	3
#11 Student DEMO flight planning (O) - Instructor DEMO flight (I)	3	3
#12 Instructor DEMO flight (O) - Risk assessment of DEMO flights (I)	2	2
#13 Risk assessment of DEMO flights (O) - Ready meeting (I)	2	2
#14 Ready meeting (O) - DEMO flight execution (I)	3	3
#15 Ready meeting (O) - Student test flight planning (I)	2	2
#16 DEMO flight execution (O) - Student test flight planning (P)	2	3
#17 Student test flight planning (O) - Risk assessment of student test flight (I)	2	3
#18 Risk assessment of student test flight (O) - Student test flight execution (I)	3	2
#19 Student test flight execution (O) - Student report (I)	2	2

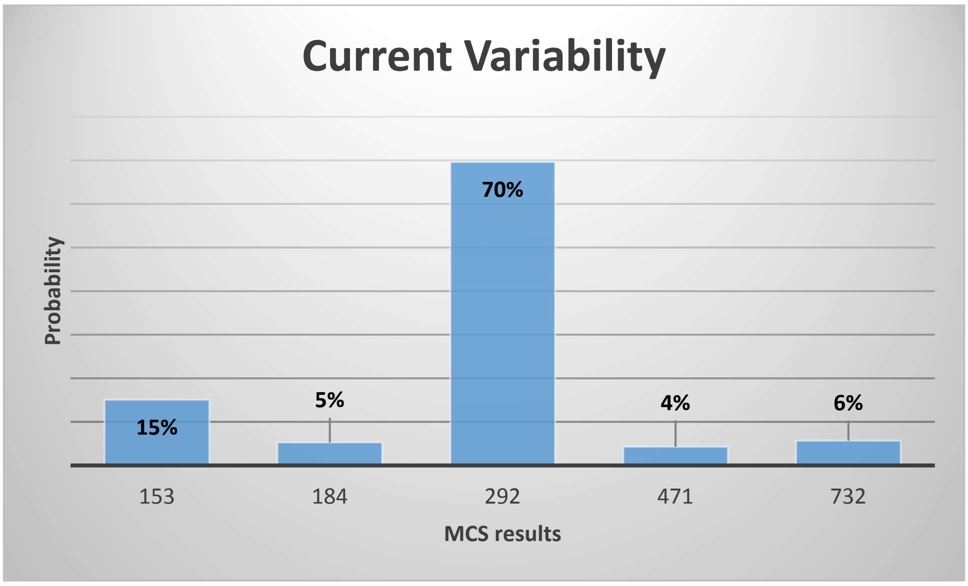

Figure 9 - Current EFEV variability.

For this coupling, 6% of the simulations generated an aggregated score of 732 points, passing 72 points of the variability score stipulated as normal for the system. Thus, the current situation of the system has a variability above of what was stipulated as ideal by the SMEs of the organization. Additionally, another approach to analyze the variability is multiplying the probability by the score of each column of Figure 9, adding the results afterward. This approach also gives an indication of total variability, since the result for Figure 8 was 249 for acceptable variability and 299, from Figure 9, for current variability, confirming the increasing of the system's variability.

The next step was to manage this excessive variability. For this, an amplifying or degrading factor for the dimensions of time and precision was added to Equation 2 for each coupling [20]. Equation 3 shows the integration of the managing factors. The linguistic description of the factors is shown in Table 6.

$$V_{(x)} = VT_{(a,\, b\, ,c\ ou\ d)} \times VP_{(a,\, b,\, c\ ou\ d)} \times T_{(a,\, n\ ou\ d)} \times P_{(a,\, n\ ou\ d)} \tag{3}$$

Table 6 - Amplifying, neutral and degrading factors.
Source: PATRIARCA (2017).

Factor	Correction	Description
T_d or P_d	0,5	In the case of the downstream function has a degrading effect on the upstream function.
T_n or P_n	1	In the case of the downstream function has no effect on the upstream function.
T_a or P_a	2	In the case of the downstream function has an amplifying effect on the upstream function.

Three scenarios were simulated for managing the variability. The first focused on the sensitivity of the “Coordinator” background function since, according to the FRAM model, Figure 5, this function leverages over nine out of eleven foreground functions, working in the time dimension. When placing a degrading correction factor (Td) in the # “2 Coordinator” couplings, which in the scenario studied means reducing the pressure for time to complete the phase, it was verified that the maximum value for the “Student test flight execution (O) – Student Report (I)” coupling, the measuring coupling, becomes 644, below the maximum value of 660 safe threshold. However, if the coordinator function, instead of relieving the time pressure on the system, which is already operating above the limit (732 points), decides to increase the pressure for time, combined with a increasing the quality of the coupling (T_a and P_d), the simulation still results in 6% of the samples with the value of 720, showing that for this system increasing the pressure to a faster execution, even improving the quality of the Coordinator's information has negligible effect in reducing the resonance of the system.

In a second scenario, the analysis of the background function “# 6 Aircraft availability” (Table 5) was attempt. A variability reduction factor in the precision dimension (Pd) was applied, which means, an improvement in the quality of the aircraft availability information reported to the system, resulting in a score of 700 for the measuring coupling, therefore not being enough to reduce the variability below the threshold value of 660. If associated with this variability reduction factor, we apply a reduction on the time factor (Td), meaning that the aircraft availability information, in addition to being more accurate, arrives at the system earlier, the result became 684, not being enough to bring the variability to an acceptable level.

For the third scenario, all the couplings between the foreground functions were evaluated, stating reducing mitigating factors for time and precision dimensions, and for each coupling separately. The result for the coupling in sight, "Student test flight execution (O) – Student Report (I)" is shown in Table 7.

Table 7 - Foreground function couplings management.

Foreground function couplings	#19
#8 WWT (O) – Theory classes and Tests (I)	705
#9 Theory classes and Tests (O) - Ready meeting (P)	723
#10 WWT (O) - Student DEMO flight planning (I)	732
#11 Student DEMO flight planning (O) - Instructor DEMO flight (I)	708
#12 Instructor DEMO flight (O) - Risk assessment of DEMO flights (I)	714
#13 Risk assessment of DEMO flights (O) - Ready meeting (I)	723
#14 Ready meeting (O) - DEMO flight execution (I)	732
#15 Ready meeting (O) - Student test flight planning (I)	723
#16 DEMO flight execution (O) - Student test flight planning (P)	723
#17 Student test flight planning (O) - Risk assessment of student test flight (I)	723
#18 Risk assessment of student test flight (O) - Student test flight execution (I)	720

It appears that the sensitivity to an attenuating factor in the couplings in between the foreground functions is lower than the background function # 2 Coordinator, showing that the human performance of this actor is preponderant to reduce the variability of the socio-technical system of this study.

4. CONCLUSION

The current study was motivated by the constant search for methods that allow a more reliable and realistic identification of hazards in organizational processes that involves flight test instruction, in order to increase safety and identify possible areas for high resonance in the socio-technical systems [12].

Thus, this article proposed the integration of the FRAM and MCS methods to map and quantify the stages of the organizational process of flight test instruction. Through the application of FRAM, the mapping of the process in question was accomplished by consulting SMEs, ending with a graphic illustration that, by itself, allows a more didactic and practical identification of the complexity existing in that process, an aspect considered fundamental to characterize the activity as being done [10].

Once this step was over, MCS was used to, based on scenario simulation, statistically semi-quantify the process functions, previously identified by FRAM, and thus allowing the identification of those that have greater degree of variability therefore being more susceptible to errors and failures.

Thus, the proposed method allowed an evolution in risk management in flight test instruction activities, by generating a gain in quality on the identification and quantification of process variability, since it was possible to identify that the Coordinator function has a predominant influence on the system variability, compared to the aircraft function and the couplings of the foreground functions. Furthermore, scenario simulation was an essential methodology to the verify the impact of the functions in the system as a whole, indicating to be a suitable technique for socio-technical sensitivity analysis.

Finally, in future works, an expansion of the sensitivity analysis of the couplings of the system under study analyzing not just one subphase, but the entire course, and a method to validate the MC semi-quantification are proposed, such as possibility theory.

5. REFERENCES

[1] FEDERAL AVIATION ADMINISTRATION, “Aviation Instructor’s Handbook”, FAA-H-8383-9B, U.S. Department of Transportation, p.10-6, (2020).

[2] NORTH ATLANTIC TREATY ORGANIZATION, “Introduction of Flight Test Engineering”, RTO-AG-300-V14, p. 24, (2015).

[3] BRAZILIAN AIR FORCE, “Programa de Segurança em Ensaios em Voo”, Instituto de Pesquisas e Ensaios em Voo, Brazil, (2020).

[4] FEDERAL AVIATION ADMINISTRATION, “Risk Management Handbook”, FAA-H-8383-2, U.S. Department of Transportation, p.10-6, (2009).

[5] INTERNATIONAL CIVIL AVIATION ORGANIZATION, “Safety Management Manual”, Doc 9859 AN/474, 3 ed., (2012).

[6] REASON, J., “Managing the Risks of Organizational Accidents”, Aldershot, Hants, Ashgate, (1997).

[7] HOLLNAGEL, E., WOODS, D., & LEVESON, N., “Resilience engineering: Concepts and precepts”, Ashgate, UK, (2006).

[8] ROSENHEAD, J. “The past, the present and the future of problem structuring methods”, Journal of Operational Research Society 57, p. 759–765, (2006).

[9] FEDERAL AVIATION ADMINISTRATION, “Aircraft Certification Service Flight Test Risk Management Program”, Order 4040.26B , U.S. Department of Transportation, (2012).

[10] HOLLNAGEL, E., “FRAM: The Functional Resonance Analysis Method: Modelling Complex Socio-technical Systems”, Ashgate Publishing Ltd, (2012).

[11] CARVALHO, P.V. R., “The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience”, Reliability Engineering & System Safety, v. 96, n. 11, p. 1482-1498. (2011).

[12] HOLLNAGEL, E., “The ETTO Principle: Efficiency-Thoroughness Trade-Off. Why Things That Go Right Sometimes Go Wrong”. June, (2009).

[13] OLIVEIRA, M. R. G. “Simulação De Monte Carlo e Valuation: Uma Abordagem Estocástica”, Revista de Gestão, v. 19, n. 3, p. 493–512, (2012).

[14] CHANG, K. et al. “Uncertainty Analysis for Target SIL Determination in the Offshore Industry”, Journal of Loss Prevention in the Process Industries, Volume 34, p. 151-162, (2015).

[15] SOUZA, M. C. M. “Quantificação das incertezas na avaliação de projetos: o modelo utilizado na Agência de Fomento do Estado da Bahia”, Universidade Federal de Santa Catarina, (2004).

[16] GREY, S. “Practical Risk Assessment for Project Management”. John Wiley & Sons Ltda., England, (1995).

[17] FALEGNAMI, A.; COSTANTINO, F.; DI GRAVIO, G.; PATRIARCA, R., “Unveil key functions in socio-technical systems: mapping FRAM into a multilayer network”, Cognition, Technology & Work, 22, 877–899, (2020).

[18] BIER, V. M., “Calibration of Expert Judgments in Counterterrorism Risk Assessment”, Current Research Project Synopses, paper 67, (2014).

[19] QUIGLEY, J. COLSON, A. ASPINALL, W. COOKE, R., “Elicitation in Classical Model”, International Series in Operations Research & Management Science 261, (2018).

[20] PATRIARCA, R., DI GRAVIO, G., COSTANTINO, F., “A Monte Carlo evolution of the Functional Resonance Analysis Method (FRAM) to assess performance variability in complex systems”, Safety science, v. 91, p. 49-60, (2017).

[21] KLIR, G. J., “Uncertainty and Information. Foundations of Generalized Information Theory”, John Wiley & Sons, inc., p 260-303, (2006).