Using Augmented Reality to Train Flow Patterns for Pilot Students - An Explorative Study

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Abstract. Today, just as in the early days of flying, much emphasis is put on the pilot student's flight training before flying a real commercial aircraft. In the early stages of a pilot student's education, they must, for example, learn different operating procedures known as flow patterns using very basic tools, such as exhaustive manuals and a so-called *paper tiger*. In this paper, we present a first design of a virtual and interactive *paper tiger* using augmented reality (AR), and perform an evaluation of the developed prototype. We evaluated the prototype on twenty-seven pilot students at the Lund University School of Aviation (LUSA), to explore the possibilities and technical advantages that AR can offer, in particular the procedure that is performed before takeoff. The prototype got positive results on perceived workload, and in remembering the flow pattern. The main contribution of this paper is to elucidate knowledge about the value of using AR for training pilot students.

Keywords: Augmented reality · Interaction design · Flight training · Method

1 Introduction

Already in the late 1920s, there was a great demand for flight instruction and simulators, to help pilots learn to fly in a safe environment without the deadly risks of having beginner pilots take the controls of a real aircraft [3]. Today, just as in the early days of flying, much emphasis is put on the pilot student's flight training and instrument navigation before flying a real commercial aircraft. In the early stages of a pilot student's preparation for the flight simulator of a commercial aircraft, they must learn how to operate an aircraft from the cockpit using nothing but a simulator made out of printed-paper panels also referred to as a *paper tiger* (see Fig. 1) and the aircraft's operation manual. During this stage of their flight training, pilot students are meant to familiarize

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themselves with the procedures to perform in the cockpit before, during and after a flight. Specifically, students learn these procedures partially through the repeated practice of so-called flow patterns, which aim to instill in pilots not only the procedures to be carried out but also the order in which to perform them. During this stage, pilot students also practice working together as a team of captain and copilot by practicing to execute the flow patterns together and cross-checking the other pilot's work to ensure that all steps have been carried out correctly.

Fig. 1. The *paper tiger* at LUSA.

Pilot students spend 40 h or more practicing these skills using paper tigers to prepare themselves for further training sessions in expensive full flight simulators. The aim of these practice sessions is not only to memorize the procedures to perform but also to memorize the location of the different instruments and buttons in the cockpit. Additionally, the aim is to train students' muscle memory to automatize the performance of these procedures [3]. While *paper tigers* offer a cheap and efficient way to train cockpit procedures, their low-fidelity nature also has downsides. For example, the *paper tiger* neither has guidance to help novices find the correct instruments in a complicated cockpit, nor can performance feedback be provided in this setup. Furthermore, *paper tigers* take up significant space, they are limited to certain locations and as such still impose significant resource constraints on student learning. Therefore we decided to build an AR version of the *paper tiger* and use it as a training method with low space requirements, that is portable and allows studying flows at any time and location, while simultaneously offering increased support and feedback through an interactive augmented reality (AR) user interface.

AR is a technology that can superimpose virtual objects on top of the real world. According to Azuma [2], an AR system has the following three characteristics: 1) Combines real and virtual; 2) Interactive in real-time; 3) Registered in 3-D. In the last couple of years, several head-mounted displays have appeared that offer these capabilities, such as Microsoft HoloLens [17] and the Magic Leap [16]. Such glasses-based AR systems open up new opportunities for experimenting with interactive applications for pilot students, in ways that up until now have been too difficult, expensive or time-consuming. Another emerging technology is virtual reality (VR). VR uses computer-generated simulations to create "the illusion of participation in a synthetic environment rather than external observation of such an environment [10]." However, we decided to use AR for the current application since it was the most suitable option allowing the student to simultaneously read the physical manual while interacting with the *paper tiger*, which was needed during the test. Another reason was to let the pilot students have visual contact with their co-pilot.

This paper presents the development of an interactive AR *paper tiger* that can be used to help pilot students to learn particular flow patterns that are done before a takeoff. The application was developed and evaluated using Microsoft HoloLens [17] together with the game engine Unity [20]. The evaluation was conducted at the Lund University School of Aviation (LUSA) in Ljungbyhed, Sweden.

The main contribution of this paper is to elucidate knowledge about the value of using AR for training pilot students.

The next section presents relevant related work that has previously been used to conceptualize an interactive virtual cockpit and the use of AR in the aviation industry. Then the developed AR *paper tiger* is described followed by the evaluation, results, discussion, and conclusions.

2 Related Work

Using AR technology for flight operations with different purposes, such as aircraft design, maintenance development, guidance of the actual flight phase and pilot training, is an area that has been well studied. However, most research has been conducted using AR for maintenance or as guidance of the actual flight phase but less on training for pilot students. This section reviews previous related research in using AR for aviation.

Modern aircrafts are complex machines that require a tremendous amount of manual effort to manufacture, assemble, and maintain. Therefore, mechanics in the hangar are required to use an increasing amount of information in their jobs [5]. However, AR can facilitate these maintenance mechanics' jobs by visualization of the information from maintenance systems and representing how parts should be connected in a safe and interactive way. Caudell and Mizell developed one of the first AR maintenance tools which helped the maintenance workers assemble wires and cables for an aircraft [5]. Macchiarella, and Vincenzi [15] investigated how AR can be used to help the workers to memorize difficult moments of aircraft maintenance tasks. They used AR to develop augmented scenes with which the workers could train a wide variety of flight and maintenance tasks. Macchiarella and Vincenzi [15] followed up their study to see the learning effects on long term memory by testing their participants again after seven days. The results indicate that AR-based learning had positive effects on long term memory and that the participant remembered more information.

AR has also been used to help to guide pilots during the actual flight by providing information from the Primary Flight Display (PFD) regarding speed, altitude and heading [12,13]. Heads-Up-Displays (HUD) are already used in many fighter planes and modern commercial aircrafts such as the Boeing 737 Next Generation [12]. Additionally, "Smart glasses" have been developed for private pilots, for example, Vuzix M3000 [21], Google Glasses [11] and Moverio BT-200 [8] to guide them in a visual traffic pattern. One of the earliest helmet-mounted display (HMD) was developed by Tom Furness for the USA Air Force from 1966 to 1969. It helped the pilot to see a simplified version of reality. Furness continued to improve the helmets and in 1986 he described a virtual crew station concept called the "Super Cockpit" [9]. It discussed how flight information could be portrayed virtually and interactively. However, these applications focus on augmenting information for the pilots via HUD, HMD or "smart glasses" during flight. In this paper, we utilize the potential of AR to see if we can improve learning through procedural training, i.e. the practice and understanding of so-called flows, for pilot students.

3 Building the AR Paper Tiger

The main goal with the presented work was to design and test an interactive *paper tiger* by exploring the possibilities and technical advantages of AR. First, we will explain more details about the background of the *paper tiger*, followed by flow patterns, and limitations of the AR *paper tiger*.

3.1 Background

To obtain a commercial pilot's license (CPL), which is by far the most common training given at flight schools, pilot students need a minimum of 150–200 flying hours in total [7]. However, practice in the simulator of a multi-crew aircraft is significantly less. It consists of approximately 20 h during the Multi-Crew Cooperation Course (MCC) during the final stage of the training. This is aided by approximately 30–40 h of procedure preparation in a *paper tiger*.

The pilot students are trained to use checklists. Checklists are powerful tools; they can increase the precision of a specified behavior and reduce errors. However, when pilots work with a checklist the risk for distraction increases the longer the list is. They may lose concentration and direct their focus towards something else which needs their attention. One result of this is to keep the actual checklists as short as possible. Instead, aircraft manufacturers such as Boeing have set up a working method based on so-called flows. During a flow, you prepare the cockpit for different configurations such as startup, takeoff, descend and landing. Previous research highlights the development and a need for more human-centered interaction design in pilot training [6,19]. One example is during a type-rating course, a course at the end of the pilot's training when he or she learns how to fly a large complex commercial aircraft. Before the course starts, it is good to have as much experience as possible. Due to substantial economic costs for training, approximately 16 000–34 000 EUR for a type-rating [18] and high time pressure in the learning phase, the fresh student can be overloaded with information during a type-rating course. An interactive learning environment may serve as a stepping stone and a more intuitive approach and frame to the content than starting with reading a pure text and exhaustive lists in the initial learning phase of a type-rating.

3.2 Flow Patterns

The instruments and displays in a cockpit are organized in panels and placed in the cockpit according to a specific spatial arrangement. This arrangement is designed with regard to how frequently the instruments and panels are being scanned and monitored and in proportion to their critical value for the flight. To enhance a logical flow during the configuration of the aircraft it is necessary to perform the actions in specific sequences, these sequences or procedures are called flows.

Further enhancement of procedures is obtained by the patterns shaped by the sequences of the flows. Flows follow a logical order and the items, which are to be set up, are organized in chunks within every panel. For example, in the case of the flight control panel, the part-panels on the overhead section build up the "overhead panel" and are scanned in "columns" from top to bottom. Using a top-bottom order for checking the panels and items provides a structure and thereby reduces the work to learn the items. The same spatial technique can be used when verifying items of a checklist. Flows are challenging and a bit mechanic to learn in the beginning but can be rewarding once learned. A comparison can be made to learning a dance. First, you struggle with getting all the steps right and you easily forget what comes next. But after a while, you get into a flow and one move seems to lead into another. When the pattern is recognized one intuitively connects one item to the next. In order to study the flow, pilot students use a paper as guidance which shows the fifteen panels they have to go through (see Fig. 2).

3.3 Flow Patterns with the AR Paper Tiger

The general scanflow is executed before every take off. It consists of 37 items to be set or checked, organized over fifteen panels or locations in the cockpit (see Fig. 2). The correct order of the fifteen panels and locations were reconstructed in the AR *paper tiger* to guide the user's attention to the appropriate area of

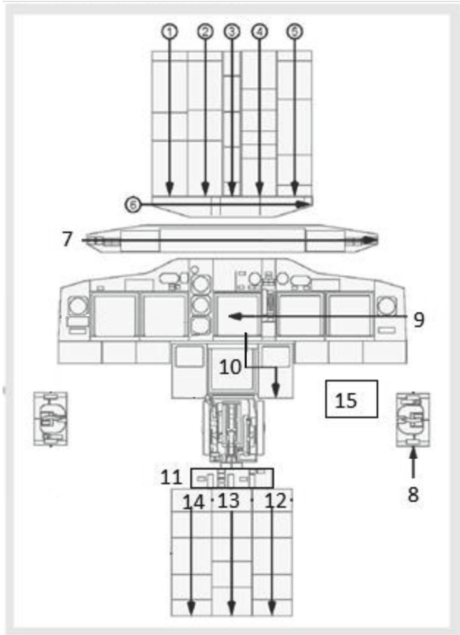

Fig. 2. The paper shows the general scan flow that consists of fifteen steps, borders around the panels are marked and arrows show where the student should start and in which direction to continue.

the items to be set or checked. Green borders are overlaid on top of the virtual *paper tiger* to highlight the specific panels and corresponding arrows similar to those of the paper version were used to tell the student where to start and in which direction to continue (see Fig. 3, left panel). However, in one instance, an additional arrow was added from the end of one section to the start of the next, because these two sections were far apart and otherwise the next section was not discoverable given the limited field of view of the HoloLens. The additional arrow can be seen in the bottom image in Fig. 3.

In order to get the student started, a "Demo" function was implemented that demonstrates the flow sequence. When the "Play Demo" button is pressed, the flow is visualized by sequentially showing a border around each step in the flow sequence together with an arrow corresponding to that step. This function is accessible by interacting with a floating button, in the near vicinity of the virtual cockpit. We chose a location that is not in the line of sight while interacting with the virtual cockpit.

3.4 Limitations

The HoloLens has several hardware and software limitations. For example, because of its narrow field of view, the users cannot use their peripheral vision

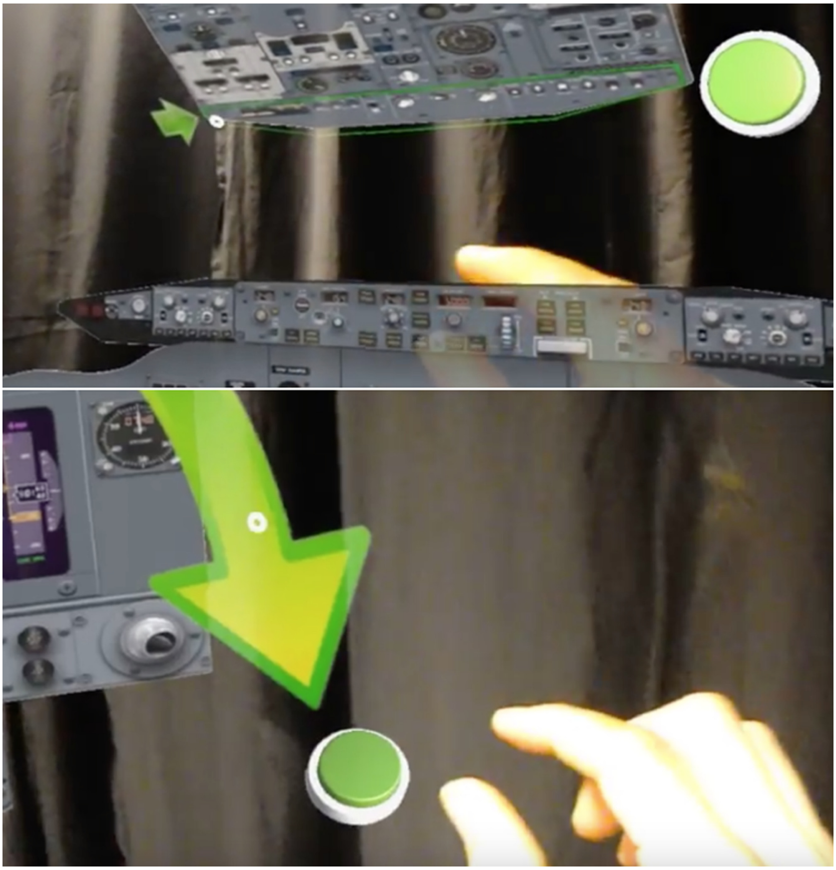

Fig. 3. Flow pattern with pointing arrows.

and therefore some sort of guidance must be added to help the user. Another limitation of the HoloLens is the low number of hand gestures available to the user. The pinch movement used for clicking on buttons in a cockpit might not come naturally to a pilot student. The AR *paper tiger* only marks the section of a certain panel. None of the elements on the virtual cockpit's panels were interactive for this first iteration of the cockpit training environment.

4 Evaluation

An evaluation was conducted in order to better understand the perceived workload and usability issues of the AR prototype. The evaluation was conducted at the Lund University School of Aviation (LUSA) in Ljungbyhed, Sweden.

4.1 Setup

One single session involved one participant and four test leaders, where one was in charge of introducing the HoloLens, two conducted the testing and one conducted a post-questionnaire as well as a structured interview (see Fig. 4). All test sessions were recorded and lasted about 20 min. The test session was designed as an assembly line, at certain points we had three pilot students at the same time but in different rooms (see Fig. 4). The technical equipment consisted of:

- Two HoloLenses.
- Two video cameras.
- One computer dedicated to questionnaires.

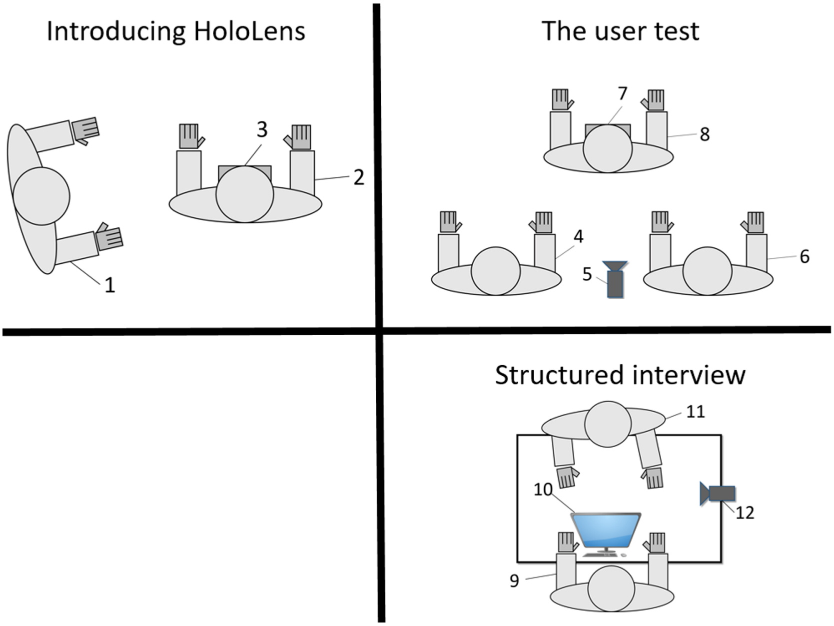

Fig. 4. The setup of the evaluation. 1) Test moderator introducing the HoloLens, 2) Pilotstudent (participant), 3) HoloLens used during introduction, 4) Test moderator leading the main test, 5) Video camera recording, 6) Test moderator responsible to help participant with HoloLens issues, 7) HoloLens running the AR *paper tiger*, 8) Pilotstudent (participant), 9) Pilotstudent (participant), 10) Computer dedicated to questionnaires, 11) Test moderator for the structured-interview, 12) Camera recording the interview.

4.2 Participants

Twenty-seven pilot students (five females) were recruited by their instructor at LUSA (age $M = 23.7$, $SD = 3.06$). Only two of them had previous experience of AR and four of them had less than two hours of experience with the *paper tiger*, while the others had no previous experience.

4.3 Procedure

All participants were given a brief introduction to the project and its purpose. Next, they filled in a short questionnaire together with informed consent regarding their participation and the use of collected data. Thereafter they were introduced to the HoloLens to familiarize them with AR and the mechanics of interacting with AR objects.

Next, they entered the room where the actual test was conducted. Before the test was performed the participant was asked to sit down by the real *paper tiger*, to understand the participant's pre-existing knowledge of the take-off flow. Then the participant got seated in a chair a couple of meters away from the real *paper tiger*, facing an empty wall. Here they opened up the virtual *paper tiger* application and got used to the user interface. The test operators made sure that they noticed all different panels and buttons before continuing with the test by instructing the participant to 1) look up to see the overhead panel, 2) look left to see the thrust and communication panels and 3) look right to see the oxygen mask and asking for a verbal confirmation. In the first step of the test, the Demo was played. The participant stood up and walked a couple of meters behind the chair to get all panels in his/her field of view at the same time. Then the participant played the Demo and observed. When the Demo was done the participant got seated again, handed a paper checklist and started to do the flow. When pilot students normally practice with the real *paper tiger* they pretend they are interacting with buttons and metrics according to a list they have in their hand. This was done in the application as well. The participant pretended to adjust all items of the flow within the outlined green marked area. When the participant was done in one area the "next-button" was clicked, after which the next section of the flow was outlined.

After the testing procedure with the HoloLens, the participant was brought back to the real *paper tiger*. Here the participant was asked to show the flow he/she just practiced with the HoloLens and some spontaneous first thoughts were talked about and noted by the test operators. Their performance in reproducing the flow was scored as number of items correctly recalled.

Last, after the tasks were completed, the participant moved to a third room and filled out the NASA Task Load Index (TLX) [14] and the System Usability Scale (SUS) [4] questionnaires. In an attempt to understand and describe the users' perceived workload NASA TLX was used as an assessment tool. NASA TLX is commonly used to evaluate perceived workload for a specific task. It consists of two parts. The first part is referred to as raw TLX and consists of six subscales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration) to measure the total workload. The second part of the NASA TLX creates an individual weighting of the subscales by letting the subjects compare them pairwise based on their perceived importance. However, as reported by Hart [14], using the second part of the NASA TLX might actually decrease experimental validity. For this reason, it was not used in this experiment. A raw NASA TLX score was calculated for each student as the sum of all subscores. Originally each subscore range up to 100, but several researchers use 20 or 10, in this study we used the maximum subscore of 10.

In an attempt to understand and describe the users' cognitive workload, SUS was used. It is often used to get a rapid usability evaluation of the system's human interaction [4]. It attempts to measure cognitive attributes such as learnability and perceived ease of use. Scores for individual items, such as, "I thought the system was easy to use," can be studied and compared, but the main intent is the combined rating (0 to 100) [1]. The questionnaires were followed by a short structured interview. All the structured interviews were video recorded. The video recordings were reviewed to detect recurring themes and to find representative quotes. The procedure is shown in Fig. 5.

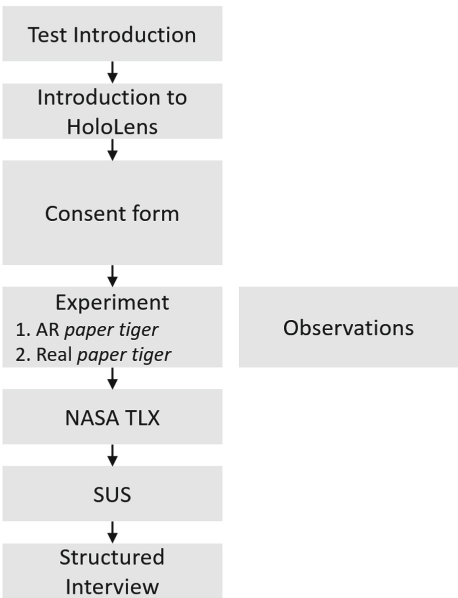

Fig. 5. The procedure of the evaluation.

4.4 Results

In the following section, the results from the NASA TLX, SUS scale, and the structured-interview are presented.

Twenty-two of the twenty-seven participants could see the potential and were positive to the AR *paper tiger*.

NASA TLX. The overall NASA TLX scores were low (see Fig. 6). Participants mean value of $M = 24.6$, $SD = 6.15$.

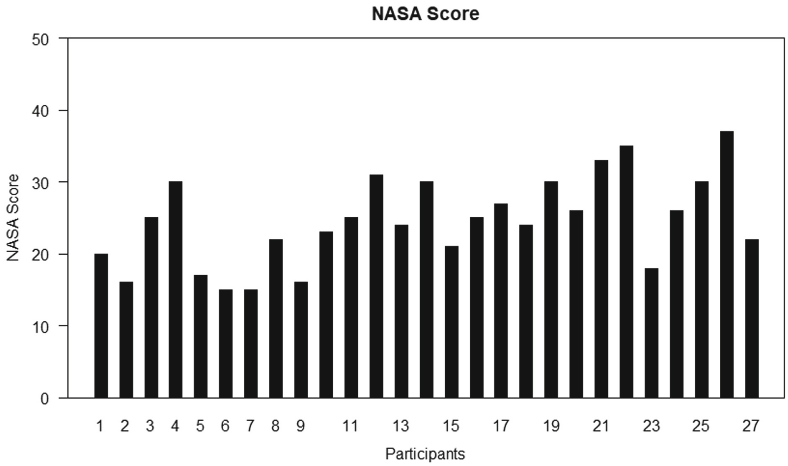

Fig. 6. The NASA TLX scores.

The results obtained from the NASA TLX subscales are illustrated in Fig. 7. All subscale values were relatively low but surprisingly Physical had the lowest median value, then Temporal and Frustration with the same low median value, which is good (Table 1).

Table 1. Median values of the NASA TLX subscore.

Subscale	MD	IQR
Mental	5	3
Physical	2	1.5
Temporal	3	2.5
Performance	7	3
Effort	4	4
Frustration	3	2

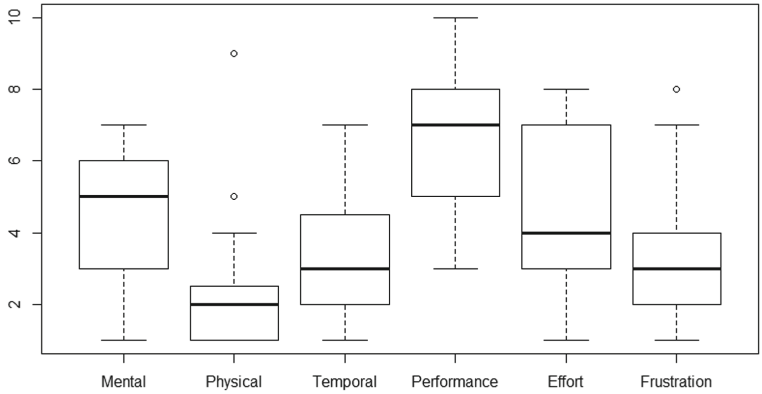

Fig. 7. The NASA TLX subscore.

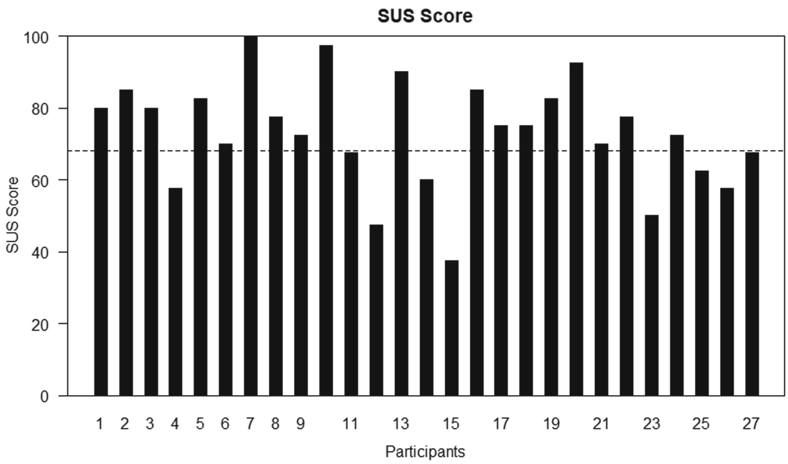

Fig. 8. SUS score for all participants.

SUS Score. The results obtained from the SUS questionnaire for the participants present a mean score of $M = 73.1$, $SD = 15.05$ with a minimum score of 37.5 and a maximum score of 100 (see Fig. 8).

Post Test Check. As described in the procedure section, after the participant used the AR *paper tiger*, the participant did a test on the real *paper tiger* to see how much the participant remembered of the flow, i.e. how many of the fifteen steps were remembered and if they were remembered in the correct order. On average, the participants remembered 73% of the fifteen steps in the correct order.

Structured-Interview. The results obtained from the structured-interviews can be divided into four different topics: 1) The impression of the AR *paper tiger*; 2) If the application managed to fulfill the purpose; 3) Thoughts about having a whole panel highlighted versus having each button highlighted; and 4) Thoughts about using the AR *paper tiger*.

Twenty-two students were positive, one was negative and four were neutral. When they were asked how they found the application, they expressed comments like "*Fun!*", "*Great learning method!*", "*different but fun way to learn.*" One student expressed it as "*more realistic than the paper tiger.*"

All students thought that the application managed to fulfill its purpose. Six of them also mentioned that it will help them to train their muscle memory.

Regarding thoughts about having the whole panel highlighted versus having each button highlighted, fourteen of the students would like to have the whole panel highlighted while thirteen would prefer to have each item highlighted.

Twenty-one of the students would consider using the application as it is and six of them could consider to use it if it was more complete. None of them expressed that this was a bad idea.

5 Discussion

In this section, we will discuss the "take-aways" from the evaluation, developing the AR *paper-tiger*. Finally, we will reflect on the benefits of AR and possible improvements of the AR *paper-tiger*.

5.1 Evaluation

The data from the evaluation suggests that AR could be a valuable tool for learning procedural flows. Overall, the AR *paper tiger* received acceptable scores on both the NASA TLX and the SUS questionnaire, which indicates that the participants were able to complete the experiment reasonably well.

Similar effects as the study by Macchiarella and Vincenzi [15] can be found in our study regarding using AR as a learning tool to recall a task. After using the AR *paper tiger*, the pilot students could recall 73% of the fifteen steps in the correct order.

NASA TLX. Despite the fact that the pilot students had none or very little experience of the real *paper tiger*, the pilot students had very good mean values. This indicates that the idea of using an interactive AR *paper tiger* as a learning tool seems to have good potential. Two interesting values from the NASA TLX subscore are the physical median value which was lowest (see Fig. 1) and the mental median value which was the second-highest value (see Fig. 1). Despite the HoloLens requiring physical movements of the participant's arm when interacting, the perceived mental workload was higher. One reason for this might be the small field of view of the HoloLens, which forced the participants to look around and made it difficult to have an overview of the whole user interface at the same time.

SUS. The AR prototype had a SUS score larger than 68, which is considered to be above average [4]. The SUS score measures cognitive attributes such as learnability and perceived ease of use, the result indicates that the AR *paper tiger* is considered to be easy to use, and easy to learn.

The Structured Interview. All students reacted to the AR *paper tiger* in a positive manner and could see the potential of the application. However, comments that could be considered as negative were mostly directed towards the Microsoft HoloLens. The new version of this headset has been improved in several areas such as the field of view and gestures used for input and may thus alleviate some of the expressed concerns.

5.2 The AR Paper Tiger

In this section, the benefits of AR and improvements are discussed.

Benefits of AR. One major benefit of using AR when training the procedure to prepare for takeoff is the ability to have an interactive paper tiger which augments the panels and helps the pilot students to find the correct panel and perform the actions in the correct order. Another advantage in the HoloLens is the fact that you can see yourself and especially your hand in the AR application. This also enables you to see and communicate with a copilot as well as seeing and working with real physical operation manuals or checklists in your own or your copilot's hand. Moreover, the AR version is mobile and can easily be used in another place. Currently, a pilot student has to use the physical *paper tiger* which is limited to be used at a fixed location for example in the practice room at LUSA which can be seen in Fig. 1. Similarly, the setup could be developed using a VR headset. Current VR headsets have several advantages such as better field of view, more accurate tracking, and a higher display resolution than the HoloLens. However, an important feature which the VR headset cannot offer (at least for now) is the interaction and communication with a copilot and using the physical operation manual or checklists. One can ask how important are these features, maybe using an avatar and virtual operation manuals are good enough but to be sure further studies need to be done. For example, it would be interesting to follow up on this study, with another when which would investigate the pros and cons of the real *paper tiger*, the AR *paper tiger* and a VR *paper tiger*.

The biggest contribution with the developed prototype of an AR *paper tiger* is the ability to choose different scenarios. While using the application you can see a demo of the flow, or interactively receive flow guidance, with the purpose to learn the flow pattern in the cockpit. In our case, we began with a general scan flow to demonstrate the spatial structure of a scanning flow, which you interactively can click your way through. Our solution allows for a potential merge between the source of knowledge - the manual, the practice interface, and the real *paper tiger*. This starting point forms a very good structure for future developments toward even more interactive possibilities for learning.

Further Research. In this section, different improvements or ideas for other projects in the area are described and discussed.

The AR *paper tiger* could be further expanded in many ways to enhance the experience when using the simulator. Panel screens could be animated as well as the surroundings e.g. moving clouds and changing light conditions. Panel lights could be turned on or off, based on what flow the user is training.

Depending on the user's knowledge, different levels of interaction could be added. For example, if the user is a total novice, it could be enough to demo the flow and the user can then be requested to do the flow in a simplified manner, much like the prototype presented in this paper. However, if the user is more advanced, as shown during testing of the prototype, there is a need for more interactive features in the AR *paper tiger*. This could be lights going on and off on the panels and thus allowing the student to follow the flow in a detailed manner.

Having detailed 3D models of the panels would make it possible to use the instruments (knobs) on the panels, thus giving the ability to change values on panel screens in a realistic manner. If the user is able to turn knobs, the AR *paper tiger* can check values against recommended values and then pass or fail a user based on the set values. However, this would not be the same as flow training, this would be more detailed. For a full version of the AR *paper tiger*, there would be a lot more flows available to train on, approximately eighteen, with a menu where the user would be able to choose desired flow.

Another flow which AR is suitable for is the *walk-around flow*. Similar to the flows in the cockpit, are the flows that a pilot does before stepping into the aircraft. The idea is to emulate a plane for a "walk-around", which is an outside check of an aircraft. The pilot checks that everything, for example, control surfaces and tires are as they should. By using a 3D model of an aircraft this could be practiced anywhere using AR, and of course, the model would be able to re-scale and rotate. This can be further developed by adding random variables such as ice or a birds nest in the jet engine that the pilot should notice and handle.

All in all, the improved application could offer a playful and enriching environment and at the same time equip the pilot student with the relevant knowledge needed to be as prepared as possible before the costly and very time-pressured full flight simulator training.

Seen from a broad perspective, the application could potentially be valuable also for Commercial Pilot Licence (CPL) flight training where practice in a real simulator is even less than in the Multi Pilot Licence (MPL) concept, and the time in the paper tiger is shorter. A further developed application could also bridge to the Jet Orientation Course (JOC) or even a type-rating.

6 Conclusion

The contribution of this paper is a novel way of using AR to train pilot students' flow patterns. At the present time, the developed product could be used mainly for early familiarization and introduction to a normal *paper tiger* as well as an introduction to the concept of flows. More development and interactive features are needed for any further applications. All pilot students evaluated the AR *paper tiger* positively and could see the potential of the application. The results indicate that the AR *paper tiger* has the potential to be helpful for pilot students for the process of learning flow patterns.

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