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Acting in Safety from the Design to the Implementation of Helicopter Maintenance

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Abstract. In order to avoid helicopters accidents, maintainability engineers seek to identify, evaluate and solve what they called “the risks of maintenance errors” done by maintenance mechanics, and sometimes pilots performing simple pre-flight maintenance tasks. Here we will argue that beyond trying to avoid errors by following procedures, acting safely involves trade-offs between safety and performance within the engineers’ and mechanics’ activity. This papers show the relations between the mechanics’ and engineers’ work using the Critical Incident interview technique.

[AQ1](#)

Keywords: Safety · Maintenance · Conception · Critical incident interview

1 Introduction

Saleh et al. (2019) presented maintenance as causal factors of accidents in 14% to 21% of helicopter accidents in the U.S. civil fleet between 2005 and 2015. In order to avoid these accidents, maintainability engineers in Airbus Helicopters’ maintainability department seek to identify, evaluate and solve what they called “the risks of maintenance errors” done by maintenance mechanics. The maintainability team contributes to design helicopters and safe maintenance procedures within the complex process design of a helicopter involving many design actors (Bernard et al. 2019). In this context, the industrial thesis work presented here is based on an action research. Design science work emphasizes the distributed nature of design (Darses and Falzon 1996): in time, space, or in various organizations, and among various protagonists with their own goals and perspectives. As a result, design processes often take on a “conflictual” character. Designing then requires negotiations and the articulation of these different perspectives and goals. Negotiation is the process of elaborating rules through the construction of trade-offs that lead to agreements on the actions to be undertaken (Hollnagel 2009). The artefacts designed are thus the result of these different trade-offs in relation to the initial

AQ2

design intent (Bucciarelli 1988). This design process continues in the use of the artefacts by users, who can develop new uses that can themselves be taken up by the designers (Bourmaud & Rétaux 2002). Reason's model (1990) highlights the primordial role of decision-makers and designers in the design of work situations presenting latent conditions of error that can lead to accidents. Workers are not passive but adapt the safety rules given to them by designers (Amalberti 2013; de Terssac and Mignard 2011). They adapt the rules in their work through processes of rule negotiation, which is done by establishing trade-offs between safety and performance. The notion of safety in action testifies to the fact that workers put these rules into action by deciding whether or not to integrate them into their action according to the context (de Terssac and Gaillard 2009). Here we will present the first part of the current thesis, which aims to provide answers to the following questions: In which situations maintainability engineers and maintenance operators build trade-offs between performance and safety? In what way is their work related?

2 Methods

Context - Most of the maintenance operations are carried out outside the manufacturer's premises, at the premises of customers who operate the aircraft or at approved maintenance workshops all around the world. We have therefore chosen a methodology for collecting information remotely from our workplace and for accessing the variability of the helicopter maintenance; the critical incident interview. The objective of the critical incident interview is to get closer to what the person has experienced by determining the critical requirements of a specific task (Bisseret Sebillotte Falzon 1999) through his or her subjectivity and experience. Butterfield and his colleagues (2005) propose three operational criteria used in the choice of incidents: (1) the incident informs us about a past event; (2) it contains a detailed description of the experience as such; (3) it describes the results of the incident. The incident selected must have had a negative or positive impact on the activity. The concept of critical incident has been replaced by significant incident by some researchers in order to avoid resistance on the part of interviewees (Butterfield et al. 2005). During the interviews we did not use the term "incident" but "situation" because the term "already" has a meaning in the field of aeronautics. An incident is an event associated with an operation on the aircraft that affects or may affect the safety of the operation. We will therefore talk about significant events later on.

Development - In the literature, critical incident interviews usually take place during a single interview or questionnaire. We deviated from this method by proposing two interviews of one hour each to the interviewees. A first exploratory interview of the participants' activity enabled us to familiarize ourselves with the participants' profession and to create the bond of trust necessary for the second interview. The second interview, the critical incident interview, allowed us to collect significant events. We begin these interviews with the following instruction: "I will ask you to remember events you have experienced that have had an impact on your ability to secure the maintenance of the helicopter. You must have experienced them and they must have been significant in your work. They may be events that had a very positive impact, a very negative impact, or an event in which you almost failed to achieve your goal."

Material and Population - Depending on the availability of the participants and the logistical constraints, the interviews took place either in person, by telephone or using a videoconferencing software. Two types of population were targeted for these interviews: (1) Those who design maintenance safety rules through maintainability, engineers working in maintainability service, (2) those who carry out maintenance, mechanics and helicopter pilots. Eight people from the maintainability department were interviewed to have at least one person from each operational function on the team, three Maintainability Engineers, two Tooling Engineers, one Maintainability Expert, one Human Factor Specialist and one Maintenance Architect. We were also able to carry out these interviews with 5 mechanics and with a pilot as an end user of the helicopter. Four of the mechanics interviewed are mechanics employed by Airbus. One is currently an engineer in the maintainability department and 3 mechanics carry out maintenance operations at customers' sites. The fifth mechanic interviewed is external to the company.

Treatment - All significant events interviews have been transcribed. The analysis of these interviews seeks to answer the following question: On which critical requirements did the significant events have an impact? This categorization will then allow us to describe how maintainability engineers and maintenance operators construct safety trade-offs. We realized an inductive thematic coding as defined by the Braun and Clarke (2006) thematic analysis method. The categories and themes of critical requirements are constructed during the coding by including elements in the categories already identified and by creating new ones if these elements cannot be placed in an existing category.

3 Results

We have identified 43 significant events, 29 of which resulted from interviews with maintainability designers and 14 from interviews with maintenance operators. The Table 1 presents the functions, the participant's identification code and the number of significant events we identified in their interview.

Within the maintainability department there are 5 different functions including one of which is called Maintainability Engineer. From now on we will designate the group of people working in the maintainability department by "maintainability designers" to differentiate the Maintainability Engineers from the others. We will then present the themes and categorizations extracted of the critical requirements needed to secure the maintenance design and implementation and the events' code included in these categories in the Table 2. Each events is identify thanks to a code included the participant's identification code and the event's number preceded by the letter I (ex, M1I1 for the first event of the first mechanic). The Table 2 should be read as follow: The significant event GSE2I1 had a positive or negative impact on the understanding of the project's history. We will explain each categories briefly before discussing them.

Table 1. Number of significant events identified in the interview for each participants.

Function	Participant's code	Number of significant events
Extern mechanic	M1	1
Airbus mechanic	M2	3
Airbus mechanics working with clients	M3	3
	TR1	2
	TR2	2
Pilot	P1	3
Maintenance architect	A1	3
Human Factor Specialist	SFH1	4
Tools engineers	GSE1	1
	GSE2	2
Maintainability engineers	SM1	5
	SM2	8
	SM3	2
Maintainability expert	EM1	3

Table 2. Categorization of the critical requirements needed to secure the maintenance design and implementation

Select the intervention method and analyze the maintainability risk
Understand the project's history (GSE2I1, SM3I1) - The Maintainability designers wanted to understand the history of the project in order to be able to intervene into the design process and evaluate the resources that could be put at their disposal
Adapt the intervention to the project's constraints (EM1I1, SM2I8) - When the constraints of the project don't allow the Maintainability designers to do "the best [they] can do in maintainability", they proposed different forms of intervention
Taking advantage of resources to analyze the risk (GSE1I1, SM2I7) - With the right resources, they organized various forms of analysis according to the complexity of the maintenance task
Choosing the analysis' complexity according to the risk (SM2I6, EM1I3) - The maintainability designers found the maintainability task complex after its first analysis. They performed simulations of the task to identify risks that were invisible during the initial analysis and tested possible solutions

(continued)

Table 2. (continued)

Mobilize the collective around maintainability
<p>Build the solution with the other designers (SFH1I4, SFH1I5, SM1I2, SM1I5) – This categorization shows how maintainability designers worked with other engineers to build solutions that work for everyone</p> <p>Focus the discussion around maintainability to deal with conflicts (A1I1, A1I3, SM1I1, SFH1I1) - The maintainability designers identified points in conflict with the requests or objectives of other designers. Their solution was to highlight the maintenance constraints and the needs of maintainability</p> <p>Ask help from authority figures (SFH1I2, A1I2) – Maintainability designers asked someone they think is an authority figure to support their message</p>
Build an acceptable and accepted solution (Maintainability designers)
<p>Include the solution in the design process (SM1I4, SM2I5, SFH1I3, EM1I2) – To be discuss a proposition of solution with the other designers, Maintainability designers tried to include it in an existing process of conception</p> <p>Constrain the practice of maintenance (SM2I4) – The Maintainability engineer created a rule to be sur a maintenance operation will be done by the customers</p> <p>Take into account the variability of helicopters (SM2I3, GSE2I2) – The Maintainability designers wanted to design for the most version of helicopters possible and not just the most current</p> <p>Negotiate to promote design changes (SM1I3, SM2I1, SM2I2) – The Maintainability designers prioritized Design modifications because they are not based on the "will" of the operators who may deviate from the procedure</p>
Compensate for a lack in design through maintenance
<p>Add operations to the procedures (M3I1, M2I2, M2I3) - The mechanics added maintenance operations from the procedure in order to act safely</p> <p>Remove operations from de procedures (M3I2) - The mechanic removed maintenance operations from the procedure in order to act safely</p>
Manage an unforeseen situation
<p>Assess the need for the aircraft's availability (M1I1, TR1I2) – The mechanics chose their action based on the customer's need for the helicopter</p> <p>Repatriate a helicopter (P1I1, P1I2, P1I3) – The pilot helped to do maintenance tasks in order to repatriate damaged helicopters to their base the fastest possible</p> <p>Manage the resources to be in time (TR2I1, TR2I2) – The mechanics had to organize their access to resources that helped them to be in time</p>
Share experiences
<p>Contact the maintenance organization (TR1I1) – The mechanic shared his conclusions after an incident to the customer's maintenance organization</p> <p>Contact the helicopter manufacturer (M2I1, M3I3) – The mechanics communicated their experiences to the customer's support service</p>

4 Discussion and Conclusion

The categorization of these significant events by critical requirements for safety highlight that the construction of safety is done in the very activity of maintenance operators and Maintainability designers. It is merged with it and is not a detached, separate and different action (Terressac and Gaillard 2009). Despite what their categorization may suggest, the critical requirements presented are interrelated. Trade-offs made in one category may affect trade-offs made in another.

4.1 Trade-offs in the Design Process

The choice of the analysis' form will impact the Maintainability designers' ability to identify risks more or less in detail and easily. They take into account the context in which their analysis and their work will be able to fit. This choice will condition their strategy to mobilize the designer collective. Maintainability designers can use several strategies to mobilize the designer collective, one of them is to focus the conversation around maintainability and convince them. They can organize collective workshops with other design actors in order to analyze the situation and build solutions with them. In one event, a maintainability engineer found his project complex and thought he needed to perform tests on a physical mock-up afterwards. He then organized working groups with the other design actors to co-construct the solutions. This allowed him to discover solutions that the maintainability engineer could not have found on his own. It also involved the other actors in the choice of solutions and facilitated the release of means for the tests because the participants were at the right hierarchical level. But highlighting the requirements and constraints of maintainability does not systematically lead to it being taken into account by the collective. That can be done according to the legitimacy that other designers give to risk analysis in the face of their own constraints. Oppositions may then persist and the engineer's solution proposals may be rejected. The collective mobilization around the constraints of maintainability conditions the process of building solutions.

Maintainability engineers build trade-offs between their goal of achieving an ideal solution from a maintainability point of view and the constraints and goals of other design actors with whom they may be in conflict. According to Benchekroun (2017), conflicts are not always an obstacle, they can be a resource of work if they are respected, listened to and worked on. For the maintainability designers an ideal solution is a solution that will be accepted by the other actors of the design, which gives the mechanic the possibility to carry out a maintenance procedure that is deemed to be risk-free. They can sometimes have the goal of constraining the mechanic's activity to avoid violations procedures. If the collective reject their solution, they will suggest alternative solutions that are either to add maintenance operations that can "lead to new human factors risks", to modify the work cards sent to the customer or to warn him of the identified risk. We can then put forward the role of conflictual cooperation in the development of conflicts in resources for activity (Benchekroun 2017), Fournier, René, Duval and Coll. (2001) define conflictual cooperation "as a mode of relationship based on critical collaboration ranging from the creation of alliances when possible to conflict when it becomes necessary to increase the power of influence". The notion of conflictual cooperation makes it possible to reflect on

the collective work mechanisms of designers immersed in a system with contradictory injunctions.

4.2 Adapt Procedures to the Maintenance Situation

Maintenance operators show their ability to act safely through the mobilization of knowledge of prudence (Cru 2014) and by adapting the procedures to the situation. For example, during an inspection in a context where the availability of the aircraft was not urgent, the mechanic added dismantling operations to make sure he could do the task safely. He considered the elements on which he had to intervene were too difficult to access and that there was a risk of damaging the elements in the vicinity, which are very sensitive to shocks. The task he had to perform in 1h30 according to the procedure finally took him 1 day and a half. We can say here that the helicopter design, result of maintenance designers' work is at this event's root.

The trade-off between safety and performance is achieved by taking into account the time pressure and the resources available to the mechanic (Atak and Kingma 2011; Chang and Wang 2010). One of the significant events followed a planned maintenance operation. During an oil sampling that was supposed to take 10 min, the home-made hose used for the sampling fell into the main gearbox. The mechanic, with the help of his workshop manager, then spent 1 h finding a way to retrieve it in a context of high time pressure. Each time the operator re-evaluated the situation, he had to re-evaluate his decision not to request a replacement helicopter and to continue in the hope of being within the contractual time frame with the client. Here the mechanic finally manage to secure the helicopter but the event was initially caused by the lack of existence of a proper tool to realize the oil sample.

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4.3 Build the Safety with Maintenance Operators' Feedback?

The parallel analysis of the significant events of maintenance operators and engineers shows us that maintainability engineers are looking for feedback on the work of mechanics by simulating the maintenance task or by interviewing in-house mechanics. At the same time, some maintenance operators their knowledge to the designers of these procedures in the hope of avoiding an incident in the future. When mechanics have to compensate for a lack of helicopter design and/or procedures and when they face an unforeseen situation they learn from the event, which impacts their future business to a greater or lesser extent.

Three significant events are centered on the sharing of this experience, either to the maintenance organization in their field or to the aircraft manufacturer. For example, during a visual inspection, a customer mechanic becomes aware of premature wear of an equipment. The element had not been correctly installed during the last maintenance operation. He remembered an older similar case in a different department than his own. The problem was due to the incomprehension from some mechanics of the procedure. The mechanic then contacted the manufacturer to trace the problem and propose modifications in the writing of the procedure and to put visual aids on a tooling concerned. One year later, the mechanic did not see any modifications and still does not understand what is preventing the manufacturer from carrying out what he considers to be simple

actions. The mechanics' sharing of experience can, however, pay off. For a mechanic who is employed by the manufacturer and who maintains an aircraft that is in the process of being developed, his work of sharing his experience has led to the modification of the work card, which he believed to be false.

In fact, the conditions for the success of feedback both in its implementation and its effectiveness depend on the organizational and socio-cultural factors structuring it (Gaillard 2005). The main reasons for the difficulties of feedback “ie in the existence of different paradigms, cultural differences between disciplines and professions, but are also due to fear of sanctions, interference with the legal system and the media, as well as competition” (Gaillard 2005). Here too, we highlight the primordial role of a maintenance design result that takes into account feedback of maintenance operators for its durability.

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