DOI: 10.13009/EUCASS2023-614
Aerospace Europe Conference 2023 – 10TH EUCASS – 9TH CEAS

Validation of a hazard taxonomy with aviation maintenance experts

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1. Abstract

This study aims to test the validity of a taxonomy that represents the hazards to which aeronautical mechanics are exposed. The taxonomy was developed and presented in a previous study [1]. We employed an open card sorting method for comparing our taxonomy with the combined one of 10 engineers and 20 aeronautical mechanics. The results were interpreted using dendrograms generated with the Optimal Sort. These show that the taxonomy developed in the previous study is consistent with the categories established by the participants. Nevertheless, the participants were more precise. Also, engineers and mechanics share a common vision.

2. Introduction

Aircraft maintenance mechanics are exposed to many hazards of a very variable nature [2]. These hazards can have a direct impact both on the health and safety of the mechanic and on the airworthiness of the aircraft. In this sense, the mechanic is a key element in maintaining safety because the consequences of his actions can be catastrophic. Nevertheless, mechanics are not the only ones responsible for safety during maintenance operations. Indeed, as Murie [3] points out, designing and updating security rules is crucial to ensure what the author calls “security in action”. For example, the aircraft manufacturer is obliged to provide technical documentation in which warnings and cautions, one of the implementations of the security rules, are inserted. The warnings are instructions concerning the health and safety aspects of the mechanics and the guarantees of the instructions relating to the airworthiness aspects of the aircraft. Thus, through these documents, mechanics are informed of the hazards to which they may be exposed and the potential consequences when carrying out a specific task. The decision to include “warnings” or “cautions” does not belong to a single person but is subject to a process of validation and verification. Processes can also be put in place to reduce the impact of the design on the maintenance activity; however, these are not necessarily systematic. For example, engineers have documents that specify ergonomic requirements that must be considered during design. They also have technological tools like design software equipped with virtual mannequins. Or even access to virtual reality to test the impact of a design on the performance of a task. This allows engineers to address potential physical and visual accessibility issues.

Maintenance organizations are also responsible for maintaining both the health and safety of mechanics and the airworthiness of the aircraft. Indeed, by being Part 145 certified, maintenance organizations must implement a safety management system. The primary objective is to reduce the risk of accidents/incidents when the aircraft is in operation. This methodology must be used as described in the Safety Management Manual [4], the first step of which is the identification of hazards. They are also required to have a Quality department and continuous improvement processes for safety during maintenance activities. Regarding health and safety aspects, the criminal liability of the maintenance organization depends on the laws put in place by the national authority in which the maintenance is carried out. For example, in France, the article L1 to L8331-1 of May 09, 2023 of the labor code [5] requires organizations to know the hazards associated with the activity and to put in place measures to reduce the risks for health and safety. Examples include personal protective equipment.

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Regarding the mechanics, they receive initial education and strict continuous training subject to regulations such as Part 147 [6] and Part 145 [7]. This allows mechanics to obtain sufficient knowledge to be able to identify the hazard they are exposed to when performing a task. Thus, the engineers in the design offices and the mechanics share a common objective which is to guarantee safety during maintenance activities. For this purpose, both populations must be able to detect the hazards associated with a specific task. Nevertheless, engineers and mechanics differ in many aspects especially when it comes to education and training. Indeed, engineers do not necessarily have the same training as mechanics regarding safety.

The main objective of our research project is to create a taxonomy that is representative of the hazards present during maintenance activities. Thus, during a preliminary study, we built a taxonomy of hazards whose validity must be tested with mechanics and engineers [1]. Indeed, as previously indicated, both engineers and mechanics are major players in aeronautical maintenance safety. Moreover, we want to test the completeness of the taxonomy, its representativeness in relation to real activity and the accuracy of the vocabulary used. The taxonomy that combines the results of the participants will be compared to the one we have built with the aim of obtaining the most complete taxonomy possible. We will not focus here on the difference that may exist between mechanics and engineers.

3. Background

Within the framework of the risk perception of aeronautical mechanics study, it appeared crucial to propose a list of hazards representative of the reality of the aircraft maintenance activity. Indeed, identifying hazards before dealing with the notion of risk is necessary for risk analysis in aeronautics [4] and the study of risk perception [2]. Thus, during a preliminary study, we tried to understand the notion of hazard and to make the distinction with the notion of risk [1]. Specifically, a hazard exists in a situation because of its intrinsic characteristics, and when the hazard is experienced, it becomes a risk to the person exposed to it [8]. The bibliographic analysis that was performed enabled us to create a definition of hazard adapted to the field of aeronautical maintenance. This definition is “Anything that can injure the mechanic and/or damage the aircraft and is a result of the design of the aircraft or enabling product”. The identification of hazards was based on the expertise of the authors of the present document but also on a bibliographic review.

The construction of a hazard taxonomy comes from the need to obtain a categorization of the different types of hazards to which mechanics are exposed during their activity. The objective is to measure the impact of a type of hazard (belonging to a specific category) on the risk perception of mechanics. A bibliographical review was carried out as part of the previous study [1], and the lack of work led us to create one. Indeed, in the aeronautical field, Zhang, et al. [9] indicate that regulatory bodies such as the FAA (Federal Aviation Agency) or the CAAC (Civil Aviation Administration of China) do not provide a clear taxonomy and specify the hazards. Regarding aeronautical maintenance, it is difficult to find studies that offer a clear vision of the hazards faced by mechanics. Yiannakides & Sergiou p.70 [10] provide a list of the most common hazards in aeronautical maintenance, considering both the impact on health and safety and on the airworthiness of the aircraft. Necula & Zaharia [2] propose a more complete representation which identifies four categories of hazards: the individual, the hazard linked to the maintenance task, the hazard linked to the environment and the hazard of the organization. For each category, the authors draw up a list of hazards to consider. Nevertheless, even if the proposed classification is interesting, certain hazards cited by other authors such as the presence of pneumatic and vibrating tools, the presence of dust [11] are absent. This is most certainly explained by the existence of many hazards in aeronautical maintenance making the task of identification complex. For this reason, we have chosen to focus only on hazards that arise from aircraft design and enabling products. More precisely, the definition makes it possible to propose a common base of hazards which is supposed to be representative of the maintenance activity independently of organizational, individual or even environmental factors. The taxonomy resulting from the previous study must still be tested with the populations who are directly concerned by the hazards in aeronautical maintenance, which are: the engineers who design the aircraft or the enabling product and the aeronautical mechanics who are exposed to these hazards. This is the reason why this study aims to test the validity of our taxonomy with these populations.

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4. Method

4.1. Approach

The process is broken down into 2 steps:

- The pre-test
- The test

Each of these steps is described below.

4.1.1. The pre-test

4.1.1.1. Goals

The pre-test aims

- To test the validity of the experimental protocol described in the "Procedure & Materials" section.
- To ensure the feasibility of the experiment with a population of mechanics and engineers.
- To ensure the feasibility of the experiment in the context and environment envisaged for the test.

4.1.1.2. Participants

The pre-test was carried out with three participants (3 men, average age: 48 years old): A "Head of maintenance team" for 10 years with an experience as aeronautical mechanic; a Part Continuing Airworthiness Maintenance Organization (CAMO) support engineer for 23 years with an experience as aeronautical mechanic; and a Part 66 licensed mechanic in operation for 7 years.

The participant whose function is "Head of maintenance team" had a global vision of the maintenance activity and the problems that mechanics may encounter regardless of their specialty. In addition, his position allows him to be informed of incidents or accidents that occur during the activity. He is in contact with various professionals concerned with health and safety, such as ergonomists, quality personnel, etc. He was able to say if the hazards that we identified are present within his organism or not, if we omitted some of them which seem crucial to him to consider, and if the way in which each hazard is named was correct, i.e., it corresponds to the terminology usually used in the maintenance activity. Moreover, having been a mechanic, he has experience and therefore can refer to known hazards and examples of incidents, accidents experienced.

The second participant had a more theoretical vision of the maintenance activity because of his current position. This allowed him to indicate the hazards that have been identified in the documentation and the barriers in place for mitigating the risk. His engineering vision offered a different vision from that of the other two participants. His experience as a mechanic also allowed him to refer to his personal experience in the domain.
The third participant made it possible to provide more up-to-date data on the hazard to which mechanics are exposed. It also allowed testing the feasibility of the test with part of the target population and certifying the naming of the hazards.

4.1.1.3. Procedure & Materials

The pre-testing phase was carried out using an open and individual card sorting for the creation of a hazard taxonomy. Sorting cards makes it possible to represent the way in which a participant groups together different information [12]. The individual approach avoids the emergence of disagreements and conflicts within a group or the influence of some on others. This approach also enables obtaining finer results. Open card sorting is used so as not to constrain the participant in the number of categories to be created [13] while avoiding suggesting a mental representation. The pre-test phase also lets us test the representativeness and exhaustiveness of the 33 identified hazards, but also to check that the title of the hazards was understandable and correct.

On each card was written a hazard and its definition in English and in French to avoid any misunderstanding (Figure 1). The participant was isolated in a room with the experimenter and was asked to group into categories 33 hazards that were placed in front of him. He was informed of the definition of hazard that we created in the previous study [1], and which is: "Anything that can injure the mechanic and/or damage the aircraft and is a result of the design of the aircraft or enabling product". The participant had the option of adding or removing cards, or even rewriting the term if it did not suit him.

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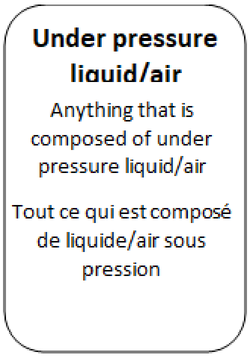

Figure 1: Example of card for the card sorting. One hazard with the definition below in French and English.

The participant was free to ask questions if necessary and it was suggested to him to verbalize his reflection as much as possible. Once the groupings were made, the participant had to name the groups created by using post-its and explain their reasoning. Indeed, it is important to understand why and according to what logic the categorization was made [14]. At the end of the session, two questions were asked: 1) What are the cards for which you had difficulty regrouping? 2) Do the hazards present on the cards are representative of those to which the mechanics are exposed during the maintenance activity? The objective was to identify the difficulties encountered by the participants and to test the completeness of the 33 hazards presented. To facilitate the analysis of the verbatim and the answers to the two questions, the session was recorded with the consent of the participant.

4.1.1.4. Results

The pre-test phase enabled us to validate the experimental protocol used during the main test. Nevertheless, some adjustments were necessary to facilitate the understanding of the participants. Indeed, some comments from the participants underline a lack of precision in the protocol, particularly concerning the consideration of hazards other than those resulting from the design of the aircraft. This phase also allowed us to obtain initial feedback on the completeness and representativeness of the hazards presented on the maps. Thus, the feedback we received allowed us to continue the study.

4.1.2. Test

4.1.2.1. Goals

The goal is to understand how mechanics and engineers categorize a list of hazards. This to test:

- The validity of the taxonomy we have constructed [1].
- The representativeness and exhaustiveness of the hazards identified in an aeronautical maintenance context.
- The correctness of the vocabulary used to name the hazards.

4.1.2.2. Participants

The study was carried out with 10 engineers and 19 mechanics:

- 10 engineers from the design departments of two different aeronautical organizations (average age: 43 years, Men: 10, average number of years of experience: 18 years). Among the 10 engineers, 3 have already been mechanics for 3, 6 and 7 years respectively and 2/10 engineers are only on tooling design and are not on aircraft design.
- 19 aeronautical mechanics (average age: 35 years, Men: 19, average number of years of experience: 15 years). The detail is presented in Table 1 below.

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Table 1: Population of mechanics

	Commercial aviation	Business aviation
Unlicensed	1	-
A1	-	1
B1	6	2
B2	-	1
B1-B2	5	-
B1-B2-C	2	-
Hydraulic	-	1
Total	14	5

4.1.2.3. Procedure & material

The protocol and equipment used are the same as those used for the "Pre-test" and presented previously (section 4.1.1.3)

4.1.2.4. Data analysis method

To analyze the results, there are several methods allowing to aggregate the individual results, the two main ones being the Actual Merge Method (AMM) and the Best Merge Method (BMM) [12]. AMM is recommended if the study involves more than 30 participants and makes it possible to know the percentage of participants who have made a specific grouping, i.e., to know that X% of the participants agree for a specific grouping. The methodology chosen to analyze the results of the participants is the AMM. We used Optimal Sort which has generated the appropriate dendrograms by using the AMM.

The comparison between the taxonomy we created and the one that combines the results of mechanics and engineers was carried out by an analysis of the similarities and differences.

We also carried out a qualitative analysis of the data from the recordings to understand the difficulties encountered by the participants: the strategy used to group the hazards, the names of the groupings, the deletion of certain hazards, the addition of other hazards or the modification of names of hazards. This provides information about the completeness of the taxonomy, understanding and representativeness of the hazards to which aeronautical maintenance mechanics are exposed.

4.1.2.5. Results

4.1.2.5.1. Participants results

The taxonomy of participants (which combines the results of mechanics and engineers) is taken from the dendrogram presented (Figure 2). Most hazards are grouped with an agreement level of 20%. At this level, the hazards have been divided into 6 groups. Only the "Vibration" hazard is not assigned to any group. The "Vibration" hazard was not grouped by one engineer (out of 10) who mentioned the fact that it does not represent much to him. He specifies that the impact on the mechanic depends on the importance of the vibrations but that the hazard is present. It also specifies that all elements vibrate in operation. As for the mechanics, two (out of 19) mentioned having had difficulty grouping the "Vibration" hazard. One of these mechanics did not include it in a group because he did not feel personally concerned by the vibrations. The mechanic justifies this by indicating that if the hazard is present, he does not touch the vibrating object. The second indicates that the mechanics are not greatly exposed to vibrations while specifying that the hazard exists.

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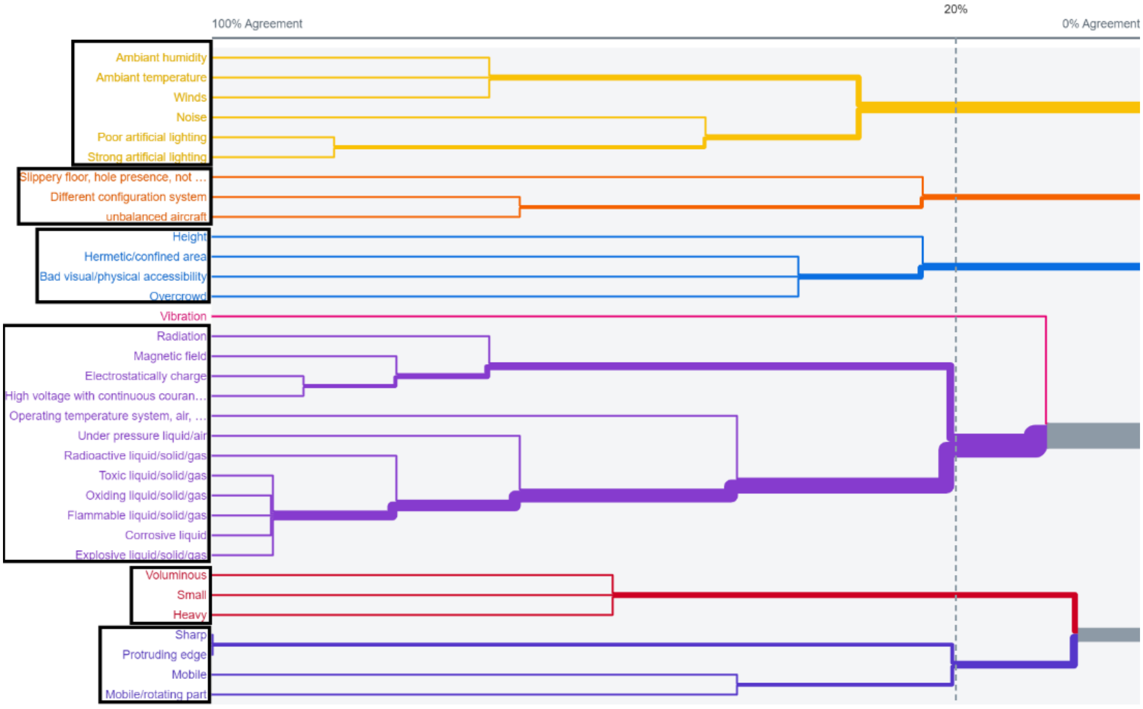

Figure 2: Dendrogram generated with Optimal Sort and the AMM with a 20% level of agreement. 6 groups are present (black boxes) and only the “vibration” hazard does not belong to any group.

Concerning the first group presented in yellow in figure 2, 30% of the participants agreed to group the 6 hazards. Nevertheless, within this group of 6 hazards, the levels of agreement vary according to the hazards grouped together. For example, 80% of participants agreed to group the hazards “Poor artificial lighting” and “Strong artificial lighting”. Only one engineer (out of 10) had difficulty grouping the “Strong artificial lighting” without providing details. If we add the hazard “Noise”, the level of agreement drops to 47%. Nevertheless, no difficulty was mentioned neither by the mechanics nor by the engineers to group this hazard. Also, at a 70% level of agreement, participants grouped the hazards “Ambient humidity”, “Ambient temperature” and “Winds”. No difficulties were mentioned by the participants for these hazards.

The following grouping (in Amber in Figure 2) is composed of three hazards with an agreement level of 23%, due to the inclusion of the hazard “Slippery floor, hole presence, not smooth floor”. For this one, only one mechanic (out of the 19) did not group this hazard because, according to him, “it does not represent much”. This same participant specifies that the presence of an open hatch can be a hazard but that the worst scenario is to sprain yourself. The two other hazards, “Different configuration system” and “unbalanced aircraft” are grouped together at a level of agreement of 66%. Nevertheless, this grouping is a little particular for both mechanics and engineers who do not see them as hazards. Specifically, the “unbalanced aircraft” hazard was difficult to group for 2 mechanics (out of 19) and 4 (out of 19) did not fit into any group. Two engineers (out of 10) had difficulty grouping it. For one of these 2 engineers, it was not really a hazard for maintenance except during cargo loading which is a very specific activity. The second engineer mentioned that this is not really a hazard because if the mechanics find themselves in a situation where the masses are badly distributed, the activity is stopped. A third engineer mentions, in this regard, that if the plane finds itself in a situation where the masses are not correctly distributed, it is because the documentation has not been followed.

The “different configuration system” hazard has always been attributed to a group. However, 3 mechanics (out of 19) indicated having encountered a difficulty in grouping it. These hazards do not really represent a risk for the health and safety of the mechanics but rather for the aircraft. They refer to specific knowledge or information available in documentation that is more within the purview of the engineers designing the aircraft. Thus, this does not represent a hazard in itself and is rather akin to human error. Concerning the engineers, only one out of the 10 did not group the hazard “Different configuration system”. He did not perceive it as a hazard because it was linked to the training of the mechanics.

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A mechanic (out of 19) had difficulty grouping it because from his point of view, the information related to the configuration of the aircraft is traced in the documentation. The participant grouped the two hazards together and mentioned that they should not be present in the taxonomy.

The third grouping in blue in Figure 2 composed of 4 hazards reaches a 23% level of agreement with the inclusion of the “Height” hazard. Two mechanics (out of 19) indicated having encountered a difficulty in associating it with a group. This was not the case for engineers. Without it, the level of agreement increases to 36% and includes the three other hazards. Regarding the “Hermetic/confined area” and “Overcrowd” hazards, no participant mentioned having had any difficulties. However, for the “Bad visual/physical accessibility” hazard, two engineers (out of 10) did not group it. The first mentioned having hesitated to insert it into two groupings, one referred to the environment of the hangar and the other to its close environment. Eventually, the hazard was passed over. The second indicated that it was not a hazard because it is something that is already considered during the design and that there are means to evaluate it, to counter it.
The fourth purple cluster in Figure 2 includes 12 hazards at a 20% level of agreement. To gain precision, it is possible to split the group into two: 1) The first (presented in Figure 3) corresponds to an agreement level of 70% and includes four hazards. Only one mechanic (out of 19) indicated that he had difficulty grouping the “Radiation” hazard because he did not know which group to include it in.

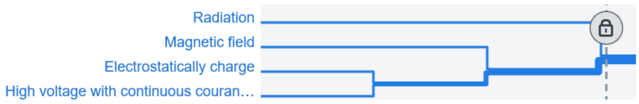

Figure 3: Dendrogram generated with Optimal Sort and the AMM with a 70% level of agreement.

2) The second group (shown in Figure 4) corresponds to a 43% level of agreement following the inclusion of the hazard “Operating temperature system, air, liquid”. We note, in this group, a great variability in the level of agreement which goes from 93% for the creation of the group including the hazard “toxic, Oxidizing, Flammable liquid/solid/gas” and “Corrosive liquid”, to 43% when “Operating temperature system/air/liquid” is inserted. Nevertheless, no difficulty was indicated by the participants on any of the hazards of this grouping.

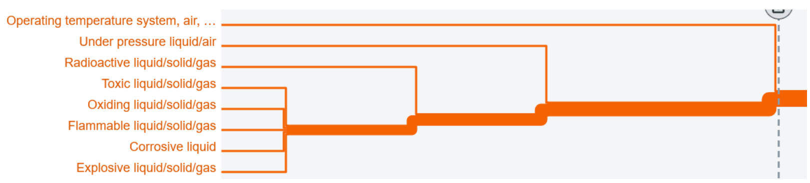

Figure 4: Dendrogram generated with Optimal Sort and the AMM with a 43% level of agreement.

The fifth group in red in Figure 2 includes 3 hazards at a 56% level of agreement. Regarding the “small” hazard, one of the mechanics (out of 19) had difficulty grouping it because he did not really perceive it as a hazard. Another to indicate that the hazard could be linked to the presence of a Foreign Object Damage (FOD) but if this is the case, he must seek the lost object until he has found it. This, in accordance with the instructions received by anyone carrying out an activity on an aircraft. Thus, the participant did not group it because considers it an oversight. According to an engineer, "Small" is not considered to be a hazard but more of the order of human error. For example, the mechanic forgets a small element in the plane. Regarding the “Voluminous” hazard, a mechanic had difficulty grouping it together because, according to him, “it does not represent much”. An engineer (out of 10) indicated having encountered difficulties because for him the bulky elements are not handled by hand but with the help of equipment and therefore do not represent a hazard. No difficulty with the “Heavy” hazard was mentioned by the participants.
The sixth and last group in Figure 2 includes 4 hazards and corresponds to an agreement level of 20%. We notice that “Sharp” and “Protruding edge” have been grouped together with an agreement level of 100%. But also, that “Mobile” and “Mobile/rotating part” are grouped at a 43% level of agreement. Regarding the “Mobile” hazard, 2 mechanics did not include it in a group because it did not correspond to a hazard for them. One mechanic commented that even though he grouped the hazard, he didn't really know where to insert it because "it doesn't mean much" to him. Only one engineer (out of 10) reported having difficulty grouping the hazard “mobile".

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The participant mentions that during maintenance activities the ground is flat and that the mobile equipment or the aircraft had brakes. No difficulty was mentioned for integration into a group for other hazards.

4.1.2.5.2. Participant taxonomy

The results presented above allowed us to establish a taxonomy that combines the results of mechanics and those of engineers (Table 2). This taxonomy is finally composed of 5 categories comprising 33 hazards. Note that, as explained in the previous part, the inclusion of the “Different configuration system” and “Unbalanced aircraft” hazards was strongly questioned by both mechanics and engineers. Nevertheless, we have chosen to show them to explain the belonging to a very specific category, which is “aircraft characteristics”.
The choice of the title of the categories was made by analysing the results of the participants. We selected those that best matched the grouping and how participants described the groups.

Table 2: Combined Taxonomy of Mechanics and Engineers

Category	Details	Hazards
System	Includes all hazards that are related to the intrinsic characteristics of the systems that enable the airplane or any enabling product to operate. The vibration hazard has been added to this category.	Vibration, Operating temperature system/air/liquid, Under pressure liquid/air, Toxic liquid/solid/gas, Oxiding liquid/solid/gas, Flammable liquid/solid/gas, Corrosive liquid, Explosive liquid/solid/gas, Radioactive liquid/solid/gas.
Electrical	Includes all hazards that are related to the intrinsic characteristics of the aircraft's electrical systems or any enabling product.	Electrostatically charge, High voltage with continuous courant, Magnetic field, Radiation.
Working condition	Includes all hazards that are related to the working conditions of mechanics induced by the design of an aircraft or any enabling product.	Hermetic/confined area, Bad Visual/Physical accessibility, Height, Overcrowd, Slippery floor/ hole presence/not smooth floor.
Environmental	Includes all hazards that are related to the mechanic's environment and not necessarily related to the design of an aircraft or any enabling product.	Ambient humidity, Ambient temperature, Noise, Poor artificial lighting, Strong artificial lighting
Object characteristics	Includes all hazards that are related to the intrinsic characteristics of objects handled by mechanics.	Small, Heavy, Voluminous, Mobile, Mobile/rotating part, Sharp, Protruding edge
Aircraft characteristic	Include the two hazards that the participants thought should not be present in the taxonomy. These correspond to the intrinsic characteristics of the aircraft.	Unbalanced aircraft, Different configuration system

4.1.2.5.3. Comparison with our taxonomy

Generally, participants were more specific in their categorization compared to the taxonomy we established. For example, the “Structural characteristics” category of our taxonomy is an assembly of the “Working condition” and “Object characteristics” categories proposed by the participants.

Other similarities exist between the two taxonomies. For example, like the participants, we grouped together in the same category the hazards “Toxic liquid/solid/gas, Oxiding liquid/solid/gas, Flammable liquid/solid/gas, Corrosive liquid, Explosive liquid/solid/gas, Radioactive liquid/solid/gas”. Nevertheless, we have considered these hazards as a separate category entitled “Chemical product characteristics" while participants included it in the "System" category (Table 2). From our point of view, chemicals are not only a component of aircraft systems, for example, but can be present in various containers.

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The main disagreement concerns the categories labeled "System" in the two taxonomies. Specifically, we have chosen to create a category that includes all hazards related to the aircraft system and any enabling product. Participants chose to do the same but only 3 hazards are common to both categories which are: "Vibration", "Operating temperature system/air/liquid", "Under pressure liquid/air". Indeed, we have chosen to:

- Consider the “Magnetic field”, “Radiation” and “High voltage with continuous current” hazards as being related to the aircraft system or any enabling support. The participants chose to consider them as electrical hazards (Table 2).
- Consider the “Noise”, “Poor artificial lighting” and “Strong artificial lighting” hazards also as being related to the characteristics of the systems. The participants, themselves, inserted the hazards in the “Environmental” category. Category we also have created includes four hazards: "Ambient humidity", "Ambient temperature", "Winds" and "Overcrowd". The disagreement concerns the "Overcrowd" hazard which is considered by the participants to be a component of working conditions.
- Consider “Electrostatically charge” as a hazard from aircraft structure or equipment being handled. Participants considered it an electrical hazard (Table 2).

More generally, we agree on specific hazard groupings but not necessarily on the category to which these groupings should belong.

4.1.2.5.4. Representativity of the identified hazards

The results show that the participants agree that the 33 hazards are sufficiently representative of the maintenance activity. In addition, they considered the list to be exhaustive, i.e., the participants did not see any other hazards to add. Only one mechanic indicated that the hazard "High voltage with continuous current" is not specific enough. Indeed, according to this participant it would be preferable to create two distinct hazards, one called "Alternating current (AC)" and the other "Direct current (DC)", because the two types of current do not refer to the same consequences. This is supported by the fact that in the technical documentation used by mechanics during their activity, a distinction is made between the two types of current. Thus, these two hazards should replace the hazard "High voltage with continuous current" and be inserted in the "Electrical" category.

5. Discussion

The aim of the study was to test the validity of a hazard taxonomy created in a previous study [1]. In this study, we made the choice to consider only the hazard resulting from a decision taken during the design phase of the aircraft or any enabling product. Indeed, it was a question of focusing on the hazards which are present regardless of the location of the maintenance and the varieties of the environment, the individual or the organization. In this study, the objective was to verify that our taxonomy was representative of the maintenance activity, i.e., whether it is made up of hazards that are present during the maintenance activity, and whether the taxonomy was reflecting the way participants (engineers and mechanics) categorize hazards.

5.1. Participant taxonomy

Before comparing the two taxonomies, we had to create the taxonomy from the results of the study participants, using the dendrogram presented in Figure 2. The first result shows some heterogeneity in the way of grouping the hazards between participants. Indeed, a level of agreement of 20% was necessary for most of the hazards to be integrated into a group. We believe that these differences in representations can be explained in several ways.

In the first case, some participants indicated that they encountered difficulties in classifying a hazard but nevertheless included it in a group. For example, an engineer indicated that he had difficulty considering the “Voluminous” hazard because for him the bulky elements are not handled by hand but with the help of equipment and therefore do not represent a hazard. This type of result indicates that a participant may not consider an element as a hazard because there are safety barriers already implemented and supposed to be operational. However, a hazard is an intrinsic characteristic of a situation, object, equipment, etc. [15]. The hazard exists independently of any interaction, even if safety measures are already in place. In addition, safety measures aim to reduce the risk to an acceptable level and not to reduce/remove the presence of a hazard. To explain this, the hazard “Small” constitutes another example which was not considered by one of the mechanics as a hazard due to the presence of a safety measure (“look for the small element”) which would reduce or eliminate the risk of an incident/accident occurring when the aircraft is in operation.

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However, from our point of view, the presence of the “Small” hazard is the result of a decision during the design phase.

Thus, the hazard can only be eliminated if the design of the aircraft does not include any small elements and objects. This result may reflect a confusion between the notion of risk and hazard among the participants because the hazard should not be associated with safety measures. However, these discrepancies can be problematic for safety during maintenance operations. For example, an engineer who does not consider a hazard as such during the design, because there are safety measures, will not necessarily be in a process of eliminating the hazard to which mechanics will be exposed. Similarly, if a mechanic does not consider a hazard when exposed to it, he may not act in a safe manner with respect to this hazard. Thus, it would be relevant to better understand the way in which the hazards and risks are taught, transmitted to both engineers and mechanics. But also, to study how the two populations define and understand these two concepts in the context of aeronautical maintenance.

In the second case, the participants did not insert the hazard into a group. For example, two mechanics have not grouped the hazard “Mobile” because it does not represent a hazard for them. Or a mechanic did not group the “Vibration” hazard because he did not feel personally concerned. An engineer also indicated that he did not see what this hazard referred to because all the elements of an aircraft vibrate in operation. So, even if he agrees that the hazard exists, it does not mean much to him. These results indicate that despite the definition provided, some participants do not consider a hazard as such, which can have a real impact on safety during maintenance operations. Moreover, these results express a part of subjectivity in the consideration of an element as being a hazard or not. Nevertheless, from a safety point of view, everyone should be agreed about the hazards present during maintenance activity. An engineer who does not consider a hazard in his design may not try to limit his presence and therefore his impact on the maintenance activity. In this case, the implementation of a process that includes stages of validation and verification of the design activity, as may already be done, makes it possible to reduce the impact of an individual decision on the maintenance activity. Indeed, several engineers mentioned the existence of internal processes that required them to consider certain hazards during the design phase. Similarly, a mechanic who does not perceive a hazard to be present may not act in a safe manner when exposed to it. Also in this case, measures exist to improve the consideration of hazards by mechanics, such as training, company culture, etc. However, the study does not allow us to understand precisely the reasons why such differences exist. Thus, it would be relevant to study the factors that prevent a mechanic or an engineer from identifying hazard. Is it for lack of experience? Training, education? Or because it does not distinguish between hazard and risk as indicated above? etc

In the last case, some participants did not indicate having had any difficulty, but indicated that they had not grouped the hazards. Nevertheless, the level of agreement that made it possible to build the taxonomy remains very low, which indicates a certain heterogeneity between the participants in the way a hazard can be categorized. For example, for the hazard “Operating temperature system, air, liquid” no difficulty was noted by the participants. However, it is difficult in our study to understand where these distinctions can come from, which can be problematic for safety in aeronautical maintenance. Indeed, to avoid interpretations, a definition of the hazard was written on each card. The problem in terms of safety comes from the fact that, for example, if two engineers, define a hazard in a different way, they may not consider it in the same way during the design. The same applies to mechanics who may behave differently when exposed to the same hazard because they do not perceive or define hazard in the same way. Thus, as for the previous cases, it would be relevant to understand why two mechanics, or two engineers do not have the same representation of the same hazard.

5.2. Validity of our taxonomy

The results indicate a certain homogeneity between the two taxonomies even if the participants were more precise in their categorization, which led them to categorize certain hazard groups differently. For example, we have chosen to insert the hazards “Poor artificial lighting” and “Strong artificial lighting” in a category called “System characteristics”. Indeed, from our point of view, these hazards are intrinsic components of the aircraft or of the equipment handled. Nevertheless, some mechanics indicated that these hazards were not only related to components present in the aircraft but could be any light source present in the environment. For example, they can be dazzled by spotlights present around them but not used directly by them. Thus, the expertise of the participants will make it possible to create a taxonomy that will be more representative of the reality of the aeronautical maintenance activity. These results highlight the idea that engineers and mechanics have their own way to categorise and to consider hazard during maintenance activity. Thus, it could be interesting to better understanding how mechanics consider the notion of hazard for improving safety in aircraft maintenance.

DOI: 10.13009/EUCASS2023-614

The main disagreement identified concerns the inclusion of the hazards “Unbalanced aircraft” and “Different configuration system”. From our point of view, they respond to the notion of hazard because the weights of the aircraft are an intrinsic characteristic of it. The same applies to system configurations which may vary. Nevertheless, the participants indicated that these two hazards referred to overly specific work situations that did not represent a hazard but rather an error by the mechanic because everything is indicated in the documentation. A mechanic also mentioned that if we consider these two elements then it is possible to consider many other hazards that would also be present during the maintenance activity.

The main criticism we can make concerns the influence of our decisions on the taxonomy of the participants. Indeed, as with the "Vibration" hazard, the dendrogram provided in Figure 2 did not accurately assign the hazard to a specific group. Thus, we had to make a choice that was influenced by our own judgment. Maybe, with more participants we could have a greater homogeneity in the results.

6. Conclusion

This study represents a work whose objective is to propose a taxonomy representative of the reality of the aeronautical maintenance activity, and which corresponds to the way in which mechanics and engineers categorize the hazard. The comparison of the taxonomy of the participants with ours will make it possible to propose a categorization which is the most representative of the activity of aeronautical maintenance. Thus, the next step will be to create a so-called “final” taxonomy that combines our taxonomy with that of the participants to be able to offer the most representative version of the aeronautical maintenance activity. Nevertheless, some questions remain opened regarding the subjectivity in the way to consider and to categorise hazards in aircraft maintenance field. Thus, more research is needed to better understand the reality of maintenance activity through aircraft mechanics.

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