Dedicated to innovation in aerospace

NLR-TP-2017-549 | February 2018

Innovative cockpit touch screen HMI design using Direct Manipulation

CUSTOMER: Netherlands Aerospace Centre

NLR – Netherlands Aerospace Centre

Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and integral solutions for the complex challenges in the aerospace sector.

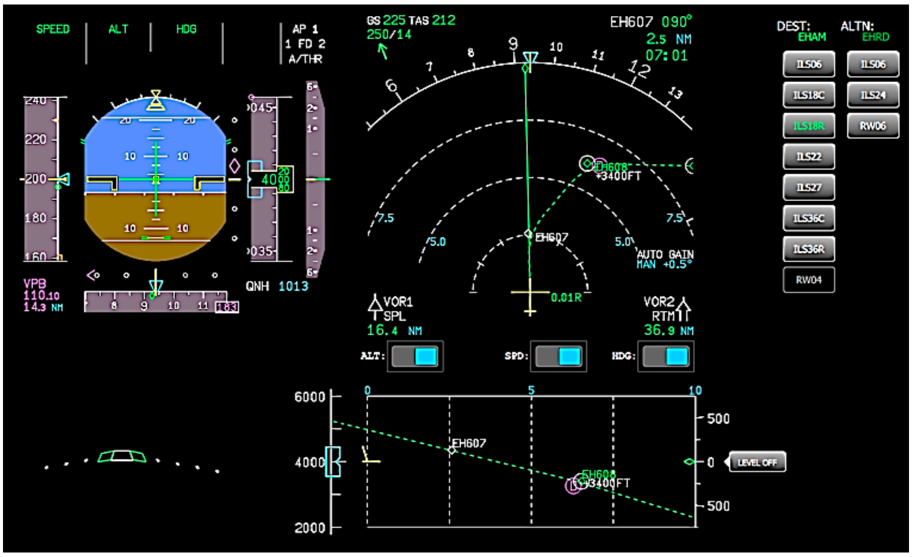
NLR's activities span the full spectrum of Research Development Test & Evaluation (RDT & E). Given NLR's specialist knowledge and facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. NLR thereby bridges the gap between research and practical applications, while working for both government and industry at home and abroad.
NLR stands for practical and innovative solutions, technical expertise and a long-term design vision. This allows NLR's cutting edge technology to find its way into successful aerospace programs of OEMs, including Airbus, Embraer and Pilatus. NLR contributes to (military) programs, such as ESA's IXV re-entry vehicle, the F-35, the Apache helicopter, and European programs, including SESAR and Clean Sky 2.
Founded in 1919, and employing some 650 people, NLR achieved a turnover of 71 million euros in 2016, of which three-quarters derived from contract research, and the remaining from government funds.

Dedicated to innovation in aerospace

EXECUTIVE SUMMARY

UNCLASSIFIED

Innovative cockpit touch screen HMI design using Direct Manipulation



Problem area

As a widely-used and proven technology touchscreens are entering the cockpits of civil aircraft. As part of the project ACROSS (Advanced Cockpit for Reduction Of StreSs and workload) NLR designed an innovative cockpit display with touch interaction for Tactical Flight Control; changing the aircraft's (vertical) speed, heading and/or altitude. In current cockpit configurations, the controls for this auto-pilot functionality are spatially separated from the visualization of the parameters they adjust, introducing aspects of physical and mental workload.

Description of work

In this paper, the Human Machine Interface design process of eliminating this physical gap and creating an intuitive interaction by means of Direct Manipulation is described. Direct Manipulation is characterized by manipulating graphical objects directly on the position where they are visualized in a manner that at least loosely

REPORT NUMBER
NLR-TP-2017-549

AUTHOR(S)
H.C.H. Suijkerbuijk
W.F.J.A. Rouwhorst
R.P.M. Verhoeven
R.R.D. Arents

REPORT CLASSIFICATION
UNCLASSIFIED

DATE
February 2018

KNOWLEDGE AREA(S)
Cockpit
Third Party Risk and Policy Support

DESCRIPTOR(S)
HMI design
Touch screen
Direct Manipulation
Flight Control
Auto-pilot

corresponds to manipulating physical objects. It has the potential to be highly intuitive, and less prone to error. Therefore, the Human Machine Interface design was hypothesized to reduce pilot's workload and simultaneously increase Situational Awareness. NLR designed an HMI concept for Tactical Flight Control using a touch screen with intuitive interaction by means of Direct Manipulation. This concept is evaluated using NLR's flight simulators APERO and GRACE.

Results and conclusions

Experiment results showed that the idea of bridging the physical gap and presenting the Tactical Flight Controls on the cockpit displays was well received. Especially as part of a full blown touch cockpit it has the potential to increase Situational Awareness. The results also showed that the interaction implementation needs to be improved by further iterative testing and evaluation since workload was increased, especially under turbulent conditions.

GENERAL NOTE
This report is based on a presentation held at the Human Factors and Ergonomics Society HFES Europe Chapter, Rome, September 28th 2017.

NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl

Dedicated to innovation in aerospace

NLR-TP-2017-549 | February 2018

Innovative cockpit touch screen HMI design using Direct Manipulation

CUSTOMER: Netherlands Aerospace Centre

AUTHOR(S):

H.C.H. Suijkerbuijk	NLR
W.F.J.A. Rouwhorst	NLR
R.P.M. Verhoeven	NLR
R.R.D. Arents	NLR

NLR - Netherlands Aerospace Centre

This report is based on a presentation held at the Human Factors and Ergonomics Society HFES Europe Chapter, Rome, September 28th 2017.

The contents of this report may be cited on condition that full credit is given to NLR and the authors.
This publication has been refereed by the Advisory Committee AEROSPACE OPERATIONS (AO).

CUSTOMER	**Netherlands Aerospace Centre**
CONTRACT NUMBER	**ACP2-GA-2012-314501**
OWNER	**NLR**
DIVISION NLR	**Aerospace Operations**
DISTRIBUTION	**Unlimited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY :		
AUTHOR	**REVIEWER**	**MANAGING DEPARTMENT**
H.C.H. Suijkerbuijk	T.J.J. Bos	H.G.M. Bohnen
DATE 21 12 17	DATE 21 12 17	DATE 08 02 18

Abstract

As a widely-used and proven technology touchscreens are entering the cockpits of civil aircraft. As part of the project ACROSS (Advanced Cockpit for Reduction Of StreSs and workload) NLR designed an innovative cockpit display with touch interaction for Tactical Flight Control; changing the aircraft's (vertical) speed, heading and/or altitude. In current cockpit configurations, the controls for this auto-pilot functionality are spatially separated from the visualization of the parameters they adjust, introducing aspects of physical and mental workload. In this paper, the Human Machine Interface design process of eliminating this physical gap and creating an intuitive interaction by means of Direct Manipulation is described. Direct Manipulation is characterized by manipulating graphical objects directly on the position where they are visualized in a manner that at least loosely corresponds to manipulating physical objects. It has the potential to be highly intuitive, and less prone to error. Therefore, the Human Machine Interface design was hypothesized to reduce pilot's workload and simultaneously increase Situational Awareness. The concept is evaluated using NLR's flight simulators. Experiment results showed that the Tactical Flight Control design concept has great potential, but the interaction implementation needs further improvement, since it increased the pilot's workload, especially under turbulent conditions.

This page is intentionally left blank.

Contents

Abbreviations

ACRONIEM	OMSCHRIJVING
AP	Auto-Pilot
ATC	Air Traffic Control
DM	Direct Manipulation
HMI	Human Machine Interface
ND	Navigation Display
NM	Nautical Mile
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
RSME	Rating Scale Mental Effort
SA	Situational Awareness
VSD	Vertical Situation Display

1 Introduction

The project ACROSS (Advanced Cockpit for Reduction Of StreSs and workload) aimed to research novel technologies to reduce the workload levels for flight crews in civil aircraft. Amongst other things a way to reduce crew workload during tactical flight control is researched.

1.1 Tactical flight control

Two methods can be discerned for flying an aircraft from point A to point B; *strategic* and *tactical* flight control. In a *strategic approach*, the aircraft is automatically guided along a predefined trajectory between A and B. In a *tactical approach,* the flight crew sets speed, heading, altitude and/or vertical speed to accomplish a desired flight manoeuvre, in general using the Auto-Pilot (AP) system.

1.2 Direct manipulation & touch screens

The term Direct Manipulation (DM) was introduced by Shneiderman (1982). Since then it has been widely adopted as a successful Human Machine Interface (HMI) design style. The idea behind DM is to create a direct intuitive interaction with visually presented objects in a manner that at least loosely corresponds to manipulating physical objects. A well-known example is drag-and-drop functionality in file systems.

The introduction of touch screens enabled a very high sense of DM; a user is able to manipulate visual objects in a way they recognize from the physical world, like moving, resizing and rotating an image with the use of their fingers. Touch screens are not novel technology in everyday's live, but they are in a cockpit; especially for use in main piloting tasks. According to Avsar et al. (2016a, 2016b), Boeing (2016), Gauci et al. (2015) and Gulfstream (n.d.), touch screens are gradually entering the cockpit of business and civil transport aircraft.

In *tactical* flight control the input devices for setting the heading, speed, altitude or vertical speed are spatially separated from the visual representation of the chosen values. An example is shown in the cockpit of an A320, shown in Figure 1 (flight deck picture taken from Meriweather (n.d.)). The pilots use knobs (pushable, pullable and rotatable) on the centre of the glare shield to set a desired speed, heading, altitude or vertical speed. The chosen values are numerically displayed above the knobs. Besides, they are also graphically presented (within the orange indicatory circles) on the two displays in front of the pilot's eyes; the Primary Flight Display (PFD) and the Navigation Display (ND). These are two of the main displays during flight; a pilot continuously scans these displays as they indicate the most important variables for safe flight. Since crew procedures mandate that control actions using the knobs on the glare shield are visually verified on the PFD and/or ND, the input and output of the AP system have become spatially separated. This creates an additional aspect in mental and physical workload. Using rotary buttons to set target values for the (vertical) speed, heading and altitude has no correspondence to manipulation of physical objects and is therefore not necessarily intuitive. Since DM will bridge the physical gap and give more meaning to the control actions, using DM for this task is hypothesized to reduce workload and simultaneously increase Situational Awareness (SA).

2 Design phase 1

NLR has designed and evaluated a touch screen HMI for control of the auto-pilot using DM in multiple design- and evaluation cycles. As a first step in the design, a single pilot crew experiment was set up in NLR's fixed based flight simulator APERO, hosting an Airbus A320-alike aircraft model. With the DM philosophy in mind a solution was searched for manipulating the AP variables at the place where they are graphically presented; the PFD and the ND. Manipulating the variables at the scales leads to complications since the range of the scales is limited. To prevent these complications, and to stay close to the use of the rotary knobs on the glare shield, it was decided to use interaction wheels.

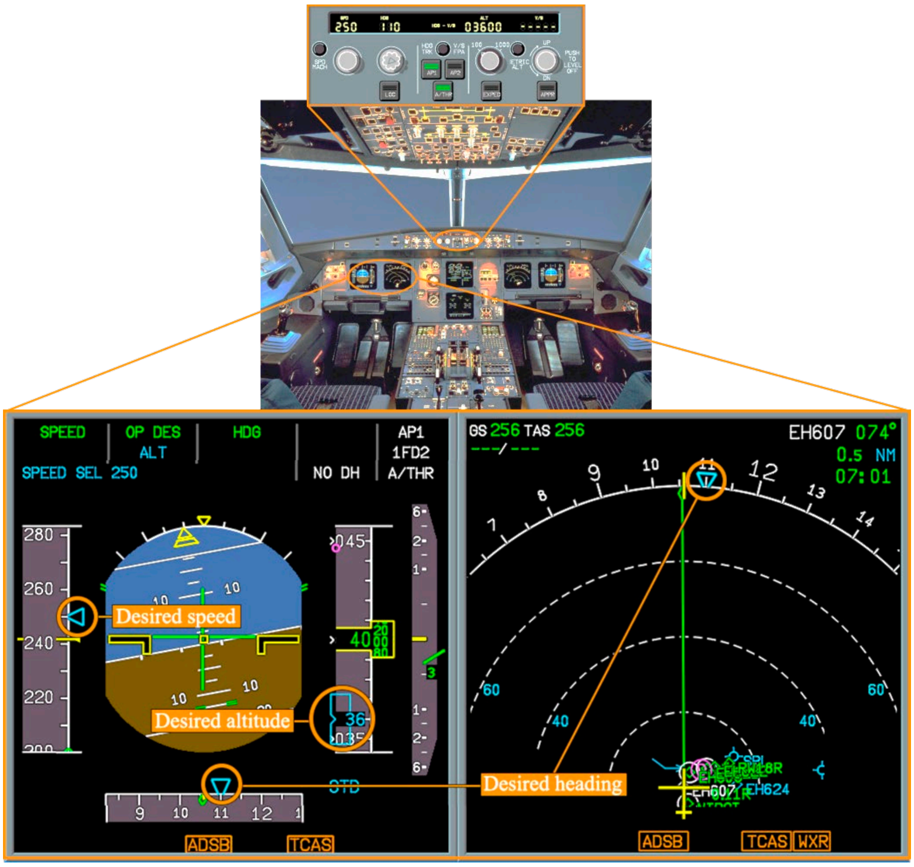


Figure 1. Location of auto-pilot input device (top, on glare shield) and graphical presentation (bottom, in front of pilots)

For every AP input variable to be adjusted, a wheel was created. These wheels were placed next to the graphical presentation of the variable at hand. By dragging the wheels one could adjust the target value; the graphical indicator next to the wheel changed position and value so the user directly got feedback. The wheels were developed in such a way that a gentle dragging resulted in a small adjustment of the value and a swipe resulted in a large adjustment of the value. In this first phase the vertical speed was left out of the design for reasons of simplicity. In Figure 2 the final design of phase 1 is presented. The HMI was displayed on a 10" tablet positioned in front of the pilot, fixated on a stand as shown in Figure 3. As can be seen, the PFD and the ND are also presented just as in the normal cockpit. The AP panel on the glare shield however, was covered. The tablet solely functioned as the input device to the AP system for adjustment of speed, heading and altitude.

Figure 2. HMI design phase 1 using touch wheels

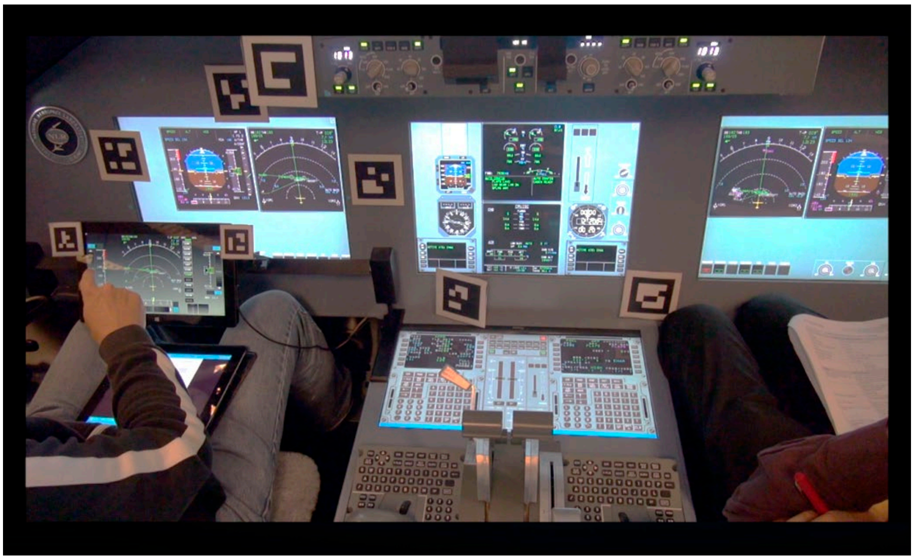


Figure 3. APERO flight simulator with the HMI presented on a tablet

Within the project, besides adjusting the AP input variables also some other cockpit controls were transferred to the touch HMI. The pilot was able to extend/retract the landing gear, adjust the flaps/slats setting and select an ND-range (in ARC-mode only) via a pinch-zoom gesture. Furthermore a novel interaction function was developed for choosing a new runway on the destination airport (see Rouwhorst et al., 2017). Since on a 10" tablet the amount of pixels is limited, it was decided to let the user decide which display would get emphasis and was magnified in the centre of the tablet. This can be seen in Figure 4; at the bottom of the tablet there are miniatures of the four optional central displays: the PFD, the ND, the gear indicator and the flaps/slats indicator. By touching one of the miniatures, the selected display was magnified in the centre of the screen. The chosen miniature was highlighted with a green border.

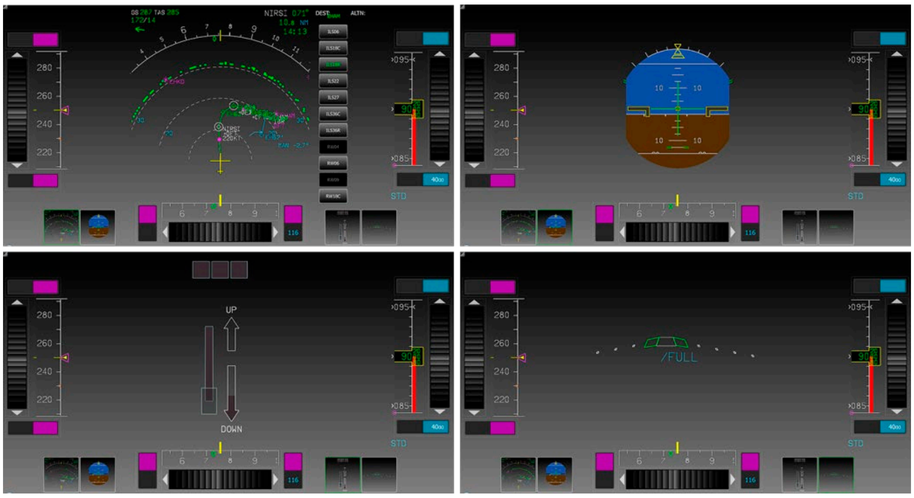


Figure 4. The user decides which display gets emphasized

As can be seen from Figure 4, the three scales for speed, heading, and altitude, which are normally attached around the PFD, were permanently present, no matter what display was chosen to be centrally emphasized. The idea behind this design decision was that the pilot should always be able to adjust the target speed, heading and altitude values, regardless of the active centre display. The three scales were placed near the edges of the touch screen. In this way the operator received some physical support from the tablet hardware; for example he could grab the tablet on the left side and use his thumb to change the target speed value.

With today's use of the knobs on the AP panel on the glare shield not only can the target value of the selected variable be adjusted, the pilot can also decide to change the flight mode from *strategic* to *tactical* and vice versa. In Airbus terminology the two modes are called *managed* (strategic) and *selected* (tactical) mode. In the graphical presentation on the PFD and the ND these two modes are distinguished by colour: *magenta* for managed mode and *cyan* for selected mode. This mode switching functionality had to be transferred to the tablet HMI as well. It was decided to use toggle switches for that purpose: for every wheel two switches were presented (see Figure 2). When the user adjusted the target values in such a way that it fell outside the range of the scale, the value was numerically presented on such a switch above (if higher than the maximum value on the scale) or under (if lower than the minimum value on the scale) the scale. The switches are coloured in correspondence of the active mode. To toggle between modes, the switch could be dragged towards the inactive side (resulting in a colour swap). In the toggle switch design an important rationale was admitted; sliding a toggle towards the centre of the display resulted in a switch towards *strategic* mode. Sliding a toggle outwards resulted in a switch towards *tactical* mode. The idea behind this was copied from the AP-panel of the A320, where a knob push results in *strategic* mode and a pull results in *tactical* mode. Pushing the knob can be interpreted as giving control to the aircraft (*strategic*) and pulling the knob can be seen as taking control in your own hands (*tactical*). On the tablet HMI sliding the toggles towards the centre display area gave control to the aircraft and sliding it outwards gave control to the user.

3 Evaluation phase 1

The HMI design was evaluated both subjectively and objectively by seven airline pilots during various descent & approach scenarios. The novel design was compared to a baseline flying the same scenarios using the conventional cockpit systems. To measure workload eye-activity was tracked, time-recordings were made and a Rating Scale Mental Effort (RSME)-scale (Zijlstra (1993)) was filled in. To measure SA, subjective questionnaires were filled in with the main self-rating question: "*Building up and maintaining SA was just as effortless during the related runs as during the conventional runs*". Detailed results on all designed items can be found in Rouwhorst et al. (2017). Here only the main results concerning the new AP HMI design are presented.

In general, the touch screen as input device was well received. Positive about the design was that building up and maintaining SA appeared to be just as effortless as in a conventional cockpit, and for some pilots even less effortless. This AP tablet HMI design did not lead to a faster, more efficient operation and subjective workload increased with 3 points on a 0-150 RSME scale. This was caused by the fact that setting a specific value turned out to be rather difficult; swiping the wheel appeared to be too sensitive and correcting this and fine-tuning the value time consuming. The ND-range pinch-zoom interaction felt intuitive and was highly appreciated. The toggle switches for changing the flight control mode were well received.

4 Design phase 2

To both asses the influence of turbulence on touch screen operation and that of multi-crew operation procedures, the evaluation platform was changed to NLR's full motion simulator GRACE. In Figure 5 the new set-up can be seen, with a seat for both a Pilot-Flying (PF) and a Pilot Monitoring (PM). With future expansion of pilot tasks using touch technology in mind, it was decided to switch from a separate tablet to fully integrated touch technology. This was achieved by using three 20" touch screens replacing the cockpit LCDs.

In this phase the interaction design is shifted from the scales of the PFD towards the ND. A trend is seen towards *strategic* flight control. This implies that the role of the ND in the cockpit will become increasingly important. Moreover, the ND would ease the understanding of the flight crew about the consequences of the tactical intervention in terms of SA, since information about terrain, traffic and weather is presented. Finally, with the use of the ND, also a correspondence to manipulation of physical objects can be obtained, which gives DM its intuitive character. To this end, the physics nature of the AP variables was considered. Speed, heading, altitude and vertical speed can be contained in just one physical object: a vector in 3D space, originated at the aircraft (see Figure 6 for a top view and a side view representation of this vector).

Figure 5. Touchscreen HMIs integrated in full-motion flight simulator GRACE

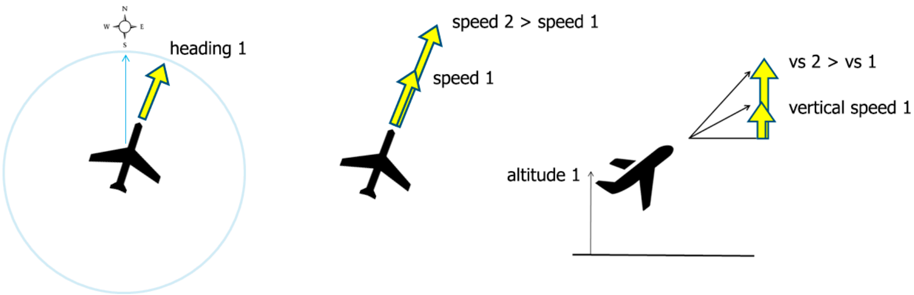


Figure 6. AP variables physics nature as a vector in 3D space

An aircraft has a position and an altitude which determine the origin of this vector. Its speed and heading give the vector length and direction. One can imagine that it is possible to control the behaviour of an aircraft by manipulating this vector; rotate it to change heading, extend/shorten its length to increase/reduce speed, tilt it to adjust its vertical speed to climb or descent towards a new target altitude. This formed the basis of the new HMI design. Since it is difficult to adjust a vector in a 3D space on a 2D screen, it was decided to split it into two views: a top view presented on the ND and a side view presented on a so-called Vertical Situation Display (VSD). This VSD has a similar nature as the ND with information about altitude, vertical speed, distance, terrain, weather and other traffic.

In Figure 7 the final HMI design of this phase is shown including this VSD. Since the mode switches were positively assessed, they are preserved and positioned in between the ND and VSD.

Figure 7. HMI design phase 2 including a VSD below the ND

4.1 Heading and speed adjustments

The heading and speed could be adjusted using the ND display. When touching the aircraft symbol on the ND, an interaction screen appeared on top of the ND, while dimming the rest of the display, see Figure 8. The heading rose was extended to a full 360 degrees circle and a speed scale was presented covering all selectable airspeeds. The blue vector originated in the aircraft symbol represented the current target heading and speed physics of the aircraft (in the figure 91 deg and 220 kts (11.32 m/s) respectively).

With this HMI design it was possible to simultaneously adjust the speed and the heading. When touching and holding the tip of the vector (at the position of the yellow arrows indicating the possible interaction directions), the user could drag it around within the heading rose, thereby adjusting both the length (i.e. aircraft speed) and the direction (i.e. aircraft heading) of the vector (see Figure 9). Since Air Traffic Control (ATC) commands can contain a combination of heading and speed, this feature was hypothesized to increase efficiency. When one stayed within the grey circular band, merely the heading was changed. On contrary, when one stayed within the speed scale, merely the speed was changed. For ease of operation and due to the fact that most adjustments do not request a higher accuracy than 5 units, both the speed and heading values were snapped at a multiple of 5 kts (2.57 m/s) or 5 degrees. For fine-tuning purposes both for the speed and the heading values, two buttons were added next to the numerical indication of the adjusted value. Touching these buttons increased/decreased the heading or speed values by 1 degree or 1 knot (0.5144 m/s).

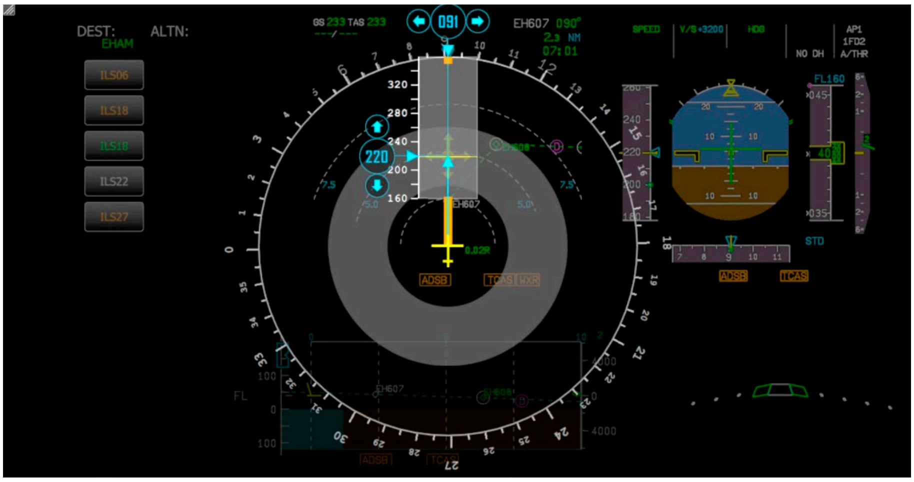


Figure 8. Interaction screen for speed and heading adjustments

Figure 9. Drag the tip of the vector to adjust the aircraft speed and heading

4.2 Altitude and vertical speed adjustments

The altitude and vertical speed could be adjusted using the VSD display. When touching the aircraft symbol in the VSD, an interaction screen appeared on top of the VSD, while dimming the rest of the display, see Figure 10. The yellow vector originating from the aircraft symbol represented the physics nature of both the current altitude and vertical speed. The aircraft symbol was positioned at half height of the VSD. The altitude scale on the left is a moving tape, indicating the actual altitude of the aircraft at the aircraft symbol. The blue icon on this altitude scale represented the target altitude; after descending/climbing towards this target altitude, the aircraft will level off when reaching the target value. A pilot could decide to control the climb/descent towards this new altitude by setting a target vertical speed. When flying with a certain vertical speed towards a certain altitude, it can be calculated what distance will be covered before reaching this altitude. These three variables were all presented simultaneously in the VSD. Vertical dotted lines were plotted in the VSD at fixed distance from the aircraft (in this view at every 10 Nautical Miles (NM) (18.52 km)). Imaginary sloped lines from the aircraft symbol towards the right side of the VSD scale indicated how much altitude could be covered in 40 NM (74.08 km) and therewith represented the vertical speed (indicated in small sloped lines on the right side of the VSD scale).

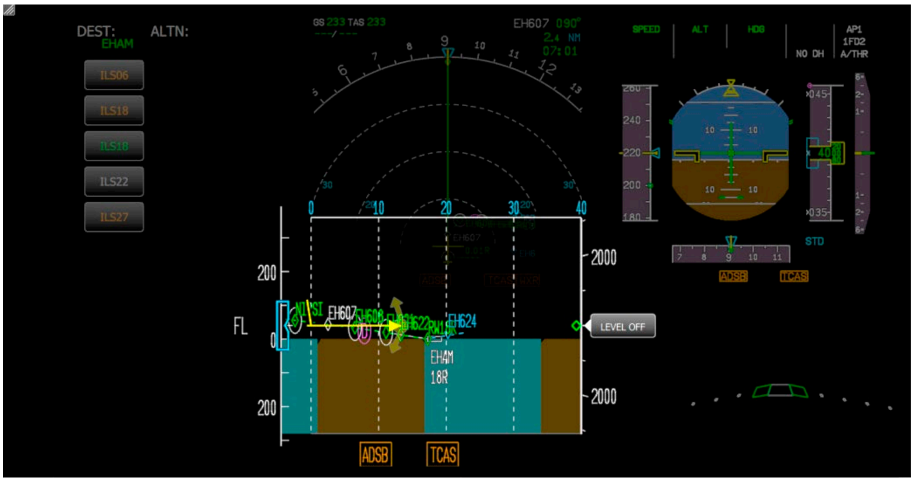


Figure 10. Interaction screen for altitude and vertical speed adjustments

This made the VSD an ideal interaction display for simultaneously adjusting the altitude and the vertical speed. When touching and holding the tip of the vector the user could drag it around within the VSD scale, thereby adjusting the desired distance at which to achieve a certain altitude. For example in Figure 11, where a pilot wanted to climb to an altitude of 15000 ft (4572 m), while climbing at 1500 ft/min (7.62 m/s), he immediately received feedback about the distance the aircraft would need to travel to reach the target altitude at this vertical speed (i.e. almost 30 NM (55.56 km)). If he wanted to reach this altitude earlier, he needed to drag his finger to the left, resulting in a higher vertical speed. This was hypothesized to be a very intuitive feature, which was not yet available using the AP-panel on the glare shield.

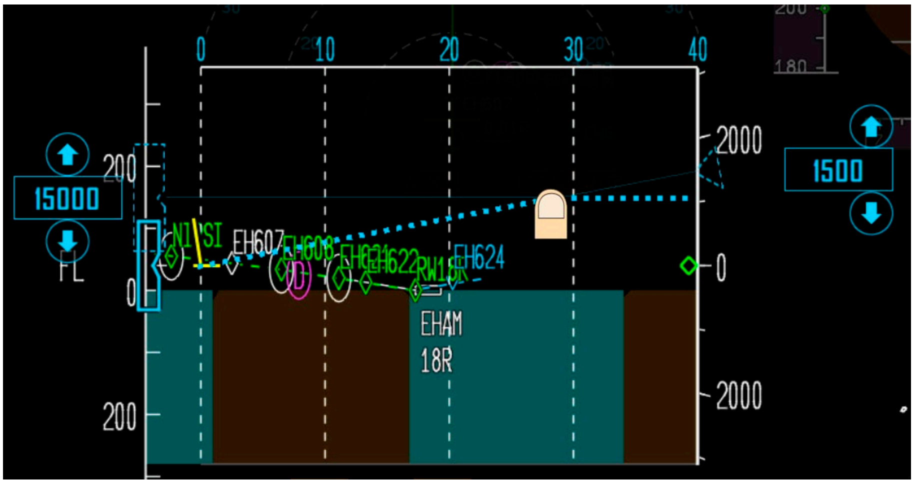


Figure 11. Simultaneously adjusting the target altitude and vertical speed

When a pilot merely wanted to set a target altitude, he could drag the tip of the vector on the left side outside the VSD scale, thereby releasing the vertical speed. The altitude value then could be adjusted by dragging the indicator along the altitude scale or by touching the fine-tuning buttons (with increments of 100/1000 ft (30.48/304.8 m)) depending on the flight phase), see Figure 12.

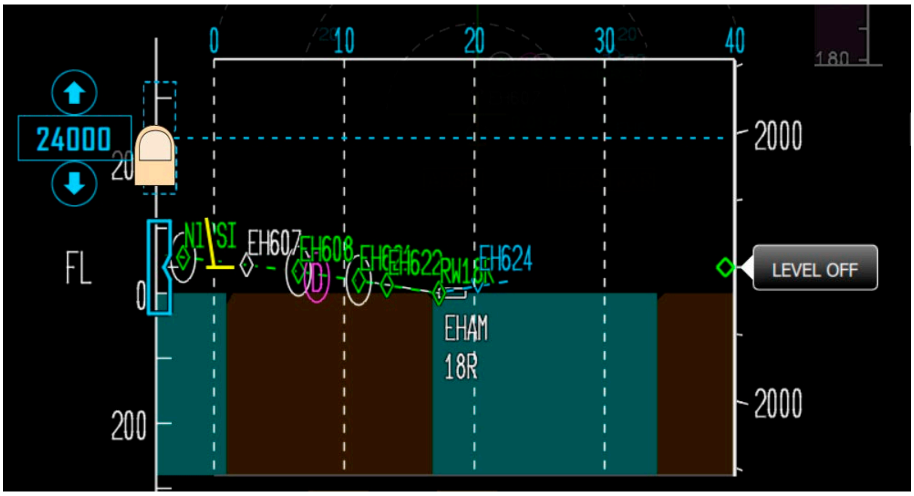


Figure 12. Merely adjusting the altitude using the VSD interaction scale

When a pilot merely wanted to set a target vertical speed, he could drag the tip of the vector on the right side outside the VSD scale, thereby releasing the altitude. The vertical speed value could be adjusted by dragging the indicator along the vertical speed scale or by touching the fine-tuning buttons (with increments of ±100 ft/min (0.508 m/s)), see Figure 13. To instantly reset the target vertical speed to 0 ft/min (0 m/s) the *Level off* button could be touched (see Figure 12).

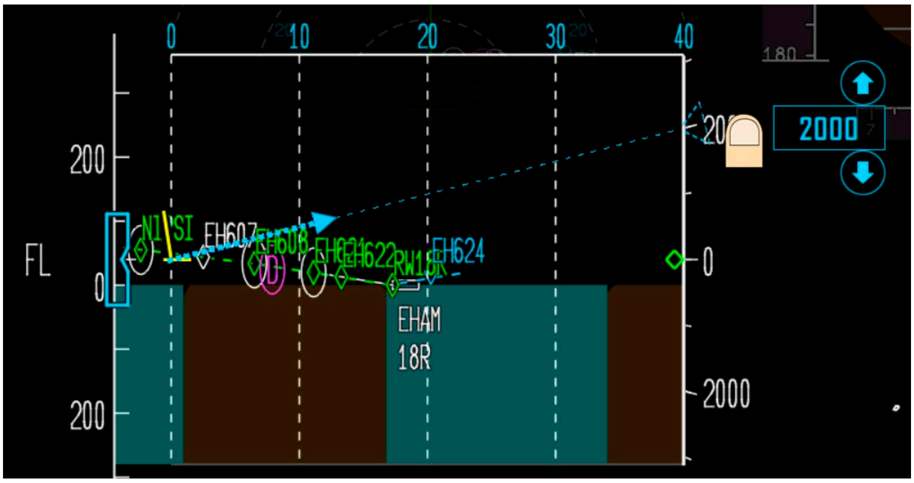


Figure 13. Merely adjusting the vertical speed using the VSD interaction scale

5 Evaluation phase 2

It has to be noted here, that during the experiment, the AP functionality was just one of several new things that were evaluated. In Rouwhorst et al. (2017) more detail is presented on some other touch functionalities.

In general, when receiving the briefing and discussing the design thoughts of the new HMI, all ten pilots supported the idea of setting auto-pilot values in this intuitive way. The idea of not having to switch focus to the glare shield display, the possibility of combined inputs of heading and speed and setting a level-off point graphically were considered promising.

The pilots received one training run for each novel functionality. All pilots experienced a steep learning curve during this run. When comparing the touch HMI design to using the rotary knobs of the AP-panel in the evaluation runs, the pilots reported it as more demanding; it took more effort (the number of actions), time and mental workload. Although beforehand they expected the combined functionality of the speed and heading inputs to be intuitive, most of the pilots advised to decouple them, since it was too hard and time consuming to accurately set them both simultaneously. Pilots had difficulty operating the system under high stress levels, such as turbulence and complex ATC commands, like those that included speed, heading and altitude changes. Such a plural request would require interaction on the ND at first, followed by another interaction on the VSD. This took too much time, and number of operations was too high; pilots tended to forget the actual instruction provided to them. Comments were received on the grey circle band. Since its placement depended on the actual speed, the radius of the band became too small for adjusting the heading when flying at low airspeeds. Pilots liked the graphical representation of the point where the aircraft will level-off to a new set altitude, however controlling this point with a finger, thereby choosing a value for the altitude and the vertical speed simultaneously appeared to be troublesome. With the use of the VSD, they predicted an expansion of use of the vertical speed mode, since this was received as very intuitive. In terms of multi-crew operation the design appeared to be inadequate; the PM had trouble staying in the loop of what the PF was doing and could not easily verify whether for example instructions received from ATC were properly addressed by the PF. During the experiment therefore a master-slave construction was developed in which the actions of the PF were passively visible on the screen of the PM.

6 Design phase 3

Unfortunately, there was not enough time to do a complete third design and piloted evaluation session, but based on the pilot comments and outcome of the experiments, the project allowed final improvements to be made. The most important improvement was the decoupling of the heading & speed and altitude & vertical speed input. Since the grey circular band appeared to be too small to set accurate heading values at low speeds, the heading was decided to be set along the outer ring of the ND arc (see Figure 14).

Figure 14. Interaction screen for decoupled speed and heading adjustments

Another improvement was the addition of the current target speed value as a reference, presented by the yellow line and cyan triangle in the speed tape on the ND. In the previous design, the interaction overlay disappeared automatically after you had stopped adjusting your input. The pilots got confused by this; they lost track of what they were actually doing, had to wait a short while before their inputs were taken over by the aircraft and missed the possibility to reset the entire action. This has been improved by given them control; an "*acknowledge*"- and "*cancel*"-icon are added. When the pilot felt confident about his actions, he could acknowledge them by touching the green check mark.

The same idea is adopted for the VSD, see Figure 15. Also on the VSD the altitude and vertical speed settings were decoupled; adjusting the altitude could be done by dragging the indicator along the altitude scale on the left and adjusting the vertical speed could be done by dragging the indicator along the vertical speed scale on the right. As the pilots had trouble finetuning the target altitude on the small scale it was decided to fixate the value indicator at the vertical centre of the VSD. In the previous design the fine-tuning increments depended on the flight phase; to give the pilots more sense of control, additional fine-tuning buttons were added, for achieving an accuracy of 100ft (30.48 m) as well as 1000ft (304.8 m). Because the pilots liked the feature of knowing where the level-off point is situated, this is preserved as a dashed bold line (so in the example in Figure 15, when climbing at 2400 ft/min (12.19 m/s) to a target altitude of 13200 ft (4023.4 m), the level off point was situated at a range of 15 NM (27.28 km)).

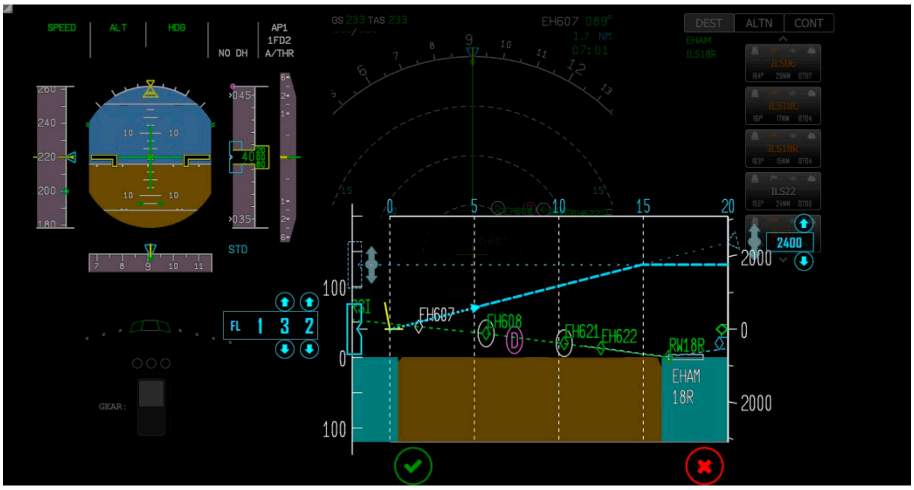


Figure 15. Interaction screen for decoupled speed and heading adjustments

7 Discussion

It can be concluded that using a touch screen in the cockpit is well received. Other functionalities evaluated in the project were already very well received (see also Rouwhorst et al. (2017)). For the task of Tactical Flight Control it can be concluded that the design concept of presenting the controls on the cockpit displays was well received and has the potential to increase SA, but there is room for improvement of the interaction implementation. Extensive iterative testing and evaluating is needed to fine-tune a complex HMI such as the present. As a first step for further research the HMI design of phase 3 could be evaluated in a pilot-in-the-loop experiment. A solution should be found for dealing with turbulence when using a touch screen. It is unlikely that the HMI design concept will reduce workload when solely comparing the Tactial Flight Control task with the conventional AP knobs functionality. It has however the potential to increase SA and be part of a full blown touch cockpit. Such integrated touch cockpit actually does have the potential to reduce overall workload levels. This research can be seen an important step towards this future touch cockpit, but more iteration cycles are needed on the HMI interaction design.

8 Acknowledgment

The project was co-funded by the EU in the 7th Frame Work Program under contract number ACP2-GA-2012-314501. The authors would like to thank all the participating pilots and involved ACROSS partners.

References

Avsar, H., Fischer, J.E., Rodden, T. (2016a). Designing Touch Screen User Interfaces for Future Flight Deck Operations. In *Digital Avionics Systems Conference (DASC), 2016 IEEE/AIAA 35th (*pp. 1-9). New York, USA: IEEE Institute of Electrical and Electronics Engineers

Avsar, H., Fischer, J.E., Rodden, T. (2016b). Mixed method approach in designing flight decks with touch screens: A framework. In *Digital Avionics Systems Conference (DASC), 2016 IEEE/AIAA 35th* (pp. 1-10). New York, USA: IEEE

Boeing (2016), *Touchscreen come to the 777X Flight Deck, bringing today's technology in the hands of pilots*, http://www.boeing.com/features/2016/07/777x-touchscreen-07-16.page

Gauci, J., Cauchi, N., Theuma, K., Zammit-Mangion, D. and Muscat, A. (2015). Design and evaluation of a touch screen concept for pilot interaction with avionics systems. In *Digital Avionics Systems Conference (DASC), 2015 IEEE/AIAA 34th* (pp. 3C2-1 - 3C2-19). New York, USA: IEEE

Gulfstream (n.d.), *Gulfstream symmetry flight deck, Piloting Perfected*, http://www.gulfstream.com/technology/symmetry-flight-deck

Meriweather (n.d.), A320 Flight Deck by Jerome Meriweather, http://meriweather.com/flightdeck/320/fd-320.html

Rouwhorst, W.F.J.A, Verhoeven, R, Suijkerbuijk, H.C.H., & Arents, R. (2017). Use of Touch Screen Display Applications for Aircraft Flight Control. In *Digital Avionics Systems Conference (DASC), 2017 IEEE/AIAA 36th Sept. 2017.* New York, USA: IEEE

Shneiderman, B. (1983). Direct manipulation: A step beyond programming languages. In *Computer, Volume: 16, Issue: 8* (pp. 57 – 69). Los Alamitos, CA, USA: IEEE Computer Society Press

Zijlstra, F.R.H. (1993). *Efficiency in work behavior. A design approach for modern tools.* PhD-thesis, University of Delft, The Netherlands, University of Delft: Delft University Press

This page is intentionally left blank.

NLR

Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl