Designing Touch-Enabled Electronic Flight Bags in SAR Helicopter Operations

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ABSTRACT

In order to benefit from potential reduced operational costs and crew workload airlines are increasingly interested in touchscreen-based Electronic Flight Bags (EFB). This paper focuses on the specific domain of Search and Rescue (SAR) Helicopters. A first set of results aiming to explore and understand potential benefits and challenges of an EFB in a SAR environment will be presented. A review of related work, operational observations and interviews with pilots were conducted to understand and specify the use context. Digital Human Modelling (DHM) software was used to determine physical constraints of an EFB in this type of flight deck. A scenario was developed which will be used in future to define features, content and functionality that a SAR pilot may wish to see in an EFB. Developed initial interface design guidelines are presented.

KEYWORDS

Electronic Flight Bag, Touch Screen, Search and Rescue, Digital Human Modelling, Human Centred Design

INTRODUCTION

In a flight deck with analogue instruments; airspeed, altitude, altimeter, heading and vertical speed indicator are separate devices. Digital technology is able to consolidate all this information on a single display called Primary Flight Display (PFD). Touchscreen technology offers the ability to both control and display avionics systems through the same device. The avionics industry is seeking to understand the challenges and benefits of touchscreens on flight decks. Major companies like Thales [45], Rockwell Collins [16], Honeywell [21] and GE Aviation are working on future flight deck designs with touchscreens.

Air carrier operators have recognised the benefits and adopted mobile Electronic Flight Bags (EFBs). In 2011, the Federal Aviation Administration (FAA) has authorised to use Apple iPad as an EFB. Mobile EFBs enable pilots to perform a variety of tasks by freeing the workspace almost entirely from paperwork. American Airlines estimates that replacing the 18 kg flight bag with a 600 gram tablet device will save more than 400.000 gallons of fuel per year [22].

Commercial flights are performed under instrument flight rules (IFR). Except at take-off and landing (2% of the entire flight [43]) pilots are not relying on looking outside. In contrast, Search and Rescue (SAR) and law enforcement operations requires actively looking outside for targets. Touchscreens request users to focus solely on the display which may be acceptable for IFR flights. However, it is likely that this fact will be a significant trade-off against the potential benefits of touchscreens. The effect of vibration and turbulence could be significantly higher in a helicopter, which would make interacting with touchscreens more difficult.

Spanish Maritime Safety Agency (SASEMAR) collaborated in this research project. Air bases were visited to understand how EFBs might be used within this context. On the basis of operational observations and interviews with pilots a scenario was developed to understand how pilots wish to benefit from an EFB. Digital Human Modelling (DHM) software was used to define physical aspects of an EFB. In addition, this paper provides initial design guidelines and recommendations for touch enabled EFBs.

BACKGROUND

The relevant background is reviewed in two sections. First hardware and software categories of EFBs are summarised. Then, related academic work is reviewed.

Electronic Flight Bags

The FAA categorised EFBs (Hardware) in three different groups [14]:

- An EFB Class 1 is a portable device that is not attached to any aircraft-mounted device. Any data connectivity to the aircraft system is forbidden, and it is not a part of the aircraft configuration. Therefore, a Class 1 device does not require airworthiness approval.
- EFB Class 2 is also portable. However, it requires a dedicated mounting device. This kind of equipment may have limited data connectivity. Airworthiness

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approval is needed for some physical aspects (e.g. mounting, connections and antennae).

- EFB Class 3 is fully integrated (fixed) into the aircraft flight compartments and systems. It requires an airworthiness approval via a type certification.

Applications (or software) that run on EFBs are defined by their functionality. The three levels of functionality are summarised below:

- Type A software are static applications such as document viewer for aeronautical data (maps, charts, manuals, checklists and NOTAM)
- Type B software include dynamic interactive applications which, could perform various calculations and are able to zoom, pan, and scroll approach charts (to display own-ship position requires further approvals). It has the permission to receive (or update) weather information. An authorised person should validate such applications.
- Type C software can display own-ship position on charts. This kind of application must run on EFB Class 3, therefore a type certification via airworthiness approval is required.

Most airlines prefer class 1 or 2 devices because they are cheaper and easier to deploy. American Airlines (AA) was the first major commercial air carrier that integrated mobile EFBs. The software [36], used by AA, has the following features: Enroute charts and airport diagrams (displays own-ship position), arrival, departure and approach procedures and change notifications (terminal and enroute).

Related Work

Some findings by scientific research about touchscreens in general are worth reviewing for this application area. Comparisons and measurements demonstrated reduced cognitive effort, workload, search time, motor movement and hand-eye coordination problems [28, 39, 41]. Since the input and output (zero displacement) occur in the same location, interaction has been found to be intuitive [26] [2].

EFB's could remove hard copies from the flight deck, which means savings in space, weight and costs. In addition, it is reported that searching, updating of documents, checklist completion and performance calculations can be done quickly and more accurately [17, 32, 38]. Using a mobile device has the flexibility to adjust the position and view angle to achieve maximum usability. Software may provide intuitive zoom interaction and the possibility to de-clutter charts [9].

One of the biggest drawback of touchscreen is accidental (or unwanted) touch and unclear positions of touchable areas [12]. Touchscreen interaction require users to focus solely on the screen. Observations showed that controlling through touchscreen disrupted the primary flying task [32]. Early research [2, 12, 32] stated poor computing power, response time and display update rate, which can be neglected by the current state of technology. Absence of tactile and aural feedback can be ignored as well because, EFBs are replacing (primarily) paper and not hard controls (e.g. rotating buttons and knobs). Fatigue due to extending arms is reduced because portable EFB's are mostly attached on kneeboards or jokes (inside the "zone of convenient reach").

Mobile EFBs are mostly attached to the kneeboard. Generated heat by the device could have a negative impact on comfort [9]. Small screens have been shown to increase information retrieval time and workload significantly [17]. Further, there are potential economic and safety risks reported for both suppliers of hardware and software. These suppliers may exit the business after experiencing litigation. Airlines would depend on devices, which become obsolete rapidly. EFB systems need to be protected from possible contamination from external viruses [44] [42].

Boeing and Airbus have slightly different flight deck design philosophies. However, there is a general agreement that the flight crew is and will remain responsible for the safety of the airplane [27]. Two-thirds of fatal accidents are caused by human error [10]. Johnstone summarized 11 reports where the use of an EFB has been cited as being a causal or contributing factor for the incidents. These incidents are caused mainly due to human error [25], which makes designing a usable interface more important.

Potential benefits of applying human centred design philosophy (Figure 1) are reduced number of errors, and increased ease of use and learning. ISO 9241-210 [23] defines human-centred design as "an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques".

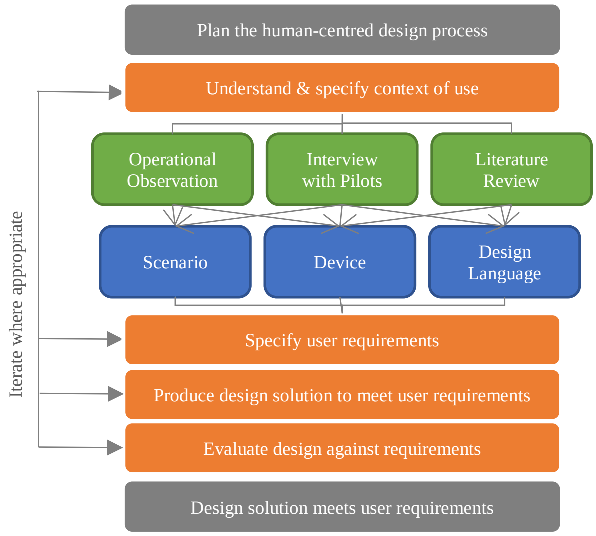

Figure 1. Human-Centred Design Process (based on ISO 9241-210 [23]).

METHOD

Figure 1 illustrates the human-centred design approach of this research which is based on ISO 9241-210 standards. There are four user centred activities (marked in orange). Spanish Maritime Safety Agency (known as SASEMAR) facilities were visited with the aim to understand the context of use and to define potential application area of an EFB. The investigator was accompanied by pilots and other crew members (rescue swimmer, hoist operator, mechanics and ground operators). The daily routine of pilots was observed on the ground as well as during operations. In order to inform design requirements semi-structured interviews with pilots were conducted to understand their tasks and to define their expectations from an EFB.

As shown on Figure 1, interviews and inflight observations were used to create future scenarios and to define physical measurements of the EFB. Interface design language guidelines were created based on information from the literature review and interviews with pilots. The following section will describe the operational observations which should help the reader to get an insight view about how SAR operations are currently conducted.

Operational Observation

SASEMAR have 11 helicopter bases alongside the Spanish coast. Each Search and Rescue (SAR) group consist of air and ground units. Air units conduct the operations and ground units maintain the helicopters for safe operation.

Crews are operating on 12-hour shifts. There are 4 crew members operating the helicopter: 2 pilots, one hoist operator and one rescue swimmer. During shift change both crews (current and next crew) have usually an informal conversation about the state of the aircraft.

The first thing that pilots are doing is to check the weather and NOTAM’s in their responsibility area. Crews that have not a scheduled training flight are on standby until they are called for a mission. Once, a distress message reaches the responsible maritime rescue coordination centre (MRCC), pilots will be contacted via mobile phone.

The MRCC provide the coordinates of the target. If there is an uncertainty about the exact position of the target, the crew have to search the estimated area. The MRCC send the search plan via email to the pilots.

Pilots check different weather reports from the destination area. If they are searching for a vessel and they know its name, they look for its picture online. It was noticeable that pilots have to visit various websites to gather all required information. In addition, they decide what kind of SAR equipment they going to use during the operation. After the flight plan is created and the amount of required fuel is calculated, pilots perform the weight and balance calculation.

Once the mission preparation is finished the captain of the flight performs a mission briefing to all crew members. After the briefing crew members require approximately 5 minutes to prepare themselves for the mission. In the meantime, ground units pull out the helicopter from the hangar. In a real mission the time between first call and take-off is approximately 15 minutes.

While pilots perform pre-flight checklist, the hoist operator checks the winch and the rescue swimmer his equipment. Once the engines run pilots require approximately 4-5 minutes to take-off. Before take-off the co-pilot uses the Flight Management System (FMS) to create the flight plan and requests clearance for take-off from the Air Traffic Controller (ATC).

Once in the air (1500-2000 feet above ground level), the crew flies with maximum cruise speed (120-130 IAS) to the target location. The co-pilot performs the after take-off checklist. On scene, targets could be small and moving objects, such as a missing person or vessel. It could be the case that helicopters have to operate in challenging areas (sea or forest) and weather conditions.

The captain informs the cabin crew approximately 10 minutes before they arrive at the target location. If the position is known, the helicopter flies directly to the target and contact the vessel; if not, the pilot head to the first waypoint of the search pattern and start to search. The search is conducted visually. Additionally, the cabin crew can use and control the FLIR camera. Pilots can mirror the imagery on their centre display.

Once the target is spotted, the co-pilot initiates the appropriate checklist. The captain slows down and transits from cruise to hover. Once the aircraft is in hover, pilots require in average 3 minutes to position the aircraft close to the target. The hoist operator opens the door and talks with the pilot to make fine adjustments. It is also possible that the hoist operator takes full control over the aircraft and positions the aircraft by using his controller.

The rescue swimmer may be connected to the winch and lowered to the target. After that the rescue equipment is lowered. The rescue swimmer uses this equipment to secure the person to be rescued. In a training mission 2 or 3 possible scenarios will be simulated.

After the rescue mission is completed the pilot transits to cruise and fly directly to the airport. Before they approach the airport, the co-pilot initiates the approach checklist and contacts the ATC to request clearance to land. The approach chart of the airport is reviewed before landing. The helicopter lands on the airport and taxis towards the hanger. In a real mission, the crew transport the person into an ambulance.

After the mission there is a debriefing session where the crew discuss the mission. Crew members share their ideas and provide constructive criticism of the mission procedure. Unusual circumstances during operation, operations which do not confirm to the manuals and procedures, and potential improvements are discussed.

After that, pilots have to do some paperwork for approximately 40 minutes. They have to fill out reports for INAER (provider of aerial emergency service and aircraft maintenance), SASEMAR, and aircraft, engine and personal logbook. Required information is similar and will be duplicated in different documents.

Interviews with Pilots

Operational requirements and expectations were unknown at the beginning; therefore, semi-structured interviews were performed to get deep insight and understanding of the operations [30]. There were always two pilots on duty and interviews were conducted with both pilots at the same time. Eight male pilots participated in the interviews. At that time SASEMAR had 3 female pilots (out of 110), which were not on duty. Participants age ranged from 32 to 47 (M=40, SD=6.2). Logged flight hours ranged from 3500 to 6000 (M=4500, SD=1200). Questions and answers are below;

- What are your opinions about future flight deck designs with touchscreens?
- Do you think they are suitable for SAR operations?

Future flight deck concepts (e.g. [45] [16] and [21]) with touchscreen were exposed to pilots. The majority of pilots were sceptical about general (fixed and mobile displays) touchscreen integration and pointed out a potential threat that was mentioned during the literature review. The nature of touchscreen usage requires pilots to look at the device while interacting with it. As stated in in the previous section, pilots perform search visually and looking at the touchscreen inside the flight deck would decrease the search performance. One of the pilots stated that pilots were able to learn the patterns of an analogue interface (hard controls like, buttons and switches). Digital systems are lot easier in design but less efficient in use compared to the analogue system. Pilots were able to interact with the device without looking at it, which is not possible with a touchscreen.

- Do you use a mobile device on the ground or during operation?
- If yes, why are you using a mobile device and what sort of task are you performing?
- If not, would you like to use one?

Two pilots use a tablet device to conduct various tasks. These are; checking weather and NOTAMs, executing checklists and searching approach charts. Both pilots reported that they have few colleagues who use a mobile device, as well. Pilots who do not use currently a mobile device would prefer to use a mobile device in the future. Keeping all important information in one place and having fast access to desired information were the main reason why pilots use/or would prefer to use a mobile device.

- What should be the physical size of the EFB on the flight deck, so it does not disrupt your primary task?
- How are you using the EFB currently?
- What problems are you facing with EFBs and how can be these addressed?

The size of the devices used by pilots range from 8 to 10 inch. The investigator showed 7, 8 and 10 inch tablets to pilots not using a mobile device and asked which device they would prefer during the flight and why? Pilots stated that there are periods where they experience high vibrations in the aircraft, especially in transition phases. Thus, retrieving information from the head down displays is difficult. Therefore, the majority of pilots' opinion was that a 7-inch tablet could be too small to see/read information in a helicopter. Since, the device is relatively small, consequently information (font size) will be small as well. A 10-inch tablet would be good for information retrieval however some pilots pointed out that this device might be too large and heavy for use in a cockpit, especially when pilots would use it on their knee. Pilots predicted that the optimal screen size will be between 8 and 10 inch.

There is no dedicated mounting device for EFBs on the flight deck to which pilots can attach the tablet. Pilots who use a device, strap their EFBs to their knee. Both pilots who already use a mobile EFB and pilots who said they would like to use one stated a common requirement. They expected that a portable EFB maximises screen area while minimising overall weight. It should also fit properly onto the knee, while there should be room on the thigh to rest the arms. As shown on Figure 2 the captain holds the stick with his right hand while resting both arms on his thighs. The cyclic control stick is between the feet of the pilot. The tablet must not reduce the controllability of the cyclic.

Figure 2. Cockpit view of AW139.

Pilots who use a tablet during the operation mentioned that heat generated by the tablet causes discomfort. Another common mention was that the angle of tablets strapped directly to the leg is not ideal, and that sun light can produce glare. They recommended the design of a kneeboard that pilots are able to tilt up the tablet, while preventing heat transformation. Some pilots requested that the tablet should be easily removable if the device is not used or if the pilot wants to show something on the EFB to his co-pilot. The captain is likely to strap the EFB to his left knee, because he is the flying pilot and he keeps his right hand on the cyclic stick. So if parallel usage is required pilots are likely to strap it to their left knee. The co-pilot has a little bit more freedom because he is not interacting with aircraft controls as much as the flying pilot. It was predicted by avionics experts that pilots would strap the EFB to the left knee, since the left hand would be used infrequently. However, considering that approximately 10% of the population is left-handed [19] there will be pilots who will prefer the right knee, to facilitate usage with their preferred hand.

Another observation which was made and stated by pilots was that pilots interacting with the aircraft system (e.g. Flight Management System (FMS)) rest (or stabilise) their hands while inputting data. This can be also seen on Figure 2; the co-pilot is interacting with FMS. To minimize the effect of vibration and turbulence, pilots may hold stabilise the EFB with their hand and operate it with their thumb.

- Which environmental factors could impede usability?

Pilots stated that in-flight vibrations and weather could impede touchscreen usability. Pilots categorized in-flight vibrations in helicopters in three categories; cruise, transition and hover. Transition down to hover phases generate the highest vibrations on the aircraft. In comparison, vibrations during cruise and however are smaller. Especially, in winter months' pilots have to operate in challenging environments (e.g. turbulences, thunder storms). Sudden movements within the aircraft can cause accidental and unwanted touches. To avoid unwanted touches or touch by accident due to inflight vibrations, pilots recommended a pressure sensitive touchscreen, where pilots have to apply a certain amount of force on the interactive element to activate it.

Discussions between pilots revealed that the display position might also influence the performance. Pilots said that it would be more difficult in a helicopter to interact with a fixed display where the pilot has to extend his arm to reach the display.

The majority of SASEMAR pilots have a military background. Two pilots stated another environmental factor which rarely occurs in a helicopter but more frequently in fast jet aircrafts. Pilots identified increased G-Force that occur during steep turns as a potential threat that could impede touchscreen usability. Pilots recommended to investigate these environmental factors and consider it in the design process.

- How should be the interface design?

All pilots expressed the desire for an easy to use and intuitive interface design. The EFB must not distract pilots. Colours and animations should be thoroughly investigated. The number of buttons on display area should be minimised to avoid clutter. Navigation through the app should be intuitive and the number of control inputs required to get to the required command should be minimised. The font size and the size of interactive elements should be appropriately large because vibrations in a helicopter could be higher compared to a fixed wing aircraft. Another pilot stated that they created the checklist using 14 pt font because they could not read the checklist in high turbulent environments. This is substantially larger than the recommended font size, which is about 8 pt [47]. In high vibration and turbulence phases pilots face difficulties in retrieving data from head down displays.

- Which features and functionality would you prefer?

Some available tablet applications were demonstrated to pilots. We asked pilots to list features and functionality they would like to have on an EFB. The most wanted features were i) performing checklist, ii) weight and balance calculations, iii) download mission related information, iv) upload the flight plan to aircraft system, v) searching approach plates, and vi) to use the tablet to fill the paperwork after the mission.

The last part of the interview was separated into three sections; pre-flight, in-flight and post-flight. It was requested to describe the pre-flight tasks they have to complete on a daily basis, then, to list the tasks that can be done via a mobile device. This part of the interview was mostly a conversation between pilots where they discussed the features and functionalities they would like to see on an EFB. The investigator asked additional questions to clarify their thoughts. This was repeated for in-flight and post-flight tasks. The outcome of these interviews were used to create a scenario describing the daily routine of a pilot who use a mobile EFB.

SCENARIO

The aim of the scenario is to figure out the features, content and functionality that pilots would like to see in a tablet app. The scenario describes the daily life of SAR pilots in a narrative. The task is to mark the point where pilots think it will improve the overall operation. Features are incorporated in the story are listed below:

Anthony is a SAR pilot based in Valencia. He has an EFB where he can perform various tasks before, during and after the flight

Pre-Flight

Anthony's working day starts with checking the state of the aircraft. He has access to aircraft, engine and personal logbooks. The app has also flight rostering capabilities where Anthony can check his upcoming duty times and periods. He checks the NOTAM, TAF, METAR and SIGMET reports and the forecast. Once, he finished his daily routine he receives a mission alert from the responsible MRCC reporting a vessel in distress. He confirms receipt and start with mission preparation.

Anthony tells his crew members that there is a mission briefing in 10 minutes. He downloads the mission file, which includes information about type of mission, target position, number of person, search type and area. The EFB automatically creates a flight plan directly to the target location (including search pattern). He is able to modify the flight plan by adding waypoints. The system calculates and updates Weight & Balance and Performance calculations automatically if a flight plan modification is conducted. The app is set to default (4 crew members and full tank). The pilot adds the weight of SAR equipment and other equipment's to the weight and balance calculations. The pilot retrieves weather information from target location. The last point is to complete the SAR mission form, which is already partially prefilled by the system using the mission file. The app creates a briefing presentation to all crew members. It is possible to share briefing information or mirror the screen of the EFB to a bigger screen (TV). After the briefing the pilot will tell how much time crew members have to prepare themselves. The device stores all required information and updates it in frequent intervals (e.g. every 30 minutes).

In-Flight

Both pilots have access to all types of checklists. The device is communicating with the aircraft system and auto-check it once a task is accomplished. In addition to that he has access to various documents (QRH, POH or IAMSAR Manual). Anthony uploads the flight plan from his tablet to the aircraft system. It shows the own ship position on different maps (aerial, street, VFR and IFR). Anthony uses his tablet as a scratchpad to take note of the clearances received from the ATC. The system has hand writing recognition which offers the possibility to send data (speed, altitude, heading, coordinates and frequencies) to the aircraft system.

During the flight the pilot can use his tablet as an additional display and is able to mirror PFD, MFD, FLIR and RADAR Displays. Anthony is able communicate, send and receive information from MRCC through his device. He can record specific time stamps (engine start, take off, time on scene, search start and finished, mission completed, landing and engine shut down) which are required afterwards for paperwork. It is also possible to control avionic systems through the device (VOR, NDB, COM, Autopilot). The EFB has the ability to record video footage via FLIR or device camera. The crew found the target and the rescue mission started.

Anthony updates his Weight and Balance calculations after the hoist operation and creates a new flight to the destination airport. The system has also a library with various points of interests (like Hospitals or areas with Helipads). The system updates the performance data, distance, times and potential fuel usage. Anthony reports the estimated time of arrival to ground units. He has access to approach plates and review the approach plate of the airport before landing.

Post-Flight

The crew enters the room for debriefing. The EFB recorded the path of aircraft for debriefing and for further analyses. It creates a presentation for debriefing where the crew can go through different steps. After the briefing pilots complete the pre-filled paperwork and send it to authorities.

DEVICE

A Digital Human Modelling (DHM) software package was used as a supporting tool for hardware selection and design. Project expectations of the DHM package were:

- Integrated anthropometric databases
- Mannequin posture database and modification
- Field of view and reach envelope capability
- Import of Computer Aided Design (CAD) files

A comparative analysis of DHM tools [35] yielded JACK from Siemens [24] as a suitable solution for this particular project. CAD files to be imported were generated with SolidWorks.

Physical expectations from a portable EFB are maximised screen real estate, while minimising overall weight. It should fit properly onto the knee and there should be room on the thigh to rest the arms. Strapping the EFB to the knee is likely to have advantages, such as reducing fatigue (pilots could use their legs to support their arms), improving accessibility (the EFB would be within the zone of convenient reach [34]), and interacting with one hand, while the other keeps the aircraft under control.

Figure 3 shows relaxed seating posture replicated from [37] (except arm and hand position). The blue rectangle defines the recommended surface area (RSA) for potential EFB's. The length (L) is defined from the fingertip to the knee and the width (W) is the width of the knee.

Universal design approach (design for adjustable range) was selected with the aim to achieve minimum fatigue, optimum performance, improved comfort and safety [18].

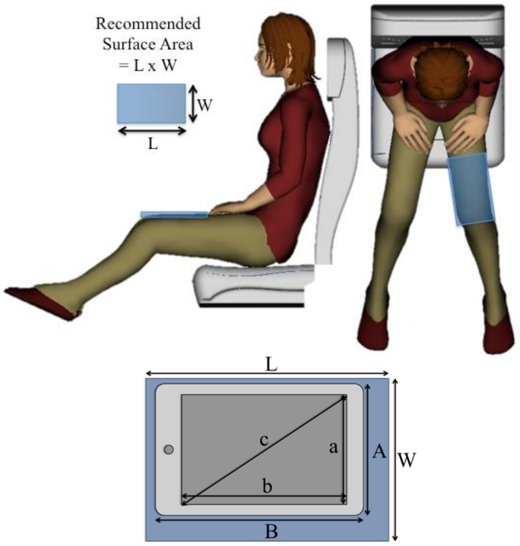

Figure 3. Relaxed seating posture.

EFB's are (currently) not safety critical for the operation, so the design limits are established as 5th percentile values for females and 95th percentile values for males. At this point it is worth to repeat that SASEMAR has three female pilots (out of 110). The device would be comfortable to use for the majority (95%) of pilots if it fits to the smallest pilot's knee (5th percentile female).

Integrated anthropometric databases in Jack are: Canadian Land Forces (1997), ANSUR – United States Army Anthropometry Survey (1988), Asian – Indian Database, Ahmedabad, National Institute of Design (1997), German Anthropometric Database, DIN 33402: German Industry Standard (2008), NA_Auto - North American automotive working population, NHANES - National Health and Nutrition Examination Survey (1990) and Chinese adults, report: GB 10000-88 (1989).

The conducted research spans 20 years between the oldest and most recent work. The secular growth in stature per decade for the USA is 10 mm and for Germany is 11.5 mm [1, 31]. The German database will be used for further analysis because all other sources can be considered as out-of-date. In addition, field trials will be performed with Spanish pilots, and the German data is therefore more likely to represent these more accurately due to closer geographic location.

By accounting for the additive effect of clothing in real world usage [1] RSA values are (L) 223 mm and (W) 142 mm. Suitable devices will be evaluated as followed: all tablet devices which are currently available on the market will be listed, devices that achieve the highest screen area to weight ratio will be selected. The final point is to calculate how well the short listed devices would fit into the recommended surface area (RSA).

101 tablet devices released since June 2013 were analysed. The screen size ranged from 5 inch (127 mm) to 18.4 inch (467 mm). Manufacturers generally supply information about the screen size (see Figure 3 – length c), resolution (length a and b in pixel) and weight. These data were used to calculate the screen area/weight ratio (mm^2/g).

The recommended minimum screen size for an EFB is 200 mm (or 7.9 inch measured diagonally) [11], which was considered in the next assessment. 8 Tablet devices that produced the best results in the previous calculation were used for the final evaluation.

The projected surface areas of tablets, were divided by the RSA. The result should be less or in ideal case equal to 1. Results are given in Table 1.

Table 1 Suitable Devices for EFB Application

Model	A (mm)	B (mm)	%
ASUS Transformer T90	137	241	1.04
Google HTC Nexus 9	153	228	1.10
Samsung Tab 4 8.0	124	210	0.82
Apple iPad Air 2 9.7	170	240	1.29
Apple iPad Mini 7.9	135	203	0.87
LG G Pad 8.3	127	217	0.87
Samsung TabPro 8.4	128	219	0.89
Samsung TabPro 10.1	171	243	1.31

Samsung GalaxyTabPro 8.4 (Aspect Ratio (AR) 16:10) was the device, which came closest to the ideal value (89%). Predictably, a device with an AR of 16:10 fits better into the RSA since the AR of the RSA is 1.57 (223/142). The next bigger available device is the ASUS transformer T90 Chi with an 8.9-inch display. The length of the device is longer than recommended in RSA. However, the width of the device is more critical because it could collide with the cyclic stick. On the other hand, Samsung GalaxyTabPro 8.4 (290 gram) is 18% lighter than ASUS Transformer. Other devices which seem to be suitable as well are the Apple iPad mini (which is used by some SASEMAR pilots) and the LG G Pad. This simulation confirmed pilots' prediction that the ideal size for a EFB is between 8 and 10 inch.

Another physical consideration is the position of the EFB on the knee. Ideally, the screen surface of the device should be approximately perpendicular to the pilot's line of sight [34].

For both extreme cases (95th % male & 5th % female) recommended angle between the thigh-line and EFB is ~ 30° (Figure 4). Figure 5 shows the improved readability with adjusted EFB angle.

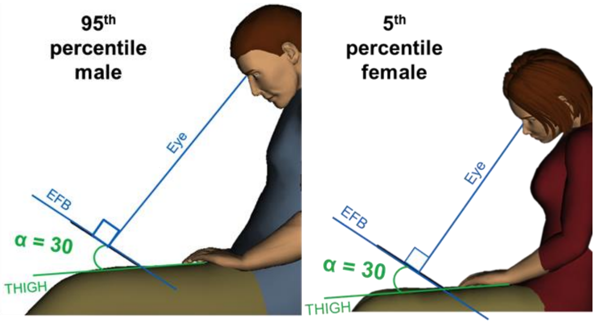

Figure 4. Recommended angle between Thigh-Line & EFB.

Figure 5. Improved EFB Position on the knee.

Functional Area of the Thumb

Not all of the display surface can be reached with the thumb of the hand that holds the device. Users change or adjust the grip frequently. The functional area of the thumb can be modelled with various approaches [8].

In this particular case it is easier to model the functional area of the thumb, since the device is supported by the knee. Pilots could use the edge to stabilize their hand and can move freely alongside the vertical axis.

Figure 6 shows different hand postures for one handed operation (modelled on an Apple iPad Mini). A 5th percentile female could reach interactive elements up to 51 mm away from the display edge. In addition, it shows the recommended area where the majority of interactive elements should be placed. This will ensure permanent support of the hand, less posture change and enhanced one handed operation. For right hand operation interactive elements should be placed on the opposite edge.

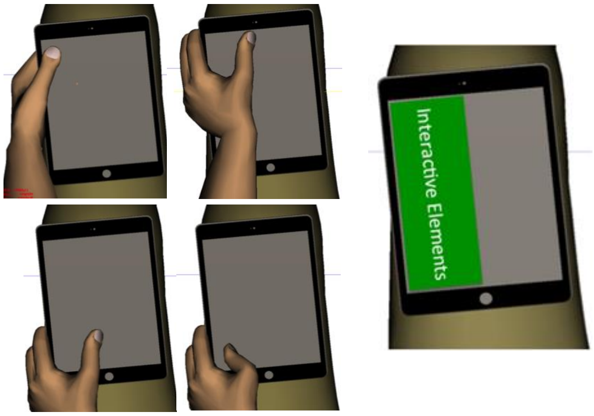

Figure 6. Reachable areas for one handed operation.

INTERFACE DESIGN GUIDELINES

Initial design guidelines were created on the basis of the information gathered from operational observations, interviews with pilots and a review of related work.

The most important point might be the need for ease of use during high vibrations. An inflight experiment was conducted over a duration of one month with 14 crew members [7]. The goal was to understand how to design effective touchscreen interfaces so they are ultimately usable by pilots. Findings suggest that 15 mm targets (size of interactive area or button size) are sufficiently large for non-safety critical Electronic Flight Bag (EFB) applications. The expected error rate during high vibrations is 3% (likely to occur during transition phases). Further, the interface should be usable with one hand. From video recordings it was noticeable that pilots support their hand by grasping the device and using their index finger or thumb to interact with the screen. It is recommended to place interactive areas within the recommend area, as shown on Figure 6. Another study revealed [29] that depending on which finger is used has a significant effect on speed and accuracy. Pilots are likely to use their EFBs with their left hand. The majority of the population is right handed. A lab study [6] revealed that there is a significant difference in error rates and movement time between dominant and non-dominant hand. Target size (button size) is the most significant factor, which may be utilized to minimize other degrading factors by selecting an appropriate target size. Thus, 15 mm targets could be large enough to eliminate other degrading factors. As requested by pilots, the number of interactions to get the desired command should be minimised.

Pilots identified increased G-Force as a potential threat for touchscreen usability. An initial lab study [4] and a field study [33] revealed that increased G-Force has a large impact on touchscreen usability which should be considered in the design process.

Another recommendation was to have pressure activated touchscreens to avoid unwanted or accidental touches. Compared to capacitive displays, which are contact activated, on displays with resistive touch technology users have to apply a certain amount of force on interactive elements to activate it. Recently, Apple introduced a new technology called 3D-Touch, which could measure the force applied to the display. Setting a force limit to activate interactive areas could eliminate errors caused by accidental touches.

The use of colours and animations on the user interface should be thoroughly investigated. The main reason for using colours is to distinguish and group information on a dense (cluttered) display area [20]. To avoid clutter on display area menus, selection and dialogue boxed should be hidden until required. Normal aging of the eye and colour blindness should be considered. Colours should be standardized and consistent with other displays. It is recommended not to use more than 6 colours [15]. It is predictable that the EFB will be subordinated in the cockpit. It is expected that pilots will interact with other avionic systems like PFD, MFD and FMS more than with the EFB. Therefore, it is recommended to apply grayscale in a pronounced form and add colour for feedback (or alerting) purposes.

Today's operating systems use more symbols and icons in their interface design (see iOS and Android OS). Research showed that icons can be easily recognised and remembered [48]. Compared to text (only) there is a possibility that icons lead to faster recognition [40]. Icons can reduce the necessity of reading and save space [46]. Icons may support the learning of a system [3].

To achieve these benefits icons must be immediately recognisable by the targeted user population [13]. Interpreting icons depends on factors like type of software application, text labels and the user's familiarity with the icons [46]. Confusion may result if the user is unfamiliar with the icons [20]. Labelled icons reduce the risk for wrong interpretations and may significantly increase the usability [48]. Therefore, it is recommended to label icons.

Findings from this study and other related studies were used to create a framework [5] showing the relation between various aspects that could impact the usability of touchscreens (fixed and mobile) on the flight deck.

FUTURE WORK

In future work, further required features, content and functionality will be determined from the generated scenario and further discussions. A card-sorting experiment will be conducted with pilots to group and categorise elements of the EFB application. The outcome of this experiment will be used to create the information architecture which can be evaluated with tree testing.

The scenario will be described with aid of a prototype (shown on a tablet that meets the requirements), which is designed as recommended in the previous chapter. This should support the understanding of the scenario and offer the opportunity to evaluate whether the interface design meets user requirements.

After the second visit the first two activities (understand and specify context and use and specify user requirements) of human-centred design approach is completed. After that it will be a back and forth procedure between designing solutions to meet user requirements and evaluating it. Rather than creating the complete app in one go and evaluating it, each bit (feature or page) will be prototyped and evaluated step by step. Prototypes will be shared online and usability tests (like first click test or task test) will be conducted.

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