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Next Generation Aircraft and the possible risks for Maintenance

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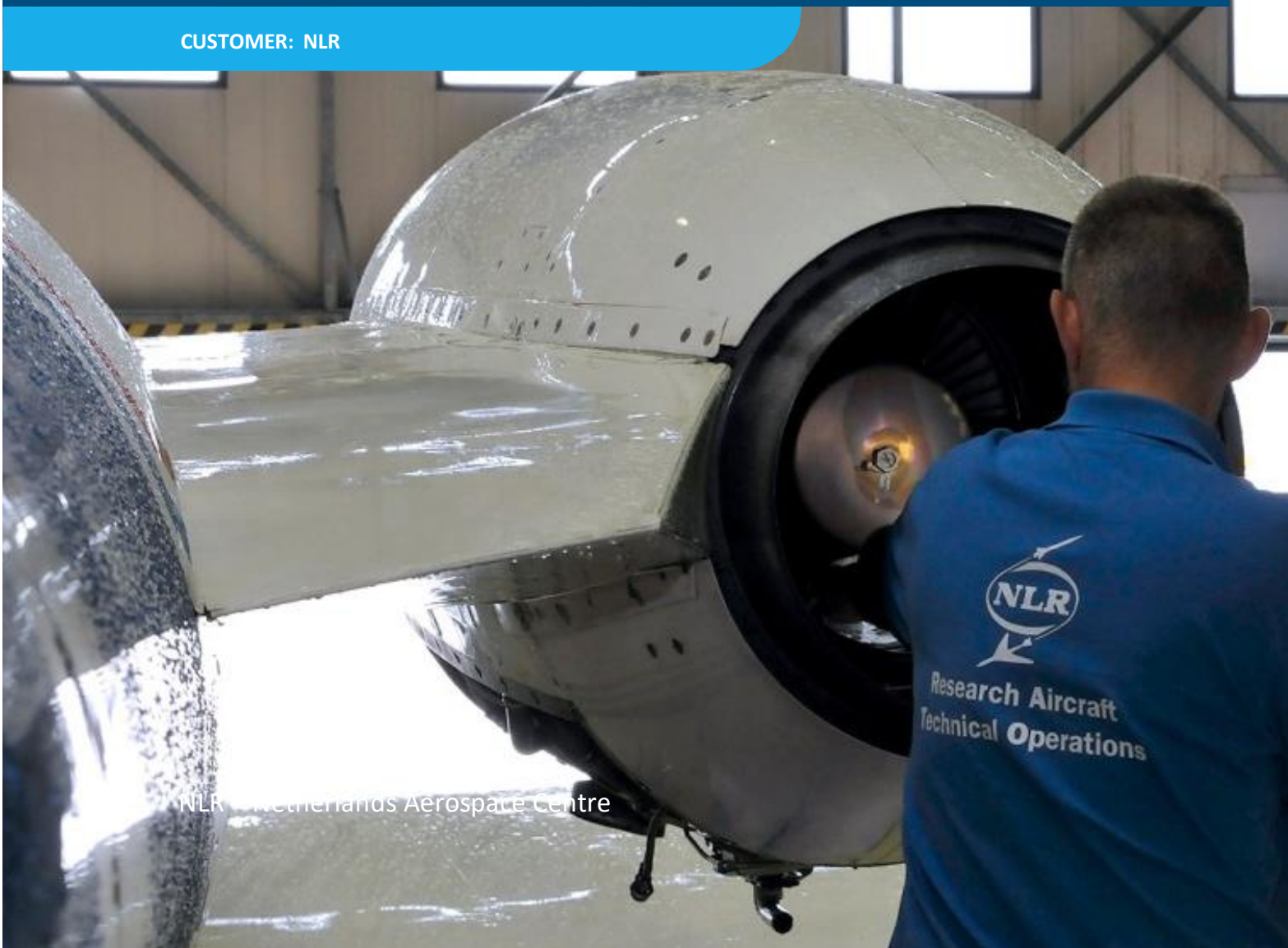

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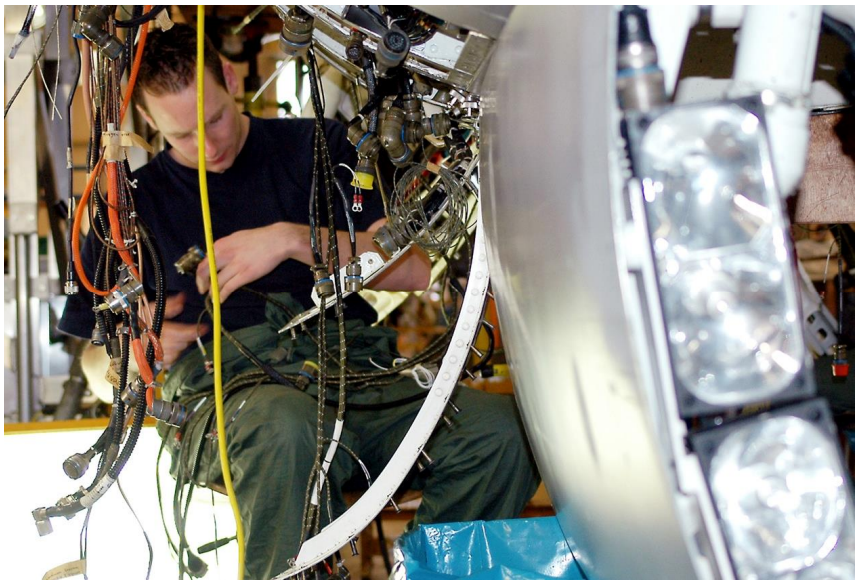
Next Generation Aircraft and the possible risks for Maintenance



Problem area

Next Generation aircraft, also called 'digital' aircraft, contain a lot of automation. This supports the maintenance mechanic but also generates new tasks and requirements. This challenges the maintenance mechanic in dealing with the automation in general and in dealing with potential imperfections in the automation in particular. Also, when automation fails, maintenance often becomes more complex. Detecting problems and defining root causes without automation support becomes more difficult due to the IT driven nature of systems, particularly when there is a lack of experience in manual troubleshooting. Finally, 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. This causes lack of oversight (situational awareness) and increases the risk that failures may go undetected. Therefore, the highly automated next generation aircraft may pose problems regarding skill deterioration of maintenance mechanics.

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Description of work

In this research two questions are explored. First, the risks of automation on human performance in aircraft maintenance are explored. Second, an answer is formulated on the question on how to deal with those risks in order to mitigate them. This is done via a literature review and field research. The field research comprised workshops with maintenance instructors and interviews with maintenance mechanics.

Results and conclusions

Automation systems support the mechanic by providing system information and solutions. 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 actions. On one side, the design should be human centered, which means that the human is involved and is part of the loop. On the other side, training needs to 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. This supports 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 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 and to improve knowledge and awareness retention due to long periods of non-use

Applicability

This paper presents the risks of maintenance automation on human performance, and suggests mitigation strategies in the area of maintenance training and system design.

GENERAL NOTE

This report is based on a presentation to be held/held at the [conferentie], [plaats], [datum].

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Next Generation Aircraft and the possible risks for Maintenance

CUSTOMER: NLR

AUTHOR(S):

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This report is based on a presentation to be held/held at the EAMTC, Paris, 4-5 October 2016.

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Summary

Next Generation aircraft, also called 'digital' aircraft, contain a lot of automation. This raises questions about skill deterioration for maintenance mechanics. Automation supports the maintenance mechanic but also generates 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. 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 in hand or becoming negligent. This causes lack of oversight (situational awareness) and when things go wrong this might not be detected.

This research comprises of two parts. First, the risks of automation on human performance in aircraft maintenance are explored. Second, how to deal with those risks in order to mitigate them is investigated. 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 were performed. The field research comprised several workshops with maintenance instructors and interviews with maintenance mechanics.

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.


KLM

Contents

Abbreviations

ACRONYM	DESCRIPTION
DNW	German-Dutch Wind Tunnels
NLR	Netherlands Aerospace Centre

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1 Next Generation Aircraft and the possible risks for Maintenance

1.1 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 enhances the execution of tasks and 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 done, 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. It might be clear that, in general, automation improves the aircraft mechanic's performance and thus improves efficiency and safety. Automation supports the maintenance mechanic but generate 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 in hand or becoming negligent.

1.2 Research question

There are two parts to the question of this research. 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 training and less on the area of aircraft system design.

2 Research methods

For this study a mixed-methods approach is applied containing a literature review, workshops, and interviews. Practical experiences of maintenance instructors and maintenance mechanics were gathered and formed into an inventory by means of a series of facilitated workshops with maintenance instructors and interviews with maintenance mechanics.

2.1 Literature review

This review started with a literature search in which the first search terms were: 'Aircraft maintenance & automation' and 'Aircraft maintenance, automation and human factors'. A further detailed search was carried out by NLR's information center having the following information to understand the topic and guide their search: "Nowadays pilots rely on automation and act more and more as observers. There are a lot of tasks that are not carried out anymore by the pilots. Therefore, there is an ongoing concern about potential decline of manual flying skills of pilots in case of emergencies. Aircraft maintenance is also subject to automation, which raises also questions about skill deterioration for maintenance mechanics." With these words 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.

2.2 Workshop

During the instructor seminar of the European Aviation Maintenance Training Committee (EAMTC) in Maastricht 2015, two workshops were organized. During these workshops a 5 minute introduction presentation was made on the possible risks during Maintenance on the next generation aircraft. The focus was to elicit answers to the following questions:

- What are the risks of automation according to maintenance instructors? (risks)
- What is it that needs to be trained? (content)
- In which manner should this be trained? (method)
- What do you need as instructors to achieve this? (conditions)

After the 5 minute introduction presentation a group discussion was held to permit the instructors to list what they considered to be the maintenance risks. After this collective inventory the instructors divided into smaller groups (of 4 to 5 people) to discuss their workplace experiences and what, according to them, is needed in relation to content, method and (instructor) conditions when training the next generation aircraft maintenance personnel. This resulted in a list of the instructors' ideas or opinions on how to mitigate automation risks by means of training. In total 43 instructors joined the workshops. The workshop outcomes were discussed with the instructors. The results of the instructors' expected risks, including the proposed mitigation actions, are presented in this section 3.2.1.

2.3 Interviews

In order to get a thorough insight into the topic 12 operational persons were interviewed. These persons were working as maintenance mechanics on legacy and new generation or 'digital' aircraft. The 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. Of the 12 persons interviewed 6 were from the Dutch defense organization that worked on the legacy LYNX helicopter and the new NH-90. The other 6 persons were from the airline KLM. They had mainly worked on the legacy Boeing 737 aircraft and the new digital Boeing 787 aircraft. During the interviews no clear separation was made between B1 and B2 privileges due to the mixed interview setting.

3 Results of the different research methods

3.1 Literature review

This literature review provides an understanding about the risks of automation on human performance including the causes of these risks, followed by proposed mitigation strategies.

3.1.1 Automation 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 feeling of quiet pleasure or security, often while unaware of some potential danger, defect, or the like; self-satisfaction or smug satisfaction with an existing situation, condition etc. (Dictionary.com 2015). According to Grey Owl Aviation consultancy INC (1997), complacency is a negative result of automation. The main contributing factor to improper or incomplete installation, equipment not installed, or foreign object damages during engine overhaul was the aircraft technicians' state of mind, that is: not being actively involved in the task due to blind trust in the procedures and computers. Their research revealed that from all inflight shut downs that were traceable to the human element, only 6% were caused by technicians who were actively troubleshooting with a rational state of mind. Parasuramen and Manzey (2010) note that complacency is generally found in multitasking environments where in manual tasks as well as supervise 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. When a person is biased he or she has a particular tendency, trend, inclination, feeling, or opinion, especially one that is preconceived or unreasoned (Dictionary.com 2015). 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 reveal contradictory information. Trusting this computer aided information without properly checking the other information sources, in its turn, refers to complacency. According to Parasuramen and Manzey (2010) automation bias is reflected in commission errors and omission errors when interacting with imperfect decision aids. In this context an act of commission is including something wrong and an act of omission is not including something that should have been included. Both can lead to an undesirable outcome.
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 different tasks of different nature such as cognitive or psychomotor tasks, procedural tasks (closed loop / reproductive skills) or non-procedural tasks (open-loop / productive skills) and complex tasks or simple tasks. 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). Arthur et al. (1998) say that complex skills are less subject to skill decay due to their meaningfulness, the time needed for processing the task and the time needed to assess or test the task performance. In the comparison of psychomotor skills with cognitive skills, the complex cognitive skills are more prone to decay than the complex psychomotor skills. There are different factors that influence the 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. They also proved that symbolic rehearsal (imaginary practice) interventions, which are less costly than real rehearsal interventions, help in decreasing cognitive decay in particular. However, symbolic rehearsal is less effective than real practice, concluding that a combination of both interventions might be an interesting approach. Arthur et al. (1998) 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.
Finally, ***skill atrophy*** *is* mentioned by Drury (1994). 'Skill atrophy origins for example from the elimination of the requirement that cashiers are able to calculate. In this way more workers can be found. But when the skills are not practiced regularly they may be unavailable when needed, for example in cases when the cash register fails'.

3.1.2 Mitigation

The automation risks mentioned in this paper, find their origin in different factors. (1) The level of automation and the way this automation is built around the maintenance mechanic. (2) The fact that builders of automated expert systems cannot capture all the knowledge and skills of a human expert in the automated system. (3) Training does not have the focus on the new skills maintenance mechanics need to have in order to detect automation failures or shortcomings. In the next section, mitigation by design and mitigation by training are discussed.

Mitigation by design

The *design of automation* plays a big role in the human-machine team performance. According to Drury (1996), automation is usually confined to job assistance that has some degree of autonomous control. There are advantages like gathering, analyzing and presenting data to support decisions, performing dangerous tasks, tracking of spare-parts, registration of task performance and optimizing planning. However, also disadvantages occur, such as inflexibility, not having the ability to adapt to situations, and hiding internal operations from the user. If the automation is not built correctly, if the human is not taken into the loop, the human machine team is not performing optimally. Therefore, this paper provides a short review of which design requirements are important for good automation. Knowing to what good automation needs to adhere, might help in recognizing the quality of automation and defining mitigation strategies.
According to Drury (1996), a number of problems can be defined. First of all, it should be carefully considered which tasks are good candidates for automation and which tasks are not. Often designers have the tendency to fully automate tasks and this leaves the human with the most boring and uninteresting jobs. If the integration of human-computer tasks is done poorly, the maintenance mechanic can be overworked or underworked. Thus, the key is a proper function allocation for computerized tasks and tasks that people are uniquely good at, taking proper integration of human workers with the machine into account. Second, the design of the automation can be bad. 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. This is a requirement for successful human machine cooperation. Adhering to a human centered design approach, meaning the automation is not the goal and that supporting the human in job performance is the 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. Finally, when the automation is designed the manner of implementation also plays an important role.

An *expert system* gathers and analyses information coming from different sources in order to make decisions. It might be clear that when designing such a system, it is impossible to capture all knowledge and abilities human experts own to draw conclusions. This can result in erroneous conclusions made by the system. Therefore, it is vital that the mechanic has enough knowledge to know what the computer is doing to detect wrong conclusions. Since the mechanic is not involved in the decision making process the mechanic does not build the ability to understand fully what is going on. This can result in not detecting computer mistakes and wrong maintenance actions (Office of Aviation Medicine FAA, 1993)

Mitigation by training

Next to human-centered automation design, training is a primary way to deal with automation and safety. Training practices however are not fully using their potential to mitigate automation risks. First, the automation and technology has exceeded the skills of many workers (Collins, 2009). More attention to this is required. Second, training does not have the focus on the new skills maintenance mechanics need to have in order to detect automation failures, and third, the budget for maintenance training is inadequate. Below two specific training mitigation strategies are elaborated.

Pay attention to automation failure and incorrect information

The research of Bahner et al. (2008) provided evidence for complacency as an issue of human-automation interaction. They found that complacency signs were smaller in a group of participants that experienced automation failure during training compared to a group that was only informed that the aid might fail. The last group was considerably less careful in verifying the outcome of the aid system before following its advice. Thus only informing participants about possible failures is not enough. The main finding of the research is that confronting participants with rare automation failures sensitizes the participant to the fact that automatically generated advice can be incorrect. It diminishes complacency, 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. A related finding is that training diminishes complacency but does not prevent its occurrence. However, there is a slight relationship in that the higher the level of complacency the more errors were committed. It was also noted that most likely there are also other factors that influence the number of committed errors. These include risk behavior, personality characteristics or general attitudes towards technology.

According to Wickens (2014), it is useful to invest effort in checking the 'raw data' that underlie the automation's decisions in order to mitigate the unfortunate circumstances that complacency and automation bias can cause. Additionally, the Flight Safety Foundation mentions, in the article 'Increased reliance on automation may weaken pilots' skills for managing system failures' (2005), that procedures need to be taught in the operational context. In the operational context there can be differences with regard to the normal operation of the automations because there are many factors that influence the operational context. Now, often training is limited to use of systems in normal mode and with hardware failures only (e.g. total automation breakdowns). However, the focus should also be on incorrect advice provided by an automated system due to programming/input failures. Also, in theory 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 nevertheless the focus there is on normal behaviors. Further, 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. This finding suggests that human-automation performance is improved by training and expertise. According to Ebbens et al (2013) and Colby et al (2007) there are different levels of learning. First there is the level of learning based on knowing and understanding, also called reproductive learning. The student can reproduce knowledge, procedures or skills and can apply the material learned in standard or repetitive situations. The second level is productive learning. Productive learning integrates knowledge and requires creative appliance of knowledge and problem solving. In productive leaning relations between different aspects of the content are made and different approaches to problems are considered. The student can apply the material learned in unknown and unexperienced situations and becomes resilient. Parasuraman and Manzey (2010) conclude that automation complacency and bias, which occurs for naïve and expert participants, are somehow related but show different automation-induced events, with attention at the center. Automation complacency cannot be overcome with simple practice. Different conditions need to be taken into account. Automation bias, which results in omission and commission errors when decision aids are imperfect, cannot be prevented by training or instruction. 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.
Dzindolet, Beck and Pierce (2000) found that providing information on the reliability of an automated decision aid and the performance of the human operator reduced the bias towards disuse of the automated system. This research was done with a rather simple subject matter (detecting a camouflaged soldier in a terrain) which is not comparable with data processing of multiple complex systems and variables as is the case in aircraft maintenance. However, the results suggest that using an automated system in realistic situations and being provided with focused feedback on the system accuracy may support appropriate reliance on automated systems. This is in line with the conclusions of Bahner (2008) and the Flight Safety Foundation (2005). Something that should be taken into account when using events of automation failure 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)

Pay attention to retention of skills and (procedural) knowledge

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 retention and skill retention is essential. According to Kluge and Frank (2013), refresher interventions during training are useful. For skill retention a practice intervention (practicing the task a few times while using supportive information), is better in the sense that it generates a lower mental workload for the participant than a demonstration intervention (only one change to do the task correctly while using supportive information). However, the results of the assessment were similar. For procedural knowledge retention the procedural knowledge intervention (write down the steps by heart without any clues) scored slightly better than the group that did symbolic rehearsal (organizing of already given steps, fill in blanks and find errors). The most effective intervention may be determined by the dependence on the required accuracy of the skill or knowledge maintenance of the task, e.g. time, costs and safety can influence the choice of intervention. Practice intervention is best to support skill retention. Skill demonstration will achieve the same result but generates a higher mental load. Further, procedural knowledge interventions support knowledge retention especially and also reduce skills decay. Concluding, it can be said that a retention intervention is more effective than no intervention at all.

3.2 Field research

In this section of this document mitigation by training is elaborated with the help of the instructors during the EAMTC instructor seminar and interviews with maintenance mechanics of the Dutch aviation industry.

3.2.1 Workshops with maintenance instructors

Instructor concerns maintenance automation

During the workshops a number of concerns with regard to automation in aircraft maintenance were identified by the instructors (see Table 1). These concerns can roughly be separated in two groups, that is: 'knowledge, skills & attitudes' and 'system'. Summarizing, for knowledge and skills the instructors were concerned about loss of troubleshooting skills and system understanding. Mechanics may not know how data is composed and what the logic behind the automation is. This leads 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. It brings high costs and low flexibility. Appendix A lists all concerns mentioned in the workshop.

Knowledge, skills & attitudes	System
- Can lead to lack of compliance with mechanics. They do not have knowledge on what the computer is doing but do have trust in what the computer is doing - Automation takes away the human side. It relies too heavily on the system and the human is not eager or willing to think anymore. Mechanics get lazy. - Mechanics loos troubleshooting skills - The mechanics don't have the technical feeling anymore. They need computers. - No experience is gained in troubleshooting. The mechanics never get the hands-on experience. - The mechanics loos track. The fundamentals are skipped and the mechanics don't know how the data is composed or how the automation works. They are out of the loop. - Basic skills get lost. Less training for mechanics because the computer fixes the problems. The aircraft become more complex but the training gets less.	- Flexibility is lost due to heavy reliance on updates. - You need to hire experts if systems break down. - Initial costs are high and also replacement is high. - It consists of predetermined rules that do not take all possible options into account (rule based error). It can lead to more black or white decision. - The system is made by people that can make mistakes. - Computers can be hacked. - Mechanics lose jobs.

Table 1: *concerns with regard to automation in aircraft maintenance as identified by the instructors.*

Suggested mitigation actions

With above concerns in mind the workshop participants divided into groups of 4 to 5 instructors. Each group thought of actions that could be incorporated in the area of training in order to mitigate the risks that are related to automation in aircraft maintenance. These mitigating actions are divided into three groups, that is: content, method, and conditions (see Table 2)

What is it that needs to be trained ? (content)	In which manner should this be trained? (method)	What do you need as instructors to achieve this? (conditions)
- Basic system knowledge and basic skills. - Deep knowledge of the system. - Understanding of what is happening in the system. - Understanding of system architecture, hierarchy, limitations, benefits and correct interpretation of automated messages/outcomes. - Ensure system electric-pneumatic operation is understood (interfaces) and include operational feedback in courses. Shared recourses between training and operation. - Ensure that new technologies are incorporated in the content. - Correct correlation between automated equipment and other elements of the systems and documents. - Know the effect of automation in each system. - Know how to detect failures by using on board maintenance systems (OBMS) and test equipment. - Look at system reaction for malfunction. - Awareness about not being complacent and the need to use critical thinking. - Compare old and new technology. - Use automation as a tool.	- Demonstrate that automation is not always 100% correct. Perform troubleshooting exercises. - Competence based training. Practical exercises with simulation tools including defects. - Refresher training on systems. - Practical training with repetitive tasks. Also familiarization with the procedures for various scenarios. For example scenarios based on failures coming out Pilot flight reports for which the mechanic needs to isolate the fault by means of the troubleshooting and maintenance manuals. - Use of maintenance simulator and synthetic training devices and mock-up.	- Experience on aircraft. - Good understanding of the system. - Actual knowledge from the vendor/manufacturer training. - Knowledge of functions of equipment (LRU) - Integration between the instructor and the maintenance environment - Refresher training on systems. - Knowing the fleet status. - The instructors need to be pro-active. Make sure that the training is sufficiently 'contemporary'. - Instructors need up to date information - The instructor should be a facilitator, not a lecturer. - The instructor needs to assess skills and ensure understanding - The instructor needs to be a motivator

Table 2: Instructor defined mitigation actions

As general mitigation actions, instructors mention 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 agree that the trainees need to learn how the system works (system logics) and need to understand system correlations. They also need to learn how to work with automated equipment and understand

the interfaces and automated messages/outcomes. In order to detect faults, they need to have an idea 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. To achieve this, scenario or problem based training by means of simulators, mock–ups or other technical devices is needed according the instructors. They also agree that all of this has an impact on the instructor role. The instructor should be more of a facilitator and coach on competencies and understanding. Also, the instructor needs to be proactive and make sure the training is sufficiently contemporary.

3.2.2 Interviews with maintenance mechanics

The main results that followed from the interviews with 12 technicians working on the NH-90 or B787 digital aircraft are described in this chapter. The structure of this chapter follows the process steps belonging to maintenance task: receive assignment, task preparation, task performance, task closing. For each step the difference between highly automated and traditional aircraft is analysed. Also the needed 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 appeared 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.
There were no significant differences in experiences between the NH-90 and the B787. Therefore, there is no distinction between aircraft types in the description below.

Maintenance task process steps

Receive assignment

- For digital aircraft the manner in which assignments are received is different compared with legacy aircraft. Now technical complaints and assignments are digitally stored and available instead of paper based logbooks and assignments. Further, not only the assignment is given but also solutions are already proposed due to the health management systems. Health management systems have the ability to monitor aircraft conditions, present information and malfunctions to the mechanics, and directly link to related Maintenance Manual and Fault Isolation procedures. This means that information is already interpreted by the system and solutions (in other words assignments) are already proposed.
- The health management system can also share system conditions with the ground while the aircraft is still flying. This information can be used by the mechanics in order to prepare for the required maintenance.
- Due to the newness 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.
- To receive assignments the mechanic needs to be able to work with maintenance computers that provide system information and propose repair solutions.

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. It also deters or prevents the printing of procedures, while sometimes it is easy to have paper support near to or on the aircraft.
- With regard to task preparation the mechanic needs to be aware of maintenance tasks that can be performed (concurrently) in the same time. 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 are necessary and this requires operational system information with regard to circuit-breakers and load-shedding is necessary
- Skills in working with digitalized manual systems are important. Information is organized and described differently.
- Thanks to the health management system, the mechanic can prepare tasks in advance, which requires a pro-active attitude.

Task performance

- For the legacy aircraft there are lots of removal and installation actions; for the digital aircraft most of the problems are solved with computer tests and resets in the cockpit.
- The physical work on legacy or digital aircraft for mechanic repairs is roughly the same. The difference is that digital aircraft use a lot of Line Replaceable Units (LRUs).
- 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 be easy to associate to the initial problem. Also it is not always clear how data are compiled and which data are compiled. In general the participants have trust in the information and have the feeling that task performance is well supported by automation.
- When working on the aircraft, more people are working simultaneously. Communication is important, because, for example, load-shedding can influence other system behavior. This can have an impact on maintenance that is being carried out simultaneously. It should be clear which systems are influenced in order to not influence other maintenance activities that are performed simultaneously.
- Some 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 B2 activities and pure B2 tasks are decreasing.
- Deep system knowledge is of less importance due the increase of LRU's.
- System knowledge that supports the understanding and use of the manuals is important, especially if you have to make decisions/interpretations for follow-up actions.
- Thinking ahead is necessary as there is less experience and there are less spare parts. Also the load shedding and 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).
- Finally, 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.

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.
- 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.

Complexity and retention

After the analysis of the process step the maintenance mechanics were asked if maintenance is experienced as more or less complex when working on digital aircraft compared to working on legacy aircraft. Also they have been asked if they are concerned that knowledge and skills are fading due to the arrival of digital aircraft.

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 used to it, 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). They want to understand the technical problem and discus with other colleagues. They share information and sometimes have a group app to share pictures in order to build up knowledge and understanding.

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. hydraulics needs to be turned on as per 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. Certain skills are new but that is normal when transitioning between aircraft types. Though, in general the accessibility of components is easier on digital aircraft.

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. The current population still wants to know how things work. They try to understand and find out. According to them it is easy if the mechanic can 'empathize' with the system. However, the current population does not know if this is still the case for the future population. The future population might be more used to follow up automation without questioning. While 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 Conclusion

Automation problems are a main concern in the near future for maintenance mechanics working with digital aircraft. This study investigated 1) the main risks of automation on human performance in aircraft maintenance and 2) how these risks can be mitigated.

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. According to literature, there are four strongly interrelating risks to automation in aviation maintenance, these 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 indicate 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. It needs to be taken into account that builders of automated expert systems cannot capture all the knowledge and skills of a human expert in the automated system. Automation is rule based and includes programmed possible events and combinations of events. Designers cannot foresee all situations and the system does not have the capability to adapt to all situations. It may happen that a system does not detect the problem or does not propose the correct solution. Therefore, it is important that the maintenance mechanic is to be able to assume control when automation fails.

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. 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. This finding suggests that human-automation performance is improved by training and expertise.

The training should focus on skills that maintenance mechanics need to work with automation in general, and to detect automation failures or shortcomings, in specific. To detect automation shortcomings, training needs to contribute to a certain level of system understanding. System logic and system inputs and outputs should be clear. Bahner et al. (2008) found that only informing participants about possible failures or incompleteness is not enough. Confronting participants with automation failures or incompleteness makes the participants aware of the fact that automatically generated data and advice can be incorrect or incomplete. 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.

During the workshops, the instructors agreed that it was important to practice problem based training scenarios with simulators, mock–ups or other technical devices. For productive problem solving, the fidelity level of simulation does not have to be high because it is about the concept. According Sugrue and Clark (2000) the system logic and the inputs and outputs of the simulation should be correct, but the physical fidelity can vary. Kluge and Frank (2013) say that even imaginary practice helps in mitigating skill decay. 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. Arthur et al. (1998) conclude that post training intervention for decay prevention is helpful. This means that when maintenance mechanics perform productive troubleshooting tasks during refresher or continuation training they do not lose the skill and awareness to detect possible automation shortcomings in different situations. Arthur et al. (1998) also state that self-management and goal setting is key to be more consciously active with the learning tasks, which in turn, supports active task performance on the job. Therefore, it is important that maintenance mechanics experience self-management and goal setting during training. 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, it must be stated that using events of automation failure in training, may have long lasting effects on the trust in automated systems, despite the fact that they represent overall rare events in the real world (Lee, Moray, 1992; Dzindelot et al., 2003). Therefore, 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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