ADAPTED MEASUREMENT METHOD TO ASSESS MENTAL WORKLOAD IN MAINTAINABILITY STUDIES: INDUSTRIAL POINT OF VIEW

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Abstract

It is essential to ensure that the mental workload during a maintenance activity is not too high, in order to protect the integrity of maintenance operators and aviation safety. In particular, anticipating human error, which remains one of the consequences of the variability of the mental workload, leads us to define an appropriate method for measuring the mental workload during the maintenance activity. In the aviation industry and in the frame of mental workload assessment, subjective, objective, and physiological approaches will provide adequate solutions in a context always influenced by multiple constraints. Ultimately, these data will enable us to better anticipate the design of more robust and fault-tolerant systems that ensure the protection of operators' physical and mental integrity.

1. INTRODUCTION

The evolution of systems and functionalities has led to a more complex maintenance. World War II accelerated the sophistication of maintenance, despite relatively limited reliability of aircraft. For example, the availability rates of the Royal Air Force in the 1940s ranged between 60% and 80% in terms of serviceability[1] [Ref 1,2]. Due to the specialized expertise and knowledge required, maintenance activities induce significant occupational stress [Ref 3]. Maintenance represents complex and technical tasks involving potential risks that can lead to incidents and accidents, threatening the safety of operators and systems. The succession of maintenance tasks, whether simple or complex, demands mental resources such as decision-making, memory, and attention. The link between physical and mental workload exists within the activity, the individual and the surrounding environment with which they interact [Ref 3, 4, 5]. The use of digital simulation tools allows better integration of Human Factors & Ergonomics (HFE) throughout the design phases in maintainability. In this domain, the Preliminary Ergonomic Analysis in Maintainability (PEAM) approach allows the integration of the physical workload of the HFE through the use of digital and physical simulation tools depending on the phase of the design process [Ref 6]. However, this is not the only workload that maintenance operators experience. The mental workload, if not taken into account, can have negative consequences on maintenance activity and can lead to human errors which can pose a serious threat to system safety. However, in maintainability, it seems that no certified method for measuring mental workload has yet emerged. In the present paper, the various existing methods for measuring mental workload and how these methods need to be adapted based on the constraints of maintenance activities (physical constraints, work organization, environmental constraints) are described. To this end, simulating maintenance tasks in an immersive environment, using digital simulation tools (Virtual Reality, Augmented Reality, Mixed Reality), and physical simulation (mock-up), encourages the exploration of the relationship between the user and the maintenance environment in a development context. From a cognitive point of view, and as part of our research, we are very interested in being able to identify the fidelity of the level of mental workload in all these aspects between reality and simulation. This is why, in order to optimize design anticipation, the fidelity of measurements of maintenance operator's mental workload will have to be similar between real and simulated activity. This method will precisely and efficiently measure the mental workload of a maintenance operator while taking into account the constraints linked to their activity.

[1]*Serviceability: The degree to which equipment can be easily restored to a satisfactory operational condition*

2. EFFICIENT MAINTAINABILITY FOR SAFE MAINTENANCE

2.1. Maintenance activity

The primary objective of aircraft maintenance remains safety, the other objective of the maintenance are performance and fleet availability. In the 1960s, the advent of commercial aviation led to a strong desire to develop and maintain equipment reliability. The emergence of the MSG1 standard [Ref 7], developed by the "Maintenance Steering Group", allowed the establishment of revision procedures, restoration criteria, and maintainability criteria to reduce maintenance costs and improve aircraft safety throughout their lifetimes [Ref 1]. Historically, significant changes in the arrangement of the cockpit design have already been studied [Ref 8], contrary to equipment design aiming to facilitate maintenance. At the end of the 20th century, several notable accidents highlighted the importance of human performance in aircraft inspection and maintenance. To improve the quality and efficiency of maintenance, it is crucial to understand both the capabilities and limitations of the maintenance technician. Maintenance includes all technical, administrative, and management operations necessary to ensure or restore a property, equipment, or installation to a level that allows it to perform its function [Ref 9]. Maintenance operators work in a riskier environment than most other professions. This work requires physical strength, agility, balance, and diverse technical skills [Ref 3, 5, 10]. Maintenance tasks can also occur under demanding working conditions (temperature variations, work at height, restricted spaces, unperfect documentation, etc.) which can increase workload and cause professional stress [Ref 3, 11]. In his study, Sugiharto [Ref 3] outlined that 73.2% of maintenance agents reported a significant mental workload. In detail, maintenance operators in the aviation sector operate in demanding environments, requiring their physical and mental abilities, under constant workload and pressure. The operators' health and safety become increasingly important in the future of maintenance design [Ref 5]. Maintenance activities can be divided into two main categories:

- Preventive maintenance: carried out at specific times to minimize the risks of deterioration or failure of the equipment;
- Corrective maintenance: undertaken following the detection of a failure with the aim of restoring the equipment to a functional state.

To optimize the quality and efficiency of maintenance, it is essential to understand the skills and limitations of maintenance operators during task execution. This echoes the ergonomics of activity in work analysis. Identifying the characteristics of the operator and the task, as well as measuring their impact on performance and workload, are essential in optimizing a maintenance system [Ref 12, 13]. Anticipating the operators' interaction with the maintenance environment will facilitate the progress of future maintenance activities and improve operator safety. However, to achieve this, it is crucial to understand and diagnose the workload that an operator may experience during his activity.

2.2. Maintenance workload

The concept of workload has two aspects: constraint and strain. Constraint generally refers to a factor or set of factors external to the task itself, while strain represents the resultant, i.e., the "cost" linked to the effects of this constraint on the individual [Ref 14]. Workload can be classified into two categories: physical workload and mental workload [Ref 3, 15]:

- Physical workload: caused by efforts, postures, movements, and carrying loads due to the operator's activity;
- Mental workload: caused by reflections, memorization, and planning due to the operator's activities.

Workload can be affected by the complexity of the task, temporal pressure, work time, rest time, posted work, task succession, and the work environment [Ref 11]. These interdependent factors can cause an activity generating stress or fatigue and can therefore lead to the occurrence of dangerous acts, contributing to errors on the part of maintenance operators [Ref 16]. In conditions where mental workload levels are reduced (underload), operators may see their concentration capabilities deteriorate and not ensure the necessary performance level. Mental workload and stress are both related. Stress is present when there is an imbalance between the demands of the environment and a person's individual capacities. It refers to the emotional tension associated with a state of anxiety in response to the threat of an unpredictable negative event over which the individual has no control [Ref 17]. Therefore, it could be suggested that stress in maintenance comes from three main factors:

- The operator refers to the personal characteristics, culture and resources. But also, the technical skills and knowledge;
- The task refers to the type of work, its complexity, its repetitiveness and the temporal constraints related to it;
- The environment refers to the social interactions in the work environment, the material and ambient conditions of the workplace.

2.3. The role of maintainability

Maintainability is defined as the ability of an element, under specific conditions of use, to be preserved or restored to a state that allows it to perform a required function, provided that maintenance is carried out under defined conditions [Ref 18, 19]. In other words, maintainability is a part of the design office defining the future maintenance. Poorly studied maintainability is likely to lead directly or indirectly to maintenance errors. Examples of poor designs include:

- Difficult-to-reach components;
- Obstruction to vision due to the position of the components;
- Incentive to incorrect installation of the components.

HFE play an important role in both intrinsic and extrinsic maintainability of equipment. Intrinsic maintainability refers to characteristics related to maintenance equipment (low accessibility, disassembly, etc.). Extrinsic maintainability concerns characteristics related to the overall maintenance environment (restricted workspace, work at height, access means, etc.). The late detection of maintainability problems leads to higher costs, highlighting the importance of anticipating maintainability to anticipate the impacts of design on system repair. Various approaches have been used to evaluate maintainability and can be classified into three categories [Ref 20]:

- Extrapolation: predicts the performance of the new product based on experience gained with similar equipment;
- Sum of times: decomposes the maintenance effort into elementary tasks and adds the average durations for each task;
- Checklist: provides the important characteristics of a system to evaluate according to maintainability index criteria.

Dhillon [Ref 21] stated that in terms of improving maintenance and maintainability, it would be necessary to look further into areas such as HFE in order to improve safety. Most of the performed errors while using complex equipment result from design choices. By adequately integrating human factors into the design process, it is possible to significantly reduce these potential errors. Obviously, the training and practice of a maintenance operator can enhance his performance level and decrease his likelihood of making a maintenance error. However, this should not be opposed to a well-thought-out and quality design [Ref 21]. Nonetheless, the quality of maintainability analysis will largely depend on the engineer's experience who conducts these studies. And therefore, on the designer's ability to consider and visualize the future maintenance situation to be evaluated. Consequently, it is evident that the feedback from maintenance operators is crucial during the design phases [Ref 2]. This is why the use of digital simulation tools (Virtual Reality, Augmented Reality, and Mixed Reality) is effective for simulating human/system interaction. Bernard [Ref 6] develops the PEAM (Preliminary Ergonomics Analysis in Maintainability) approach allowing to integrate HFE through the use of digital and physical simulation tools according to the stage of the design process. This process improves the integration of physical ergonomics into maintainability and makes designers more aware of the difficulties encountered by operators during the activity.

3. ANTICIPATION AND DIGITAL SIMULATION TOOLS

Digital simulation tools are essential for anticipating complex human interactions linked to maintenance actions [Ref 20, 22, 23]. The use of these tools reduces our dependence on physical mock-ups, which are a costly and time-consuming part of the design cycle [Ref 22, 24]. The simulation should provide sufficient information to the designer and/or operator, to appropriate the future environment and to discern all the subtleties of the interaction between human and the environment [Ref 25]. Anticipating these parameters allows us to perfect the design. For this, there are three main simulation tools: Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). Each of these tools enhance in a specific way immersive experience of the end user [Ref 26,27,28]. However, these tools may have sensory, motor and technical limitations in their use. In sensory-motor terms, these limitations are caused by a disparity between real and virtual experiences. On the one hand on the sensory level due to visuo-vestibular conflicts and on the other hand on the motor level due to an imbalance between real action and virtual feedback in the interaction with the virtual environment [Ref 29]. On a technical level, the resolution of display devices, the limited field of view, brightness, contrast and ergonomics can interfere with the study of HFEs. Concretely, in maintainability, an HFE analysis using MR technology was used to optimize the position of the foot and wrist steps on a helicopter [Ref 24]. HFEs are working to improve design by taking operators into account and by creating assessment methods adapted to the use of digital simulation tools.

4. A PROPOSED METHOD FOR MEASURING MENTAL WORKLOAD ADAPTED TO THE MAINTENANCE ENVIRONMENT

The International Ergonomics Association [Ref 30] specifies that for a thorough analysis of HFE, it is necessary to consider all domains of specialties (Physical Factors, Cognitive Factors and Organizational Factors). In addition to physical factors, it is now essential to study the impact of cognitive factors on maintenance design. The research and use of new methods for collecting information on mental workload require considering the global operational environment as a source of information [Ref 31]. Measuring mental workload is fundamental for design improvement of complex systems and optimizing human-machine interaction [Ref 32]. It is now essential to develop methods for measuring mental workload to help reduce human error in maintenance. Several categories of measures exist to evaluate mental workload, subjective measurement, objective performance measurement, and physiological measurement.

4.1. Subjective measurement

Subjective measures include a participant who gives qualitative and/or quantitative feedback on their own experience in performing a primary and/or secondary task [Ref 31, 32, 33]. Subjective measures are used because they are easy to implement, provide sensitive measurements and are theoretically validated [Ref 33, 34]. In the majority of these methods, the operator has to complete a questionnaire after the task has been performed. This could lead to a memory bias and a reinterpretation of the sensations experienced as a result of the operator's mental workload.

4.2. Performance measurement

Performance measures assess the operator's ability to perform a task at an acceptable level and indirectly measure their mental workload in isolation. This method allows for the extraction of dependent variables such as response times, task execution times, error rates, these types of variables are generally the most observed [Ref 32, 35]. Performance measures can be classified into two main categories. The primary tasks category provides a direct measure of performance and have high precision for evaluating long periods of mental workload. However, their disadvantage lies in their inability to discern the origin of mental workload variations when several tasks are performed simultaneously. The secondary tasks category relies on measuring the operator's residual capacity during the execution of the primary task [Ref 13, 31]. However, this method could cause alterations due to the increased level of vigilance caused by the sensory interference generated by divided attention between the primary and secondary tasks.

4.3. Physiological measurement

Some physiological measures are intrinsically linked to mental workload, they reflect the actions of the Sympathetic and Parasympathetic Nervous System (SNS & PNS) which will reflect the changes in cognitive functioning of the operator. The increase in mental workload will involve an increase in cognitive resources, which will be reflected in physiological activation [Ref 36, 37]. Different categories of physiological measures exist to measure mental workload. Cardiovascular measures, ocular measures, salivary measures, electrodermal measures, neurophysiological measures [Ref 31, 32, 37]. However, it is evident that each measurement tool has limitations that can potentially bias the interpretation of the data. In fact, identifying the strengths and weaknesses of physiological measurement tools is necessary to facilitate the selection of measurement tools and methods, especially for a maintenance activity. In the course of his operations, the maintenance operator often needs to move actively, accessing areas that are physically and visually challenging to reach (Figure 1).

Figure 1: Visual check of a maintenance operator in the tail boom of an H225 aircraft

The frequent need to change positions and expend significant physical energy can negatively impact the accuracy of the physiological measurements collected. For ocular measurements, a stimulus such as light can affect pupillary dilation and bias the raw measurement of mental workload. For neurophysiological measures, the ElectroEncephaloGram (EEG) which allows the measurement of the electrical activity of the cerebral cortex requires that the participant remains immobile during the measurements. However, the operator’s movement (muscular, ocular, etc.) can be a source of bias. The cardiovascular measures indicate the predominance of the PNS or SNS which can result, among others, from physical or mental activity, emotional nature (positive or negative) or stress [Ref 38]. In more detail, Heart Rate Variability (HRV) is a measure that has shown a correlation with mental workload. It is generally accepted that HRV decreases with increasing mental workload [Ref 39, 40]. On the other hand, the multiplicity of factors (experience level, type of task, time of day, etc.) to which the cardiovascular system reacts reduces its selectivity and diagnostic capability [Ref 37].

4.4. Quality criteria in the measurement of mental workload

Several researchers have defined measurement criteria concerning the quality of mental workload measurements [Ref 33, 35, 32, 41]. Among these multiple criteria, here are the most common:

- Sensitivity: Focuses on the ability to discern different levels of task demands. For example, variation in pupil diameter is considered to be a sensitive measure of mental workload;
- Selectivity: Requires the measurement to remain constant when the workload remains constant on its own. Pupil diameter variation is not selective because of light variation. But objective measures of performance are selective in their measurement of mental workload;
- Diagnosticity: Focuses on the measure's ability to determine the origin of the load in the task. Subjective measures have a relevant multidimensional diagnostic capacity. In particular, NASA-TLX identifies underload and overload in several dimensions. However, Heart rate measurement has a slightly limited diagnostic capacity due to its difficulty in differentiating between the causes of workload.
- Data quantity: Measuring mental workload using several methods in an adapted way will enable a more precise and comprehensive diagnosis of the type of workload. Assimilate and apply the measurement units (instantaneous load, average load, cumulative load, maximum load and overall load) is crucial in optimizing data acquisition. This will allow us to identify across a broader spectrum, each measurement specificity [Ref 35, 41].

5. CONCLUDING REMARKS AND INDUSTRIAL APPLICABILITY

In the search of constant optimization of design in maintainability, understanding the maintenance activity, the workload of maintenance operators, and the development of methods for measuring workload is essential for designing a safer maintenance system. Anticipating the operator's activity within the maintenance environment will allow understanding the physical and mental workload constraints that could pose a threat to the maintenance operator [Ref 23]. The future challenge will be to design a multidimensional method for measuring mental workload adapted to optimize maintainability. This method will also allow the maintainability engineer, who is not an HFE expert, to consider the cognitive behavior of maintenance operators from the beginning of the design phases. Specifically, our future method for measuring mental workload will include the following three types of measurements (see Chapter 4):

- NASA-TLX: This tool is the most widely used in the subjective evaluation of workload. It allows for the diagnosis and effective measurement of the different sources of workload that an operator may experience during their activity [Ref 34].
- Maintenance performance measurement: Performance measurement is a direct indicator of an operator's efficiency in carrying out their task. Measuring the number of assembly, disassembly, inspection errors, and/or the time required to perform a maintenance task can be linked to a distinct set of contributing factors, revealing different levels of cognitive control when a person faces increasingly familiar and predictable situations [Ref 11].
- Cardiovascular measurements: Cardiovascular measurements are the most suitable for maintenance activities due to their ability to resist the noise associated with movement during the activity. Therefore, HRV indicators and respiratory rate measurements will be used in our future method for measuring mental workload [Ref 39].

Diagnosing by anticipation of the mental workload will facilitate the reduction of human errors in maintenance. This method allows for an effective measurement of mental workload, resulting in a multidimensional assessment of the operator's strain through the combination of multiple measurement requirements. Indeed, a combination of specific measurement methods of the mental workload would ensure optimal acquisition of the cognitive data of maintenance operators to improve the integration of HFE. Therefore, in order to refine the choice of a pattern (combination of subjective measurement, performance objectives, and physiological) for measuring the mental workload of the operator, it is necessary to consider and anticipate the constraints of maintenance activity to improve the choice of methods for measuring mental workload and associated tools. On a broader scale, research in HFE improves the design of new systems thanks to a human-centered approach and resolves the problems of sub-optimal existing designs [Ref 42]. Once implemented, this method will allow us to specifically determine a level of precision of the mental workload. Moreover, thanks to the immersive quality of digital simulation tools, it is possible to proactively replicate maintenance activities and thus measure the workload of operators. From a cognitive point of view, and as part of our research, we are very interested in being able to identify the fidelity of the level of mental workload in all these aspects between reality and simulation. This is why, in order to optimize design anticipation, the fidelity of measurements of maintenance operator's mental workload will have to be similar between real and simulated activity. Anticipating the reactions of maintenance operators will allow more robust and error-tolerant systems to be developed, to ensure the protection of the physical and mental integrity of operators and aviation safety [Ref 16].

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6. REFERENCES

1. Zwingelstein, G. La maintenance basée sur la fiabilité: guide pratique d'application de la RCM. Hermès; 1996 Sep.

2. Dibsdale, C. E., *Aerospace Predictive Maintenance*. SAE International, 2020, Chapter 7.

3. Sugiharto, Fauziah Mukti. "The Relationship between Mental Workload and Occupational Stress among Aircraft Maintenance Officers at PT X Hubungan Beban Kerja Mental dengan Stres Kerja pada Tenaga Kerja Bagian Perawatan Pesawat di PT X." *The Indonesian Journal of Occupational Safety and Health* 8, no. 2, 2019, pp. 233–239. DOI: 10.20473/ijosh.v8i2.2019.233-239.

4. Causse, M., and Dehais, F., *Influence de la récompense et de l'âge sur la performance de pilotage: une contribution de la neuroergonomie à la sécurité aérienne*. Ed. universitaires européennes, 2010.

5. Bernard F, Zare M, Sagot JC, Paquin R. "Using digital and physical simulation to focus on human factors and ergonomics in aviation maintainability," *Human factors*. Vol. 62, (1), Feb 2020, pp.37-54. https://doi.org/10.1177/0018720819861496.

6. Bernard, F. Zare, M. Paquin, R. Sagot, J.C. "A new approach for human factors integration into design for maintenance: a case study in the aviation industry," *International Journal of Human*

Factors and Ergonomics, Vol. 10, (2), 2023, pp144-64. https://doi.org/10.1504/IJHFE.2023.130537.

7. MSG, I. Handbook maintenance evaluation and program development. 747 Maintenance Steering Group. Air Transport Association Washington, 1968.
8. Graziani I, Berberian B, Kirwan B, Le Blaye P, Napoletano L, Rognin L, Silvagni S. Development of the human performance envelope concept for cockpit HMI design. InHCI-Aero 2016 International Conference on Human-Computer Interaction in Aerospace September 2016.
9. INRS, 2023. Maintenance : des activités à risques. INRS : Santé et sécurité au travail. https://www.inrs.fr/media.html?refINRS=ED%20123 .
10. Hobbs, A. “Aircraft Maintenance and Inspection,” *International Encyclopedia of Transportation*, Elsevier, 2021, pp. 25-33. https://doi.org/10.1016/B978-0-08-102671-7.10103-4.
11. Hobbs, A. and Williamson, A. “Associations between errors and contributing factors in aircraft maintenance”. *Human factors*, Vol. 45, (2), 2003, pp.186-201.
12. Leplat, J. "Les facteurs déterminant la charge de travail Rapport introductif". Le travail humain, Vol. 40, (3), 1977, pp. 195-202.
13. Sperandio, J.C. "Charge de travail et régulation des processus opératoires". Le travail humain, Vol. 35, (2), 1972, pp. 85-98.
14. DIN EN ISO 10075-1, (2018). Ergonomic principles related to mental workload—Part 1: general issues and concepts, terms and definitions (ISO 10075-1:2017).
15. Sperandio, J.C. *L'ergonomie du travail mental*. FeniXX, 1987, pp 80-95.
16. Yiannakides, D., and Sergiou, C. Human Factors in Aircraft Maintenance. *CRC Press*, 2019, pp. 43-54.
17. Mandrick, K., Peysakhovich, V., Rémy, F., Lepron, E. and Causse, M., Neural and psychophysiological correlates of human performance under stress and high mental workload. *Biological psychology*, Vol 121, 2016, pp.62-73.
18. Dhillon, B. S. Engineering Maintainability: How to Design for Reliability and Easy Maintenance. *Elsevier*, 1999, pp. 13-31.
19. Zaki, R., Barabadi, A., Qarahasanlou, A.N. and Garmabaki, A.H.S., A mixture frailty model for maintainability analysis of mechanical components: a case study. *International Journal of System Assurance Engineering and Management*, 10, 2019 pp.1646-1653. https://doi.org/10.1007/s13198-019-00917-3.
20. Zwingmann, X. Modèle d'évaluation de la fiabilité et de la maintenabilité au stade de la conception. Université Laval, 2005.
21. Dhillon, B. S. Engineering maintenance: a modern approach. *cRc press*, 2002, pp. 12-18.
22. Chedmail, P., Maille, B. and Ramstein, E., État de l'art sur l'accessibilité et l'étude de l'ergonomie en réalité virtuelle. *Mécanique & industries*, Vol. 3, (2), 2002 pp.147-152.
23. Bernard, F., Zare, M., Murie, C. and Sagot, J.C., Dimensions physiques et cognitives: vers une nécessaire prise en compte en maintenabilité aéronautique. *Archives des Maladies Professionnelles et de l'Environnement*, Vol. 82, (2), 2021, pp.170-183.
24. Paquin, R. and Bernard, F., Augmented reality to perform human factors analysis in maintainability. *International Journal of Human Factors Modelling and Simulation*, Vol. 8, (1), 2023, pp.76-95.
25. Bernard, F., Bonnardel, X., Paquin, R., Petit, M., Marandel, K., Bordin, N. and Bonnardel, F., Digital simulation tools in aviation maintainability training. *Computer Applications in Engineering Education*, Vol. 30, (2), 2022 pp.384-395.
26. Fuchs P. *Le traité de la réalité virtuelle*. Presses des MINES; 2006.
27. Fuchs P, Moreau G, Guitton P, editors. *Virtual reality: concepts and technologies*. CRC Press; 2011 Jul 27.
28. Lacoche, J., 2016. *Plasticity for user interfaces in mixed reality* (Doctoral dissertation, Université de Rennes).
29. Weech, S., Kenny, S. and Barnett-Cowan, M., Presence and cybersickness in virtual reality are negatively related: a review. *Frontiers in psychology*, Vol. 10, 2019, p.415654.

30. IEA, I., What is Ergonomics–Definition and Domains of Ergonomics. *Measuring the impact of human factors interventions*, 2000, p.2091.

31. Young, M.S., Brookhuis, K.A., Wickens, C.D. and Hancock, P.A., State of science: mental workload in ergonomics. *Ergonomics*, Vol. 58, (1), 2015 pp.1-17. https://doi.org/10.1080/00140139.2014.956151

32. Longo, L., Wickens, C.D., Hancock, G. and Hancock, P.A., Human mental workload: A survey and a novel inclusive definition. *Frontiers in psychology, Vol.* 13, 2022, p.883321.

33. Cain B. A review of the mental workload literature. *DTIC Document*. 2007 Jul 1.

34. Hart, S.G. and Staveland, L.E., Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *In Advances in psychology*, Vol. 52, 1988 pp. 139-183).

35. Cegarra, J. and Chevalier, A., The use of Tholos software for combining measures of mental workload: Toward theoretical and methodological improvements. *Behavior Research Methods*, Vol. 40, (4), 2008, pp.988-1000. https://doi.org/10.3758/BRM.40.4.988.

36. Kramer, A.F., Physiological metrics of mental workload: A review of recent progress. *Multiple task performance*, 1990, pp.279-328.

37. Charles, R.L. and Nixon, J., Measuring mental workload using physiological measures: A systematic review. *Applied ergonomics*, Vol. 74, 2019, pp.221-232.

38. Kostenko, Alexandre Sviatoslave. "*Évaluation multidimensionnelle et dynamique de la maitrise de la situation par l'opérateur: création d'un indicateur temps réel de charge mentale pour l'activité de supervision de drones."* PhD diss., Université de Bretagne Sud, 2017.

39. Meshkati, N., Heart rate variability and mental workload assessment. *In Advances in psychology*, Vol. 52, 1988, pp. 101-115). North-Holland.

40. Laouar-Zouyed, Amine. "*Étude de la prise de décision chez les pilotes d'aviation commerciale: relation entre le contrôle cognitif et la charge mentale.*" PhD diss., Lorient, 2021.

41. Xie, B. and Salvendy, G., Prediction of mental workload in single and multiple tasks environments. *International journal of cognitive ergonomics*, Vol. 4, (3), 2000, pp.213-242.

42. Gramopadhye, A.K. and Drury, C.G., Human factors in aviation maintenance: how we got to where we are. *International Journal of Industrial Ergonomics*, Vol. 26, (2), 2000, pp.125-131.