NEXT GENERATION AIRCRAFT AND POSSIBLE RISKS FOR MAINTENANCE

Anneke Nabben MSc.
Netherlands Aerospace Centre NLR
Amsterdam, the Netherlands
Anneke.Nabben@nlr.nl

ABSTRACT

Next Generation aircraft, also called 'digital' aircraft, contain a lot of automation. Automation supports the maintenance mechanic but also introduces new tasks and requirements. These relate to the capabilities of the maintenance mechanics in dealing with the automation in general and dealing with potential imperfections in the automation in particular. When automation fails, maintenance may become more complex. Detecting problems and defining root causes without automation support becomes difficult due to the IT driven nature of systems particularly when there is a lack of experience in manual troubleshooting. Importantly, when the machine takes over the work of humans, and the human is only an observer in the process, the maintenance mechanic risks loss of concentration on the task at hand or becoming negligent. This causes lack of oversight (situational awareness) and when things go wrong this might not be detected. This raises questions about skill deterioration for maintenance mechanics.

This research aims to analyze the risks of next generation aircraft for maintenance and suggest justified mitigation strategies by means of training. The research comprises of two parts: the risks of automation on human performance in aircraft maintenance are explored, and it is investigated how to deal with those risks in order to mitigate them. The focus of this second part of the question is in the area of maintenance training and less on the area of aircraft system design. In order to find the answer to those questions a literature review and field research is performed, comprising several workshops with maintenance instructors and interviews with B1 and B2 licensed maintenance mechanics working on next generation aircraft.

The outcome of the research showed that the risks of automation on maintenance mechanics are complacency, automation bias, skill decay or atrophy. The mechanics trust the outcome of the automation systems and are positive about automation. However, they also indicate that sometimes the automation does not have the correct solution due to the combination of events on the aircraft. Automation is rule based and includes programmed possible events and combinations of events. Therefore the maintenance mechanic needs to be able to assume control when automation fails. To achieve this, there are two important mitigation areas: the design of automation and training. Design should be human centered, which means that the human is involved and is part of the loop. Training should contribute to a certain level of understanding about the input and output of the automation system. The maintenance mechanic should be able to detect abnormal situations in automation. He should study the automation and system logic. This should be reinforced by him experiencing different and unexpected troubleshooting scenarios, without the use of the (complete) documentation or relevant aircraft Fault Isolation Manual. Practicing realistic productive troubleshooting in which the student really has to think, reason, refer to manuals etc. supports the understanding of the aircraft system logic and enhances resilience in unexpected real time situations. It forces the student to be consciously and actively involved and to understand and be aware of the automation possibilities and impossibilities. The student should be active and in control of his own learning instead of the instructor leading him by the hand. The instructor should coach and stimulate self-activation, curiosity and responsibility. This principle should also be incorporated in continuation and refresher training in order to prevent loss of skill, knowledge, and awareness retention.

1 - INTRODUCTION

Next Generation aircraft, also called 'digital' aircraft, contain a lot of automation. This ranges from partial to full automation in cognitive tasks (decision support systems) and/or psychomotor skill tasks. The automation has an impact on the performance of maintenance on aircraft systems. Previous generation aircraft required the maintenance mechanic to troubleshoot 'manually'. Mechanics needed to have a clear understanding of the system operation to detect, confirm, isolate, and solve abnormal system behavior. Now automation supports or even (partially) replaces the mechanic with the execution of those troubleshooting steps.

In the pilot area much research on this topic is already done. Experiments are performed, conclusions are drawn and possible solutions are mentioned with regard to the impact of automation on human performance and safety. To date, for the maintenance area, this is considerably less so. In general, automation improves the aircraft mechanic's performance and thus improves efficiency and safety. Automation supports the maintenance mechanic but introduces new tasks and requirements as well. These relate to the capabilities of the maintenance mechanics in dealing with the automation in general and dealing with potential imperfections in the automation in particular. When automation fails, maintenance may become more complex. This raises questions about skill deterioration for maintenance mechanics. Detecting problems and defining root causes without automation support might become difficult due to the IT driven nature of systems, particularly when there is a lack of experience in manual troubleshooting. Importantly, when the machine takes over the work of humans, and the human is only an observer in the process, the maintenance mechanic might risk loss of concentration on the task at hand or become negligent.

In this paper two questions are investigated. First, what are the risks of automation on human performance in aircraft maintenance? Second, how to deal with those risks in order to mitigate them? The focus of this second question will be in the area of maintenance type training, and less on the area of aircraft system design.

2 - RESEARCH APPROACH

For this study a mixed-methods approach is applied. First a literature study is done to find the risks, causes and mitigations of those risks. After this study workshops with instructors and interviews with mechanics where held to validate the literature and to define justified automation risk mitigation actions by means of training. For the literature research the NLR information center started a search for maintenance related subjects on this matter. The literature search resulted in thirty articles of which sixteen were relevant for this paper. The workshops where facilitated workshops with maintenance instructors and maintenance mechanics. During the workshops the four following questions were answered: 'What are the risks of automation according to maintenance instructors?'; 'What is it that needs to be trained?'; In which manner should this be trained?'; and 'What do you need as instructors to achieve this?'. Finally, in order to get a thorough insight into the topic 12 line and base maintenance licensed mechanics were interviewed. These persons had experience on legacy aircraft and currently work as licensed maintenance mechanics of automated or 'digital' aircraft. The licensed maintenance mechanics were asked what they considered to be the main differences between elements in the different phases of a task, that is: receive assignment, task preparation, task performance and task closure. They were also asked for the differences in cognitive complexity, procedural complexity, psychomotor complexity, and their perception of knowledge and skill retention as a result of automation.

3 –RESEACH RESULTS

3.1 LITERATURE RESEARCH

3.1.1 Human factor risks

According to literature four strongly interrelating risks result from automation in aviation maintenance, these are: complacency, automation bias, skill decay and atrophy.

Complacency is a negative result of automation. The main contributing is not being actively involved in the task due to blind trust in the procedures and computers. Parasuraman and Manzey (2010) note that complacency is generally found in multitasking environments where manual tasks as well as supervised automation tasks have to be performed simultaneously. The manual tasks tend to get more attention than, and at the expense of, the automated tasks.

Bahner et al. (2008) mention ***automation bias*** as well as complacency. Automation bias appears when the maintenance mechanic decides to rely on the outcome of a computer aided decision support tool and to neglect other information sources that could reveal contradictory information.

Arthur et al. (1998) mention ***skill decay*** as a risk. ‘Skill decay refers to the loss or decay of trained or acquired skills (or knowledge) after periods of non-use’ (p58). There are procedural and non- procedural skills of which different studies prove that procedural skills (standard operation procedures) are more prone to skill decay while non-procedural skills, in which an active state of mind is needed, are less prone to skill decay (Bodilly et al. 1986; Farr, 1987; Martinussen & Hunter, 2010). There are different factors that influence decay. Arthur et al. (1998) describes training and assessment factors like retention interval, condition of retrieval, criterion type, operationalizing of the acquisition, training structure and decay prevention intervention. Kluge and Frank (2013) proved that skill and knowledge decay can be attenuated and even avoided by refresher interventions.

Finally, this can also lead to ***skill atrophy*** *as* mentioned by Drury (1994). Skill atrophy is for example the elimination of the requirement that cashiers are able to calculate. In this way more workers can be found. But this means that, when the cash register fails, the cashier is not able to sell the product to the customer.

3.1.2 – Mitigation strategies

In this section, mitigation by design and mitigation by training are discussed.

3.1.2.1 –Mitigation by design

According to Drury (1996), first of all it should be carefully considered which tasks are good candidates for automation and which tasks are not. If the integration of human-computer tasks is done poorly, the maintenance mechanic can be overworked or underworked. Second, the design of the automation can be sub-optimal. This is the case when the user has no idea what the automation system is doing or why. Transparency of automation is an important factor in automation design. Adhering to a human centered design approach means that the automation is not the goal but supporting optimal human performance is main goal. Taking those requirements into account, the level of automation can range from full automation, flexible automation, supporting or supervising automation or no automation at all.

3.1.2.2 –Mitigation by training

Bahner et al. (2008) provide evidence for complacency as an issue of human-automation interaction. They found that complacency signs were smaller for participants that experienced automation failure during training compared to participants that were only informed that the automation might fail. This means that confronting participants with rare automation failures makes them aware of the fact that automatically generated advice can be incorrect. Now, training is often geared towards use of systems in normal mode and with hardware failures only (e.g. total automation breakdowns), but the focus should also be on incorrect advice provided by an automated system due to programming/input failures. Nevertheless, providing automation failures in training diminishes but does not eliminate complacency. An explanation of this finding might be the perceived time pressure in fault management and/or costs in terms of elevated risks of the committing of errors, which pushes operators to more complacent behavior. This is especially the case in highly demanding multiple task environments where several tasks need to be performed simultaneously and time pressure is comparatively high.

Also, in training often facts are presented and knowledge on how to perform a task is limited. Practical training helps assimilating knowledge on how to perform tasks, but the focus there is on normal behaviors. It is advocated that the complex nature of these systems will be picked up on the line, while in reality the line does not offer the possibility to practice abnormal situations unless there is a real problem and then it might be too late. According to Lee, Merrit and Unnerstall (2014), users who are more successful in task performance without automation support, identify and correct automation failure more easily. Something that should be taken into account when using events of automation failure, is that this might have long lasting effects on the trust in automated systems, even though overall they might represent rare events (Lee, Moray, 1992; Dzindelot et al., 2003)

According to Ebbens et al. (2013) and Colby et al (2007) there are different levels of learning. Reproductive learning in which the student reproduces knowledge, procedures or skills and can apply the material learned in standard or repetitive situations, and productive learning, which requires integration of knowledge, creative appliance of knowledge and problem solving. The student can apply the material learned in unknown and unexperienced situations and becomes resilient. Thus, automation complacency cannot be overcome with simple practice. Different conditions and unexpected situations need to be taken into account, which asks for a more productive training approach. Also, automation bias cannot be prevented by training or instruction alone. Their research shows positive results towards decision aids that give information to support decisions but do not recommend decisions, which is in line with human in the loop design (Drury, 1996). They state that more research is necessary. Nevertheless, giving a role to the human in the decision making also asks for a productive training approach in which the student combines knowledge and takes part in the problem-solving process. Finally, due to automation, certain skills (e.g. troubleshooting) are not performed often as the system informs you on the solution. Nevertheless, it might happen that a system does not detect the problem or does not propose the correct solution. At such rare moments, procedural knowledge and skill refresher interventions are always useful (Kluge and Frank, 2013). However, the level of retention depends on the intervention. For skill retention, practicing the task a few times is better than a one-time demonstration of skill mastery to an assessor. Practicing is better because the mental workload of practicing the task a few times is lower compared to demonstration, the result however is the same. When offering theoretical interventions (e.g. listing the procedural steps on paper), mainly knowledge retention is supported, but there is also limited reduction of skill decay. Arthur et al. (1998) also conclude that post training intervention for decay prevention is helpful and that self-management and goal setting is key to be more consciously active with the learning tasks.

3.2 – WORKSHOP RESULTS

During the workshops a number of concerns with regard to automation in aircraft maintenance were identified by the instructors. These concerns can roughly be separated in two groups, that is: ‘knowledge, skills & attitudes’ and ‘system’. For knowledge and skills the instructors were concerned about loss of troubleshooting skills and system understanding. Mechanics do not know how data is composed and what the logic behind the automation is. This can lead to complacency. With regard to the system, the major concerns are the fact that the system can make mistakes, the system is rule based and might neglect possible solutions. Also it can bring high costs and low flexibility. As general mitigation actions, instructors mentioned that the training needs to be up to date, that vendor information is available, and that training has a strong link with the actual maintenance context (environment). The instructors agreed that the trainees need to learn how the system works (system logics) and need to understand system correlations. In order to detect faults, they need to have an understanding of how this information is generated. It is important that they are aware of the danger of complacency and during the training this should be experienced. This can be achieved by scenario- or problem-based training by means of simulators, mock–ups or other technical devices. Instructors also agree that this changes the instructor role to be more of a facilitator and coach on competencies and system understanding.

3.3 – INTERVIEW RESULTS

The interviews with 12 technicians currently working on the NH-90 or B787 digital aircraft followed the structure of the process steps belonging to maintenance task: receive assignment, task preparation, task performance and task closing. For each step the difference between highly automated and traditional aircraft is analysed. Also the required knowledge, skills and attitude are discussed. After this analysis, the difference in cognitive, procedural and psychomotor complexity between digital and legacy aircraft is described briefly.

During the interviews it became clear that not only the aircraft automation influences the work of the mechanic. Also the differences in the organization of work, which came along with the implementation of the digital aircraft, have an influence on the work of the mechanic. The digitalization of aircraft and the organizational changes are strongly interconnected, therefore the interviews include descriptions of changes the mechanics experience due to aircraft digitalization and due to the organization of work. Further, there were no differences in experiences between the NH-90 and the B787. Therefore, there is no distinction between aircraft types in the description below.

3.3.1 Receive assignment

For digital aircraft complaints and assignments are digitally stored. System information is already interpreted by the health management system and solutions (in other words assignments) are already proposed. This system can also share system conditions with the ground while the aircraft is still flying. Mechanics can use this information in order to prepare for the required maintenance, which requires a pro-active attitude from the mechanics. Further, due to the novelty of the aircraft, tasks/work orders are not always prepared in detail for scheduled maintenance, as is done for the legacy aircraft. Therefore, more interpretation on which procedure is valid for certain scheduled tasks is sometimes needed.

3.3.2 Task preparation

The use of the manuals is different. The manuals are not paper or pdf-based but manuals have a web based design with hyperlinks etc. It is not always easy to understand the structure of the 'books' and different parts of procedures are somewhat scattered, which gives the technicians the feeling they do not have an overview. With regard to task preparation the mechanic needs to be aware of maintenance tasks that can be performed (concurrently) in the same time. For example, circuit breakers are linked to more systems simultaneously. Also the aircraft can require a lot of load-shedding. The result is that certain systems will be shut down when performing a task. Therefore, more planning skills and in some cases operational system understanding is necessary.

3.3.3 Task performance

B1 (mechanical) technicians have the feeling that they are increasingly becoming B2 (avionics) technicians. KLM even combines B1/B2 privileges in one technician. The reason for this is that B1 tasks comprise more and more avionic activities and pure B2 tasks are decreasing. For legacy aircraft there are lots of removal and installation actions while for the digital aircraft most of the problems are solved with computer tests and resets in the cockpit. Nevertheless, the physical work on legacy or digital aircraft for mechanic repairs is roughly the same, with the difference that digital aircraft use a lot of Line Replaceable Units (LRUs). Further, for digital aircraft, the use of data coming from the aircraft systems has increased. The use of data has not only increased, but where the old system gave parameters, the digital aircraft often gives results/recommendations. The logic of a proposed repair may not easily be associated with the initial problem. Also it is not always clear how data are compiled and which data are compiled. But in general the participants have trust in the information and have the feeling that task performance is well supported by automation and deep system knowledge is of less importance due to the increase of LRU's. However, system knowledge that supports understanding and the use of the manuals is important, especially if you have to make decisions/interpretations for follow-up actions. Further, load shedding, multi user circuit-breakers and multi-function computers require understanding of system logic, especially in relation with multi task performance. Communication between different team members with different tasks is important in order to know which tasks can be performed at which moment (planning). Also, patience, compliance, and precise reading are needed. The advice of the system needs to be followed step by step. There is less room for interpretation. The mechanics' experience is that they should never think they know better than the system. If the solution is not found via the manuals experts should be consulted.

3.3.4 Task closing

With the implementation of the new aircraft there are also new digital administration programs and requirements. The administration becomes more important because the information is used for predictions. Therefore, the mechanics need to be able to work with the administration systems and need to be aware of the importance of correctness and completeness of data in the system.

3.3.5 Differences in complexity between digital and legacy aircraft

According to the mechanics the aircraft is now more complex but the cognitive complexity for the maintenance mechanic is, once familiarized, equally or less complex. Often, when the Fault Isolation Manual does not have the answer the engineering department needs to be involved. However, before involving the engineering department and risking a chance of a technical delay, the mechanics try to solve the problem by logical thinking (e.g. resetting the aircraft, combining information).

Further the procedural complexity of the aircraft is higher and the steps are stricter, according to the mechanics. There is less room for interpretation and defining maintenance tips and 'work-arounds' is difficult due to the level of aircraft complexity. The computer depends on the steps in the procedure. If you do not apply them, the computer may become "confused" (or gets stressed). While in reality sometimes it is difficult to follow the steps. E.g. when hydraulics needs to be turned according to the procedure but it is already turned on, then the test fails. This needs to be understood by the mechanic. Is this procedural order linked to safety or is it just due to programming? This is an automation disadvantage. Automation is static, the reality is dynamic.

The mechanics' experience of the psychomotor complexity for digital aircraft and legacy aircraft is generally the same.

3.3.6 Knowledge and skill retention as a result of automation

The mechanics are not afraid that knowledge and skills are fading for the current population of mechanics. Ultimately, you should still be able to think for yourself, in case the Fault Isolation Manual does not give the answer. Whilst this is the case for the time being, the current population does not know if it will still be necessary to think for yourself in the future. This depends on the accuracy of the automation.

4 –CONCLUSIONS

Automation problems are a concern in the near future for maintenance mechanics working with digital aircraft. During this research it became clear that disuse of automation can be caused by a lack of trust in the outcome of the system, while on the other hand there is overreliance on automation. There are four strongly interrelating risks to automation in aviation maintenance, which are: complacency, automation bias, skill decay and skill atrophy. These automation risks find their origin in the design of automated systems and training of the users of automation.

Field research showed that mechanics indeed trust the outcomes of the automation systems and are positive about them. The experience is that the automated systems support the mechanic by providing system information and problem solutions. However, the mechanics also indicated that sometimes the automation does not have the correct solution. These automation failures or mishaps are mainly experienced due to a combination of events on the aircraft, for which the automation is not programmed. Nevertheless, in general the mechanics experience that the maintenance for digital aircraft is less complex.

Since maintenance mechanics seem to trust the automation, it is interesting to know why automation is trusted and how to mitigate risks that come along with this trust. One of the reasons for trust in automation is the fact that there is little experience with non-accuracy of the automation systems. This can cause overreliance. Another reason, which refers to the design of the system, is the complexity of data interaction and analysis within the automation systems. Therefore, an important mitigation strategy in the area of automation design is the level of automation and the way this automation is built around the maintenance mechanic.

That brings us to the second mitigation strategy, which is training. The assumption that maintenance becomes easier by/through (the introduction of) automation (and therefore fewer skills are needed) is incorrect. Automation can fail and research found that human-automation performance is improved by training and expertise. To detect and handle automation shortcomings, the type training needs to contribute to a certain level of system understanding. System logic and system inputs and outputs should be clear. Complacency can be diminished by confronting participants with automation failures or incompleteness. This makes the participants aware of possible incorrect automation events. Thus, in order to diminish complacency, the maintenance mechanic should experience different and unexpected situations (troubleshooting scenarios), in which the automation is incomplete or without the use of the (complete) Fault Isolation Manual. Practicing realistic productive troubleshooting, in which the student really has to think, reason, use documentation, refer to manuals etc. supports the understanding of system logic and enhances resilience in unexpected real time situations. It forces the students to be consciously and actively involved and to understand the automation possibilities and impossibilities. Further type training should focus on the requirements maintenance mechanics need in order to work with new generation aircraft in general, like dealing with digital information sources and data handling.

During the workshops, the instructors agreed that it was important to practice problem based training scenarios with simulators, mock–ups or other technical devices. According to literature, the level of device fidelity can vary, as long as the concept of the system logic is the same. This means that solving a paper-based case via discussion with colleagues without performing the task is already helpful in building system logic and understanding. Productive troubleshooting tasks during refresher or continuation training helps skilled mechanics to not lose the skill and awareness to detect possible automation. Further self-management and goal setting is very important to incorporate in training as the students become more consciously active with the learning tasks, which in turn, supports active task performance on the job. This means that the student should be active and in control of his own learning instead of being taken by the hand of an instructor. The instructor should coach and stimulate self-activation, curiosity and responsibility. This principle should also be incorporated in continuation and refresher training in order to prevent skill, knowledge and awareness retention being degraded due to long periods of non-use.

Finally, since using events of automation failure in training may have long lasting effects on the trust in automated systems, it is advisable to base the scenarios on events in which the automation does not have the answer due to the context (e.g. a combination of events/system faults), which happens more often than real automation failures. Also letting the students think about a problem without the Fault Isolation Manuals, instead of introducing unrealistic automation mistakes, is a good solution for active and productive participation.

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