EFFECTS OF ON BOARD TABLET USE DURING HELICOPTER OPERATIONS

Christopher Roos, National Aerospace Laboratory NLR, Amsterdam, the Netherlands
Antoine de Reus, National Aerospace Laboratory NLR, Amsterdam, the Netherlands

Abstract

Research performed at the NLR has shown that the use of a tablet as an information sharing device in helicopter operations can produce beneficial effects in building and maintaining situational awareness (SA), can support coordination and communication and can reduce workload. The results however also show that the integration of a feature rich tablet device changes the dynamic of the workplace of the flight crew, and as such touches on flight- and mission safety aspects. The results of the research program relating to the effects on flight- and mission safety are disseminated in this paper to support safe and effective integration of tablet based information exchange concepts in helicopter operations worldwide. Several (potential) effects are reported, such as cognitive and information overload and more generally the effects of digital versus radio communication. Mitigating solutions are proposed to address these effects, which include specific interface design, the creation of procedures and the implementation of flight crew training.

1. INTRODUCTION

1.1. Background and rationale

The use of tablet devices in cockpits has recently taken flight, with Electronic Flight Bags (EFBs) and other tablet based concepts finding their way into more and more cockpits. Indeed, tablet devices can provide both civil and military flight crews access to highly useful information. Provided it is presented right, this information has the potential to increase the flight crew's Situational Awareness (SA). It can also support coordination and communication and potentially reduce workload.

Based on the potential of tablet devices to provide operational support to the flight crew, the Royal Netherlands Air Force (RNLAF) commissioned a two year research program, to develop a comprehensive review of the effects of on board tablet use during helicopter operations. The research was subsequently carried out in the period of 2012 - 2013 at the National Aerospace Laboratory NLR in the Netherlands. Although the program was oriented towards a military use, the results generally apply to non-military helicopter operations as well. Example applications are helicopter use by civil police units and medical air assistance teams.

The results of the research program show that the use of a tablet as an information sharing device can produce beneficial effects in both SA and personal effectiveness of the flight crew. The results however also show that the integration of a feature rich tablet device changes the dynamics of the workplace of the operator(s), and as such touches on flight- and mission safety aspects.

1.2. Why consider using tablets in helicopter operations?

There are a virtually unlimited number of uses for a tablet device in a helicopter, depending on its feature set, integration with on-board systems, and possibility to communicate data. Generally, and given the current level of integration of tablets, there are several high level benefits of tablets. Compared to the current standard of sharing data through voice communication within and between helicopters, tablet devices have several beneficial characteristics.

Firstly, radio communications can be an ill-suited form of communication for certain contents such as complex (tactical) overviews or pictorial contents. Describing a situation over the radio can be a frustratingly time consuming exercise that also presents a real chance that information is communicated incompletely or misinterpreted on the receiving end. Furthermore, the time required to perform this activity also leads to a high occupancy on the available frequency space.

This overcrowding on frequencies (and relaying of information) can in turn lead to other valuable information to become delayed or even fail to reach its recipient. This is especially problematic during the busier periods of an operation where access to the latest information is important. If information fails to be communicated, a situation can occur where out-of-date information reduces the effectiveness of the team. Furthermore, a deviating operational reality (be it from assumptions in planning or out-of-date information) requires dynamic re-planning and mental flexibility, and thereby strains cognitive capacity. Out-of-date information prevents proper build-up of shared situational models, again requiring more communication between team members and introduces uncertainty induced stress that disrupts the thought processes and subsequent decision making.

Furthermore, the clarity of the communication can be compromised due to operational challenges such as background noises and/or heavy accents and language command. Heavy accents and language barriers require more active cognitive processing and increase the risk of mistakes.

Secondly, depending on the feature set and depth of integration, a tablet device can also increase crew member SA through the addition of new or improved information flows. A tablet device might allow sharing of data between different helicopters (and between helicopters and ground personnel) which can provide the crew with new information such as a more detailed overview of a local situation. Data can also be distributed within the helicopter to different crew members such as loadmasters or hoist operators. This allows them to also benefit from information that is currently only present in the cockpit such as current location, time to destination and information about the landing area. Sharing information within the helicopter solves (information) resources scarcity and enhances shared SA that increases coordination between team members which in turn increases performance.

In summary, helicopter flight crews can benefit from a tablet's ability to provide information that is both direct, clear and presented in a way that suits the content.

1.3. Research program

To identify the effects of on board tablet use during helicopter operations, a cyclic development process was performed. As part of this process, several tablet applications concepts were designed and developed (see figure 1) in close coordination with the helicopter flight crews of the RNLAF. Several iterations of the tablet concept were subsequently evaluated in simulation experiments to determine the effects of tablet use in operations. Participants only received a limited training in the functioning of the tablet concept. Also, specific operating procedures were not put in place to better allow determining the effect of introducing a tablet in the flight crews' normal procedures. Data on the effects of tablets use was collected through observations by operational experts and human factors experts, questionnaires provided to the participants and debriefs with the participants. Observations of the effects of tablet use were also performed during live exercises. After the live exercises, debriefs and interviews were held with the participants.

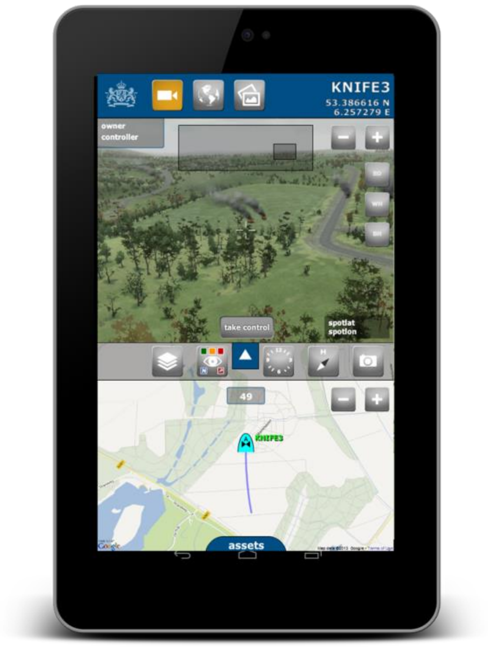

Figure 1: version of tablet concept as designed in the research program

To support the safe and effective integration of tablet based information exchange concepts in helicopter operations worldwide, the results of this research program will be disseminated to the broader public, specifically the effects on flight- and mission safety.

2. EFFECTS OF TABLET USE ON THE FLIGHT CREW

The potential negative effects of the use of tablet applications in helicopter operations can be separated into two components: the effects on the flight crew, both physical as well as cognitive; and the direct and indirect effects of tablet use on the operation.

The introduction of a salient, information rich interactive display in the cockpit invariably changes the dynamic of the flight crew's working environment. This is especially true for the military pilot who, at times of high operational demand, can have limited resources to spare.

Tablet use can have direct effects and can have indirect effects that arise as a product of the direct effects. Figure 2 illustrates the different effects on the flight crew, within the cockpit and within the larger team.

2.1. Direct effects on the flight crew

2.1.1. Cognitive overload

One of the most notable and visible effects of tablet use in helicopter operations is the possibility of overloading the flight crew. Cognitive overload can be experienced when the workload reaches higher levels than the cognitive capacity of the operator can handle, which can quickly reduce performance and increase error rates [1]. Whether or not an operator suffers cognitive overload is associated with the operators' workload. This relative workload is a combination of 1) the task saturation at the moment and the operators' experience with the main task and 2) the amount of experience with the product and the procedures surrounding it, and 3) the product design.

Task saturation during a mission is not constant and varies between missions. Certain moments in helicopter operations (e.g. flying low) provide such high workload in the operator that the remaining available cognitive resources are highly reduced. The operator's experience with the main task can also vary. If users are (relatively) inexperienced at the main task, the task itself already demands increased attention resources compared to experienced users.

The workload can also increase due to the inexperience with operating the tablet, as a result of design of the device or a combination of the two. Inexperience with the tablet increases the task load that is generated by operating the tablet, which adds to the operator's perceived workload.

Cognitive overload was not (yet) observed in the participants in the simulation experiments or in the operational exercises. This may be caused by the simulation environment in which the experiment was conducted, which provided a low task load for the flight crew. Cognitive overload was also not observed in the live exercise, which may be attributed to the low complexity of the product and careful workload management on behalf of the operators.

2.1.2. Information overload

Besides adding to the task load of the flight crew, the tablet also provides a large amount of information. When too much information is presented to the flight crew, information overload can occur, potentially limiting the flight crews' capability to make decisions.

In literature, information overload is defined as "the moment when the amount of input to a system exceeds its processing capacity" [3]. Decision makers (i.e. humans) have fairly limited cognitive processing capacity. Consequently, when information overload occurs, it is likely that a reduction in decision quality will occur. Research from a number of disciplines (e.g., accounting, finance, consumer behaviour) has found, for example, that information overload decreases

Figure 2: potential negative effects on the flight crew

decision quality, increases the time required to make a decision, and increases confusion regarding the decision.

Information load can be operationalised in different ways: the amount of information (e.g., number of cues: number of alternative outcomes; and overall diversity of the information). The number of information cues is the most commonly cited determinant of information overload. Direct relationship between the number of display elements and performance was also found in research [4]. An increase in task demands (i.e., task complexity) directly influences mental workload and can lead to information overload. Other research has articulated the importance of time in understanding information overload [5], suggesting that information overload occurs when the time required to meet a decision maker's processing requirements exceeds the amount of time available for such processing, resulting in degradation of decision quality.

Information overload was not observed during the simulation experiments. This is likely related to a combination the low task load provided in the simulation and to the design of the tablet application, which was designed to limit the amount of information provided to the user to only the essential information.

2.1.3. Effects digital communication

The use of the tablet will facilitate digitised communication between and within teams. By means of the Multiple Resource theory [8] it will be explained how the use of a tablet for communication between crew members will affect the operator's resources. In addition, Controller Pilot Datalink Communication (CPDLC) in commercial aviation may be considered a valuable analogy, which has been a topic of research in the past decades. With the tablet to communicate inter and intra teams via visual information, similar negative side-effects may play a role.

The effects of digital communication are presented in more detail in the following paragraphs.

Distraction

The limitations of human attention represent one of the most important bottlenecks in human information processing. Distraction is one such limitation that many flight crews have to deal with. Impairments to operator performance can arise from a competition for visual processing, from manual interference or from cognitive sources [6]. Assuming the tablet device is either hand held or manipulated by hand, requires visual scanning and the information presented needs to be understood and interpreted, all three sources of distraction are relevant for helicopter crews using the device. Visual and cognitive distraction are the most important sources in a helicopter setting. Therefore, the focus in this paragraph will be on those two sources of distraction.

Because the tablet device provides visual information an important phenomenon to discuss is visual dominance. It is commonly found that when input from vision and other modalities is put in conflict, the phenomenon of visual dominance results [7]. This phenomenon appears to oppose our natural tendency to switch attention to stimuli in the auditory and tactile modalities. When an abrupt auditory stimulus intrudes on a background of ongoing visual activity, it will probably call attention to itself and alert the operator. However, if visual stimuli are appearing at the same frequency and providing information of the same general type or importance as auditory or proprioceptive stimuli, biases towards the visual source at the expense of the other two is likely. In the case of a helicopter crew approaching a landing site while using a tablet device, this could result in pilots and/or loadmasters missing potentially important cues such as radio communication, subtle g-force changes and vibrations.

Certain forms of distraction were observed in the flight crews during the simulation experiments and operational exercises.

Tablet fixation

One of the most often mentioned effects of tablet use on the flight crew is “tablet fixation”. Tablet fixation can be described as the dominant capture of operator attention and is related to “heads-in” moments. Tablet fixation is understandable from an operational point of view, as there is a constant desire for real time, detailed information among the flight crews. Tablet fixation is a result of a combination of several effects that are presented above such as visual dominance, information overload and attention grabbing. Tablet fixation can be seen as a manifestation of earlier effects. As the operator fixates his/her attention on the tablet, the SA of what is happening outside of the aircraft can be reduced.

‘Tablet fixation’ was reported several times. During the simulation experiments operators were observed to at moments be fixated on information presented on the tablet. This acquiring of information continued for minutes on end. During the live exercise, tablet fixation was also observed. The rich information provided in the live video feed of the landing site even led one loadmaster to briefly forget his main tasks.

Reduced situational awareness and limited mental models

The visual salience of a tablet and the information provided on a tablet can provide a level of distraction from the immediate environment of the operator. Using a tablet in a helicopter operation could thus lead to less SA and a less well developed mental model.

Evaluation of the concept tablet indicates that when sharing information and coordinating within and between helicopters, it is possible to unintentionally spend too much time looking at the tablet. Combining use of the tablet and performing tasks that require attention outside the platform is difficult. For example, when a sensor operator is tracking a target with the on-board sensors, using the tablet would be a no-go. The risk to lose the track is too high. The resultant 'eyes-in' effect prevents use of the tablet device in critical, high workload conditions where attention outside the platform is required. Furthermore, it could create safety risks when crucial events are missed due to the operation of the tablet device. The 'eyes-in' effect is inherent to the system the concept is designed on, where looking at the screen is necessary.

An evaluation of the concept tablet application in the simulator experiments confirmed these negative effects. Participants in the live exercise indicated that they used auditory cues such as tone of voice to determine when attention needs to be placed on other matters.

Incongruence between mental models of crew members with and without tablet

Due to the fact that the tablet introduces extra task load to the operator, it will likely only be used by the pilot not flying or other operators that do not have an immediate safety critical task (such as loadmasters or passengers). As one operator has access to more information than the other, an imbalance in mental models could theoretically occur.

Such an imbalance has not been observed or reported in the simulator experiments, and no evidence could be found for it in the literature.

Overload in the visual channel

Team performance in a mission is nowadays relying on voice communication within the team and between teams while visually perceiving the environment. If voice communication is to be substituted (to a large extent) by digital communication via a tablet this will require visual attention instead of auditory.

The Multiple Resources theory [8], explains why certain tasks can be easily performed simultaneously whereas others interfere with one another and decrease performance on either or both tasks. The theory distinguishes the stages of perception, cognition and responding, which make use of either spatial or verbal processing codes. Using voice communication to transfer information requires multi-tasking using two different modalities (cross-modal time-sharing) e.g. to visually perceive the environment and to auditorily perceive information on different entities in the environment from team members. Using a tablet for inter- and intra-team communication will require intra-model time-sharing, requiring visual perception e.g. for observing the outside view as well as for perceiving information from team members. The latter in most cases, decreases performance. Especially when both tasks concern focal vision it may increase workload as opposed to a focal and ambient visual task that allow for better time-sharing (ambient vision is used for sensing orientation and motion).

Furthermore, analysing the operator responses using the same theory, manual and vocal tasks can be efficiently time-shared, assuming that most manual tasks are usually spatial and vocal tasks are verbal in nature. Following this theory, the manual task of operating the tablet may disrupt performance on other spatial tasks such as scanning the outside view let alone flying an aircraft.

A review of simulation studies using Controller Pilot Datalink Communication (CPDLC) concluded that datalink redistributes the workload across information processing resources by reducing speech and listening but increasing visual and manual effort [9]. Presenting Air Traffic Control instructions to pilots in a visual way rather than aurally results in a higher accuracy in the 'readback' of the instruction [10] and an improved ability to understand the message at a first attempt [11]. Nevertheless the use of datalink does not enable multitasking while responding through datalink and decreases head-up time for pilots [12].

Effects of visual overload were visible in the simulation experiments, with several (clear) external events being missed due to operators performing tasks on the tablet concept.

Misinterpretation of (digital) information

Under many conditions, humans display a robust tendency to rely more on visual information than on other forms of sensory information. Colavita [13] illustrated this visual dominance effect by showing that naive observers typically fail to respond to clearly suprathreshold tones if these are presented simultaneously with a visual target flash. This human tendency, in combination with a device that provides very salient cues (symbols, pictures, maps) on a full colour, high resolution display might result in attention capture. This does not necessarily mean that the user considers the displayed information as ‘reality’ or ‘the truth’ but the effort involved in checking the accuracy of this information, by cognitively switching, might be too high in high workload situations.

The problem of cognitive switching has been known for some time. For example, in 1979, Fischer [14] published a NASA contractor report that examined the construct and showed that pilots had difficulty with detection when using Head Up Displays (HUDs). The author and his colleagues published a NASA Technical Paper the next year [15] describing the cognitive problems, including cognitive switching, involved in HUD use. These authors prefaced ‘attentional tunnelling’ and attention capture and reported that pilots, using a HUD, failed to notice a plane taxiing onto the runway before the aircraft was to land.

A tablet device can serve to share large amounts of useful information. To do that, it depends on a sensor/communication network to gather data and to transmit an integrated picture. Such networks, unfortunately, are subject to failures that could leave units without access to information. The effectiveness of the system depends on its update frequency; if data are not updated regularly it loses value or becomes of negative value because information can change rapidly. Research [16] showed that participants performed better overall when they were able to use an information sharing system than when they performed the task without assistance. However, when a ten second latency was added to the updating of position information in the information sharing system, participants made significantly more false alarms regardless of whether they knew about the latency.

Also, at least some of the data on the tablet system is human generated. And even though a Point Of Interest (POI) might look very real and accurate on a display it might not be because of human error. All human generated data is subject to the well-known human error issues involving psychological and physiological limitations. Helicopter crews involved in complex missions who have as secondary or maybe even tertiary task the input of information might be even more susceptible to human error due to the exceptional circumstances.

These types of misinterpretations of digital information were frequently observed in the simulation experiments.

Confusion

Depending on the level of integration with the on board systems, the addition of a tablet application in the cockpit can present problems to the flight crew. A stand-alone application is usually, apart from the data link, not integrated with the on board systems such as the moving map and/or sensor devices. This allows for greater flexibility in the design and faster updating of functionality. On board systems of helicopters could contain features (such as the moving map) that overlap with those found in typical tablet applications.

If the tablet application is not, or not fully integrated with the on board systems, but shares one or more functions with the on board systems, there is a chance that a discrepancy between the two can occur. This discrepancy creates the risk that tasks that are supposed to be performed on the on board systems might be performed on the application and vice versa. This can result in a situation where crew members or team members are not aware of, and/or have access to all the information. Given the high task load environment that the flight crew is working in, there is a chance the flight crew will inadvertently use or reference to already obsolete data. This can cause confusion with the operator, and with crew members/team members.

Another tablet related cause of confusion is the delay in data transfer between tablet users/headquarters. Whereas voice communication is near instant, data can take longer periods of time to share depending on the size of the data and the limitations of the network and the availability.

During one of the simulation experiments, a large amount of data was shared between the users. This caused a delay in the data transfer. The combination of a large amount of data sent and delayed arrivals, also known as ‘information attacks’ [17], resulted in mismatched shared mental models among the flight crew. It can be very difficult to resolve this errant mental models as “People tend to explain away conflicting cues to fit the mental model they have selected“ [18]. As flight crews proceeded to coordinate on the basis of different versions of the same plan, confusion and mistakes started to develop. It can be argued that sharing this amount of data via voice communication would lead to similar delays and confusion. However, the combination with (seemingly) direct and ‘true’ digital communication makes confusion under these circumstances more likely.

2.1.4. Discomfort during long periods of use

Using a tablet for longer periods of time in a moving platform (helicopter) can also cause physiological effects. Depending on the size and weight of the device, there might be operator discomfort in terms of muscle fatigue from holding a heavy, ruggedized video terminal for multiple hours. This study focusses on a tablet based solution, where this kind of discomfort will not be likely. Another discomfort to the operator can take place in the form of motion sickness when using a device while sitting in a moving platform.

Motion sickness

In [19] an experiment is described on the operation of a Remotely Piloted Aircraft (RPA) from a (moving) aircraft. It appeared that especially conflicting motion cues (the cues on the RPA control display versus the motion cues from the outside view) degrade operator performance. In particular the vertical errors on the RPA operation task seem to be effected. Another finding of the study was that most of the 15 participants suffered motion sickness symptoms while none of them became actively sick. It was concluded that the symptoms at least distracted from the primary task (of operating the RPA).

Motion sickness was not observed in the live exercise.

2.2. Indirect effects

Beside the direct effects on the flight crew, there are a number of indirect effects that occur as a result of using a tablet. These indirect effects are products of the direct effects.

The indirect effects of digital communication are presented in more detail in the following paragraphs.

Interruptions (and the influence on information load)

If the tablet device is used as a standalone product, the use of a tablet creates an interruption from the normal flow of events. An interruption is "an externally generated, randomly occurring, discrete event that breaks continuity of cognitive focus on a primary task" [20] and typically "requires immediate attention" and "insists on action" [21].

This definition implies that another person or event creates an interruption and that the timing of an interruption is beyond the control of the individual. Interruptions can exacerbate information overload in two ways. First, they take time away from working on ongoing work activity, potentially resulting in a feeling of time pressure and, ultimately, information overload. Second, the interruptions themselves can place greater demands on cognitive processing and result in an increase in information load and task processing demands [22].

When this occurs it may result in a decision maker forgetting some of the information needed for processing the primary task and, therefore, some cues are lost or never enter working memory. As the decision maker completes the interruption task and returns to the primary task, a recovery period is needed to reprocess information that was forgotten while attending to the interruption or lost from working memory due to capacity interference. In such cases, decision accuracy may be decreased and/or decision time increased.

In general, the tenets of Distraction/Conflict Theory [23] state that distractions facilitate performance on simple tasks and inhibit performance on complex tasks. When interruptions occur during simple tasks, arousal or stress elevates, attention narrows and irrelevant cues are more likely to be dismissed or ignored. The increased arousal results in a decision maker completing the task more quickly (e.g. faster decision time) with little or no loss of task-relevant cues (e.g. equivalent decision accuracy). Decision makers performing complex tasks however have little if any excess cognitive capacity. Narrowing one's attention as a result of the interruption is likely to result in the loss of information cues, some of which may be relevant to completing the task. Under these circumstances, performance is likely to deteriorate.

As performing helicopter operations can be regarded as mostly complex tasks, interruptions can be assumed to have a negative impact on performance. The concept tablet device that was analysed has limited interrupting features that breaks continuity of cognitive focus on the primary task. Also, the experiment was performed on low-fidelity simulators that do not require tasks to be completed in full. Therefore, the effects of interruptions could not be determined in this research program.

Still, while no aural disruptions are presented to the operator, visual notifications, appearing icons and the overall visual saliency of the device could cause an interruption when observed.

Lack of verification

One of the aspects of digital communication is the absence of voice communication, and thus of read back. When there is no read back of messages there is no means of knowing whether the message has been received and at what time (delay) it was received. In several experiments with datalink and the first implementations of it, datalink supplements rather than substitutes voice communication.

An experiment in the LINK2000+ project with datalink for en-route air traffic control resulted in the finding that response time increased with datalink over voice and have therefore concluded that voice needs to be used for all time-critical and safety-related communication [24]. In the European project EMMA2 the use of datalink for taxi instructions was subjected to an experiment. It concluded that voice communication should always take precedence over datalink [25], which was also taken as a requirement for datalink use by Maastricht Upper Area Control. A NASA simulation experiment in which voice and datalink were used 1) redundantly (pilot and controller use both), 2) supplemental (pilot always uses both) and 3) datalink only. It showed that datalink only is not the optimal. When pilots read back the messages they made fewer errors and their SA was increased [26].

The effects of lack of verification have been observed in the simulation experiments and flight crews have stated that some form of 'handshake' or other type of verification is required for safe operations.

<u>Reduced voice communication (inter- and intra-team)</u>

One of the effects of digitised communications can be a reduction in voice communication. Although this effect has not been observed yet in the simulation experiments this is likely due to the inexperience with the product. A longer period of training and experience with the application could reduce communications. A NASA study on the effects of advanced navigation aids reported a reduction of both controller-pilot and intra-cockpit voice communications [27].

The reduction of voice communications may lead to a loss of SA due to the lack of what is sometimes referred to as 'party line communication' [24][28][12]. This is the effect that flight crews by listening to the radio frequency hear the instructions that are given to other flight crews and thereby build up a mental picture of other traffic in the vicinity. It was recommended that good visual information (e.g. visualisation of the other traffic on a cockpit display) could help maintain SA [24][12].

Paradoxically, while communication about certain aspects reduces, it increases on others. In the live exercise there was a large increase in voice communication. This however consisted mostly of (non-informational) communication related to the operation of the concept and instructions on which information needs to be sent through. This type of voice communication is also detrimental, as it reduces R/T time/availability for other crew members. During the simulation exercises, voice communication also increased as operators performed 'handshakes' to confirm both sending and receiving of information. Furthermore, voice communication increased on the contents of the information shared.

3. TABLET USE IN THE OPERATION

Integrating a tablet in the operation and using it as an information access point can have negative effects on the operator, the crew/team and the mission as a whole. As integrating tablet devices in helicopter operations is a relatively new trend, there is currently not yet a large body of literature available on this subject. The below mentioned effects are thus mainly build on the observations and comments mentioned by the participants during the experimental workshop sessions and during the large scale live exercise that was held in 2012. It is important to note that these effects can be temporary, and can reduce over time with proper training and experience. Alternatively, some effects can increase over time, e.g. as a result of product dependency and lack of training in alternative (analog) methods.

3.1. Mission phase limitations

Due to effects mentioned in chapter 2 and the high task load during some phases of the flight, the concept tablet is limited in its use to situations where task load allows use of the tablet device. During the landing phase, pilot flying, pilot not flying and Loadmaster all focus most of their attention to the outside world (e.g. for observing the landing zone and surroundings, potential obstacles). During the en-route phases and while in holding, the task load is limited, allowing use of the tablet device. Due to the different tasking and timings between different helicopters, these limitations in operational use of the tablet device during different flight phases can present a problem. During missions, the workload of one helicopter crew might differ from others depending on the flight phase they are currently in (e.g. landing phase vs. en-route phase). This can prevent critical information being shared or noticed by crews.

3.2. Effect on team performance when one or more crew members lose tablet functionality

When tablets are used to provide critical information to flight crews, losing partial or full product functionality could potentially have big effects on the effectiveness and safety. There are several technical problems that could occur with using tablet devices:

The product could malfunction in various ways, either noticeable or barely/unnoticeable. This could (partially) limit the functionality of the product, reducing the flight crew's access to information and/or input capabilities. Depending on the possibility to use alternative methods to acquire the information/provide the input, this can have strong implications. Undetected malfunctions in particular are potentially dangerous, as the operator can base his/her actions on incorrect information. Clear feedback of product diagnostics is therefore important to maintain safety and maintain operator trust in the product. The existence of effective alternatives/back-ups to the functionality provided by the product is also important;

The data connection could malfunction/be unavailable. This prevents the flight crew to receive up-to-date information for decision making, or to give input to other team members.

On the basis of the potential effects on the flight crew listed earlier, several suggestions for safe and effective use of tablets during helicopter operations can be made.

3.3. Operational use and protocols

Clear protocols on permissions and use of the product are necessary. Not all crew members benefit from using a tablet device equally and for some the risk of distraction from the primary tasks does not weigh against the benefits of extra information.

Operational use will also require clear procedures for the sharing, editing and removing of information, restrictions in use or permission levels. Furthermore, ambiguous information can impact Shared Situational Awareness (SSA) reducing coordination and subsequently effectiveness of the team. A tablet device therefore requires uniformity in transmission of information as well as display of information (interfacing) when sharing information between two or more operators.

3.4. Product design

It is undesirable for the tablet device to increase the workload of the flight crews. Therefore, the tablet design has to be simple, intuitive and adapted to the task and operational use as much as possible in order to be effective in an operational setting. The design should limit manual input with the product to limit manual interference with other tasks and prevent distraction. Familiarity (in the form of training or mere exposure) with the tablet device might reduce the time needed on the device and thereby reduce the distraction effect.

Integration of (the most important) data streams with the on board systems can prevent incongruence/disparity of information and reduce the chance of confusion in the flight crew. The tablet device should also be effectively integrated with the planning systems to facilitate quick and error-less conversion and transfer of planning data.

To prevent some of the effects of digital communications, the user interface in the cockpit should preferably be close to the forward field of view (to prevent too many 'heads in' moments). A distinct aural alert could be used when new (important) messages come in. This would reduce the necessity for monitoring the device and reduce the risk of missing important information. On the other hand, this would increase the level of disruption caused by the device, increasing the risk of detrimental effects on (checklist) procedures.

3.5. Procedures

Primarily, procedures need to be in place on who can use the tablet, during which situations, and to what extent, with what permissions. To prevent (too) high levels of workload, one mitigating measure would be to avoid (novel) users to use the tablet at times when the primary task is most demanding.

It can be assumed that if the tablet device is used (extensively) during low workload phases of a mission and selectively during high workload phases it could have a positive effect on overall workload by spreading workload more evenly over the different phases. Crew members that use the tablet device for coordinating with others need to consider the difference in workload between different team members at any particular time in a mission. While the sending party might experience low/normal workload, the receiving party might not. This can cause the receiving party to miss transferred data or experience distraction during a high workload period. Naturally, a tablet could store the received information, this way allowing the receiving end to use the tablet as reference, which could potentially mitigate some of these problems. Obviously this assumption needs to be tested before procedures and/or training can be provided to air crew.

Because the task of most helicopter air crew is already based on the visual channel and the tablet device uses this same channel, any new information presented on this device can be regarded as an interruption, which presents a cognitive burden on the operator. Radio (R/T) communication can also place a cognitive burden on air crew but it uses the auditory channel and therefore the impact of the interruption on performance might be smaller. R/T communication is very much proceduralised, it seems tablet device communication requires at least an equivalent level of procedures to benefit from its advantages and minimise its disadvantages.

Operational use will also require clear procedures for the sharing, editing and removing of information, restrictions in use or permission levels.

To mitigate the effects of digital information sharing it is recommended that safety-related and time critical information be transferred by voice, and voice communications to take precedence over visual information. If possible, pilots are recommended to read back the messages, and actively question safety related digital information to prevent errors and increase SA.

3.6. Training

To make optimal use of the tablet device, flight crews need to be trained in operating the device and using it to its full potential within operational circumstances. This might also require integrating a tablet device in current day education of new pilots. Training in operating the tablet device can reduce that task load that it presents to the operator and thereby reduce his/her perceived workload leading to a reduced chance of cognitive overload. Furthermore, training in operating the device should include Human Factors training modules that can address some of the more concealed effects and risks of tablet use such as the effects of visual dominance, risk for tablet fixation or misinterpretation of information.

4. CONCLUDING REMARKS

Using a tablet type of device for digital information sharing can have beneficial effects on (shared) SA. It can also support coordination and communication and reduce crew workload. However, as demonstrated in this research, its use can also have negative effects on workload, human performance and flight safety. It is recommended to prevent operator overload by limiting the use of tablets to phases of the operation that allow the extra task load. Also, clear procedures, and protocols should be in place to prevent misinterpretation of data and operator confusion. Careful user centred design and proper training with the concept can help prevent operator mistakes.

All in all, the “costs and benefits” of using tablets in helicopters should be carefully weighed for every potential user, as to achieve a solution that is as safe and effective as possible.

REFERENCES

[1] Bourne, L. J. (2003). *Stress and cognition: a cognitive psychology perspective.* NASA.

[2] Harwood, K., & Sanderson, P. (1986). Skills, rules and Knowledge: A Discussion of Rasmussen's Classification. *Human Factors and Ergonomics Society Annual Meeting*, 1002-1006.

[3] Milford, J., & Perry, R. (1977). A methodological study of overload. *Journal of General Psychology*, 131-137.

[4] Bohnen, H., & de Reus, A. (2004). Pilot workload prediction: NUmber of Display ElementS (NUDES) as a predictor. *HPSAA II, Human Performance, Situation Awareness and Automation Technology Conference.* Daytona Beach, Florida.

[5] Schick, A., Gordon, L., & Haka, S. (1990). Information Overload: A Temporal Approach. *Accounting Organizations and Society*, 199-220.

[6] Strayer, D., Watson, J., & Drews, F. (2011). Cognitive Distraction While Multitasking in the Automobile. In B. Ross, *The Psychology of Learning and Motivation*, (pp. 29-58). Burlington: Academic Press.

[7] Wickens, C., & Hollands, J. (2002). *Engineering Psychology and Human Performance (3rd ed.).* New Jersey: Prentice Hall.

[8] Wickens, C. (2002). Multiple Resources and Performance Prediction. *Theoretical Issues in Ergonomics Science*, 159-177.

[9] Kerns, K. (1991). Data-Link Communication between controllers and pilots: a review and synthesis of the simulation literature. *The International Journal of Aviation Psychology*, 181-204.

[10] Hellenberg, J., & Wickens, C. (2000). *Plot Expectancy and Attentional Effects for Hazard Awareness: Effects of Data Link Modality on Pilot Attention and Communicating Effectiveness.* University of Illinois.

[11] Hooey, B., Foyle, D., Andre, A., & Parke, B. (2000). Integrating Datalink and Cockpit Display Technologies into Current and Future Taxi Operations. *AIAA/IEEE Digital Avionics System Conference* . Philadelphia.

[12] Navarro, C., & Sikorski, S. (1999). Datalink Communication in Flight Deck Operations: A

Synthesis of Recent Studies. *The International Journal of Aviation Psychology*, 361-376.

[13] Colavita, F. (1974). Human sensory dominance. *Perception & Psychophysics*, 409-412.

[14] Fisher, E. (1979). *The role of cognitive switching in head-up displays.* NASA Contract NAS-1-3137.

[15] Fischer, E., Haines, R., & Price, T. (1980). *Cognitive issues in head-up displays (No. 1711).* Moffett Field, CA: NASA Ames Research Center.

[16] Bryant, D., & Smith, D. (2013). Impact of blue force tracking on combat identification judgments. *Human Factors*, 75-89.

[17] Endsley, M. R. & Jones, D. G. (2001). Disruptions, Interruptions and Information Attack: Impact on Situation Awareness and Decision Making, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting October 2001 vol. 45, no. 2,* 63-67.

[18] Endsley, M. R. & Jones, D. G. (2011). *Designing for Situation Awareness: An Approach to User-Centered Design*. Boca Raton, FL, USA: CRC Press.

[19] Antonov, G. S., Domogala, M. C., & Olson, W. A. (2007). *Operating an unmanned aerial vehicle from a moving platform.* Washington: IITA Institute for Information Technology Applications US Air Force Academy.

[20] Corragio, L. (1990). Deleterious effects of intermittent interruptions on the task performance of knowledge workers: A laboratory investigation. *Unpublished doctoral dissertation*. University of Arizona.

[21] Covey, S. (1989). *The seven habits of highly effective people.* New York: Simon and Schuster.

[22] Normon, D., & Bobrow, D. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, 44-64.

[23] Baron, R. (1986). Distraction-conflict theory: Progress and problems. *Advances in Experimental Social Psychology*, 1-39.

[24] Pinska, E., & Whitely, M. (2004). *LINK2000+, France Real-Time Simulation Project.* Bretigny: Eurocontrol Experimental Centre.

[25] Teutsch, J. (2009). *EMMA2, European Airport Movement Management by A-SMGCS - Validation Comparative Analysis Report.* Amsterdam: NLR National Aerospace Laboratory the Netherlands.

[26] Norman, R., Baxley, B., Adams, C., Ellis, K., Latorella, K., & Comstock, J. (2013). *Flight Crew Workload, Acceptability and Performance When Using Data Com in a High-Density Terminal Area Simulation.* NASA.

[27] Parke, B., Enfroe, D., Kanki, B., Hooey, B., Munro, P., Patankar, K., et al. (2001). The Effects of Advanced Navigation Aids and Different ATC Environments on Task-Management and Communication in Low Visibility Landing and Taxi. *11th International Symposium on Aviation Psychology.* Ohio.

[28] Mueller, E., & Lozito, S. (2008). Flight Deck Procedural Guidelines for Datalink Trajectory Negotiation. *AIAA ATIO Conference.* NASA.