Human Centered Design Approach to Integrate Touch Screen in Future Aircraft Cockpits

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Abstract. This research aimed at developing new types of Human-Machine interaction for future Airbus aircraft cockpit. Touch interaction needs to be studied because it brings some advantages for pilots. However, it is necessary to redefine pilot's workspace to optimize touch interaction according to pilot population characteristics and human physical capabilities. This paper presents the touch interaction area model and the tactile assessment carried out to validate our hypothesis, leading to rules/guidelines for cockpit layout and HMI designers.

Keywords: Human Centered Design, interaction design, anthropometry, touch screen interaction, guidelines.

1 Introduction

Many research studies are carried out at Airbus to address new types of Human-Machine interaction for pilots. This study was focused on the integration of touch screen technology in future aircraft cockpit. Indeed, this technology brings some advantages 1) for pilot interaction, for example [1]: intuitive operation requiring little thinking by a direct manipulation, easier hand-eye coordination, and 2) for cockpit definition: more software flexibility, space optimization with no extra workspace required for physical input devices such as command buttons or pointing devices. But touch screens need to be installed at a specific location inside the cockpit for accessibility and working postures concerns. Indeed, if not properly located, the use of touch screen may induce muscular fatigue, musculoskeletal disorders and could also degrade Human-Machine interaction [2], [3].

The aim of this study was to define digital manikins with their associated reach envelops and postures to provide a design model to better integrate touch screens and to optimize Human-Machine interaction. The part of the study related to anthropomorphic and biomechanics needs, focusing on pilot characteristics and working postures to be considered for building up the design model were addressed in a former paper [4]. This paper will present the global design concept and the results of the tactile assessment taking into account criteria such as touch and task performance (gesture

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accuracy, duration and difficulty of the task). This model provides rules and guidelines to be used by designers for optimizing touch screens technology integration in the cockpit. It also ensures an efficient Human-Machine interaction.

2 Theoretical Design Model

The theoretical design model is based on 6 modules (figure 1). The criteria related to Human-Machine Interaction and human physical capabilities were considered for formalizing the Touch Interaction Area Model. Each module is defined with its associated criteria.

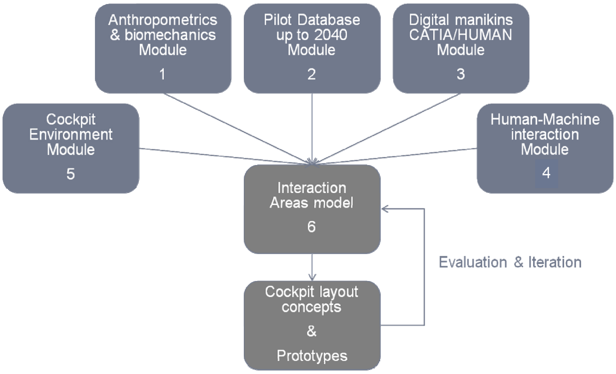


Fig. 1. Theoretical Design Model

2.1 The Anthropometrics and Biomechanics Module (1)

How to integrate human physical capabilities in the design of new equipments and systems to improve comfort, safety and efficiency? We focused mainly on the choice of the relevant anthropometric key measurements and the definition of working postures, reach and visual capabilities.

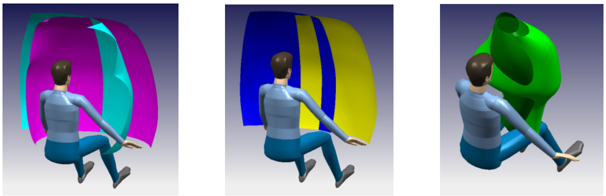
Sitting height and buttock knee length (related to seated positions) and forward reach were retained as key anthropometric measurements.

Working postures of pilots were defined according to angles of less discomfort, muscular efforts and energy expenditure reduction, contact pressures and internal disks pressures reduction. Four postures were chosen as reference. Their characteristics are: minimum discomfort and maintained during the performance of operational tasks and/or rest periods in the cockpit ("Theoretical Design Eye Posture (DEP)", "Functional DEP", "Monitoring – Cruise" and "Nap posture"). We also selected additional postures to be studied (reach areas extended) for short duration task. They are associated with bending and/or twisting of the trunk and movements of one or both upper limbs: « Forward seated posture », « Forward maximum », « Forward 45° » and « Upward » posture.

Theoretical DEP Cruise Forward Forward max Forward 45° Upward

Fig. 2. Working and additional postures for manikins created on CATIA/HUMAN

Reach capabilities for upper limb is defined by the functional hand reach envelop consisting in fully gripping a rod with the hand (Forward Reach (FR) see ISO 7250). Allowances were added to increase the reach distances: for pinch grip, FR+50 mm (figure 3-1) and, for touch, FR+100 mm (figure 3-2). A preferential area was also defined for interaction with both hands (figure 3-3) [5].



3-1 3-2 3-3

Fig. 3. Functional and preferential reach areas for left and right hands

Visual capabilities were also considered. The visual area modeling was based on the ISO 14738 to define the adequate field of vision (α) with or without movements of the head (β) and the body (γ) (figure 4).

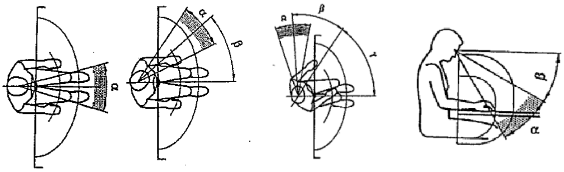


Fig. 4. Visual areas according to head and body movements (from ISO 14738)

2.2 The Pilot Database Module (2)

How to integrate morphological variability ensuring that both small and large pilots are able to reach and interact comfortably and efficiently with the touch screens from their seated position? We built up a pilot database (prediction up to 2040) taking into account the evolution of the morphologies and the geographical locations for key measurements. The range of the pilot population are defined from the small (5th percentile) Asian Japanese female to the large (95th percentile) European North male. Populations are defined by anthropometric surveys extracted from WEAR database systems [6].

2.3 The Digital Manikins Module (3)

How to perform ergonomic studies using Computer Aided Design (CAD) techniques? We chose manikins and defined body dimensions according to the variability of length for sitting height, buttock-knee length and forward reach. A set of « boundary » manikins were derived with different morphotypes related to trunk/lower limbs ratio, using bivariate distributions to define the appropriate range of variations for the 5% and the 95%. Sitting height was chosen as key dimension for 5%-95% variability and Forward reach was adjusted to cover the variability for the 2040 populations. Pair of manikins was created for each percentile retained: 5% and 95%.

2.4 The Human-Machine Interaction Module (4)

Which Human-Machine Interaction criteria to be considered?

- Duration of the tactile task (D): maintaining posture and hand motion. Duration of the tactile task may have a negative impact on comfort if duration is too long because the muscles have to fight against gravity effect to maintain the positions of the upper limbs.
- Frequency of the task (F): time for rest (sec) between two tactile tasks without upper limb rest on appropriate supports. The frequency of the task may induce fatigue at joint levels and musculo squeletal disorders (if too high).
- Repetitiveness of the task (R): repetition of similar task (in terms of gesture and posture constraints) during a flight. It contributes to physical fatigue at the postural and gestural levels.
- Gesture library (G): gestures selected for the touch screen interaction (Number of fingers & hands used).
- Task difficulty (T): accuracy and difficulty of the gesture to perform the task. They are the main factors of muscular and articular fatigue (necessity for maintaining a posture and oculomotor control of the gesture).

2.5 The Cockpit Environment Module (5)

How to consider environmental context and cockpit layout constraints? We developed the model to be used in several aircraft cockpit concepts. In this case, we took into account the specificities of the environmental context, such as the vibration (turbulences) and the cockpit layout constraints that could have an impact on touch interaction, for example: the seat position, the visual field, the cockpit nose dimension, the display locations (right /left) and the fact that information on central displays is shared by the two pilots. Moreover, lateralization (i.e. right or left hand used) needs to be addressed as it could affect the performance, the precision and the comfort of touch interaction.

2.6 Touch Interaction Area Model (6)

All the criteria from the different modules (table 1) have been gathered to build up the Touch Interaction Area Model in order to optimize the interaction according to the touch screen locations. For each criterion, we made hypotheses to be assessed.

Table 1. Criteria retained in the Touch Interaction Area Model

Type of criteria	Criteria
Human-Machine Interaction	Duration of the tactile task (D)
	Frequency of the task (F)
	Repetitiveness of the task (R)
	Gestures used (G)
	Task difficulty /accuracy (T)
Human physical capabilities	Working Posture (WP)
	Lateralization (L)
	Visual Control (VC)
	Vibration (V)

With these hypotheses, a cockpit concept was designed on CAD taking into account cockpit constraints (figure 5). Visual boundaries and reach adjustments (FR+50 mm and FR+100 mm) were based on the 5th percentile digital manikins.

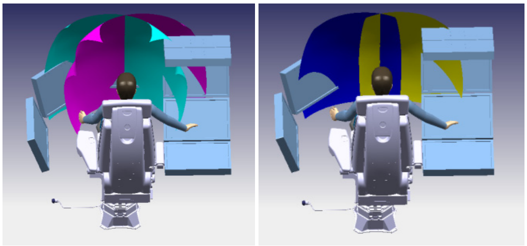


Fig. 5. Cockpit concept defined on CAD based on Touch Interaction Area Model

3 Method

Our experimental approach consisted in collecting data from a sample of 10 pilots in order to validate postures, reach area capabilities and touch interaction areas predefined with digital manikins in CAD. This should allow us to confirm the acceptability for both small and large pilots in terms of accessibility, postural constraints, physical efforts, task difficulty and visual boundaries.

3.1 Experimental Set up

We developed a physical mock-up (1/2 cockpit, at the right seated position) with 8 touch screens based on the CAD cockpit concept (figure 6, left). A Motion capture tool (Moven system) was used to capture and analyze pilots' postures and functional reach envelops in real time (figure 6, right). Anthropometric measurements for each subject were also integrated in Moven system to get personalized avatars.

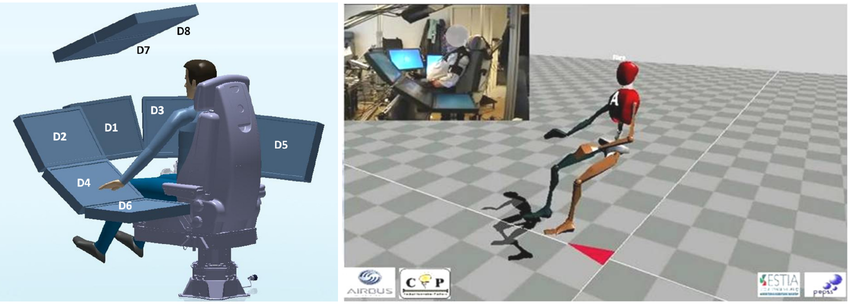


Fig. 6. Experimental mock-up and Moven capture

A sample of 10 right-hand pilots (8 males and 2 females) (age m = 46.5; SD = 13.5) was selected to cover morphological diversity for key measurements (Sitting height and Forward reach) and the pilot population, as defined in the pilot database module (§2.2).

3.2 Experimental Tasks and Protocol

Two types of tactile tasks were addressed during assessment:

- Accurate tasks: typing a short text on a virtual keyboard, selection of a waypoint on a Flight Management System (FMS) prototype or creation of a puzzle,
- Non accurate tasks: manipulation of a map to select an airport view or charts.

We collected postures and upper limbs movements when subjects performed tactile tasks on different display locations (figure 6). Six positions were analyzed (D1 to D6) with three tasks performed per display. All tests were carried out at the right seated position. A subjective assessment for the following 4 dimensions was used at the end of each task to collect the perceived level of: the performance (accuracy + quickness), the difficulty of the tactile gesture (hand motion), the physical effort (postural constraint) and the acceptability of the task (gesture + posture). Visual issues and right/left hand preferences were also collected.

Two kinds of functional postures were already characterized in a former paper [4]: postures with or without (or only small) constraints. With no constraints, the head and the pelvis are in neutral position. The lumbar has no postural constraint but there is no rest for the thoracic cage and forward upper limbs. Elbow and shoulder angles are in the range of less discomfort. On the contrary, with constraints, the head is at the acceptable limits for rotation and flexion angles; the trunk is highly constrained. So are the shoulder and the wrist extension angles.

Subjective assessments on physical effort (display location, right/left hand preferences and visual aspects) were also addressed in this former paper [4].

For this paper, we focused on the following Human-Machine interaction hypotheses to identify the relations between postures, task duration, display location and acceptability of the tactile tasks:

- H1: Postural constraints depend on display location,
- H2: Postural constraints and task duration have an influence on subjective assessments,
- H3: Subjective assessments vary according to attributed tasks, postural constraints and display location.

In order to verify these hypotheses a statistical analysis (descriptive and inferential statistics followed by geometric data analysis) [7], [8], [9] was conducted on the following data: subjective assessment, tasks (with and without accuracy), displays (D1 frontal, D2-D4 central, D3 lateral, D5-D6 backward), postures (with and without constraints), and task duration: short (9-15 s), medium (16-60 s), long (> 60 s). The resulting table was constituted of 178 lines (10 pilots x 18 tests minus 2 missing tests) and of 5 columns (4 subjective assessments and task duration).

4 Results

- **Postural constraints depend of display location. (H1)**

Cross data analysis (Posture/Displays) for subjective assessments on performance shows that pilots make the choice of postural constraints to be more efficient when displays are located in a central position (t [58] = 2.24; p < .003). Right-handed subjects prefer both hands with postural constraints (physical effort significantly higher) than their left hand to perform tactile tasks on central displays (effect of lateralization). The choice of such postural constraints contributes also to increase legibility and to lower parallax difficulties (presented in former paper [4]). It is also explained by the need for the subjects to get a better field of vision as recommended by ISO norm 14738 (see 2.1).

For other subjective assessments, tactile task difficulty is low for frontal/lateral displays (t [92] = 7.27; p < .0000) and increases for the other displays (central and backward); the difficulty is the higher for central displays when pilots adopt a posture without constraint (m = 43.94; SD = 21.06). Acceptability is better for frontal/lateral displays for “no constraint condition” than for the others. This acceptability for the others remains at a level greater than 50% (results differ significantly with central display: t [92] = 4.42; p < .0000).

- **Postural constraints and task duration have an influence on subjective assessments. (H2)**

The performance is better perceived for short and medium tasks duration than long tasks whatever postural constraints (with constraints: t [82] = 2.52; p < .01, without constraints: t [92] = 4.84; p < .0000). In addition, task difficulty increases with long duration (with constraints: t [82] = 2.10; p < .04 - no constraint: t [92] = 3.76; .0003). Acceptability remains correct whatever task duration (no significant results).

- **Subjective assessments vary according to attributed tasks, postural constraints and display location. (H3)**

The correlations between the 4 subjective assessments dimensions and duration were carried out on the sample of the collected data (table 2). These correlations were projected in a geometric space (vectors/variables space). All correlations are significant. Performance has a negative correlation with task difficulty, physical effort and duration and a positive correlation with acceptability.

Table 2. Correlation matrix

Variables	Performance	Task Difficulty	Phys. effort	Acceptability	Duration
Performance	1.00	-0.65	-0.46	0.61	-0.43
Task Difficulty	-0.65	1.00	0.72	-0.59	0.40
Phys. Effort	-0.46	0.72	1.00	-0.62	0.22
Acceptability	0.61	-0.59	-0.62	1.00	-0.18
Duration	-0.43	0.40	0.22	-0.18	1.00

For the Principal Component Analysis (PCA), duration was not retained because previously changed to a qualitative variable. All the quantitative variables were indexed with 8 qualitative variables (task identification, type of display, characterization of the posture, visual constraint, hand lateralization, task categorization, forward reach and duration). These qualitative variables allowed us characterizing the behavior profiles in the "clouds" derived from PCA (derived clouds of mean points).

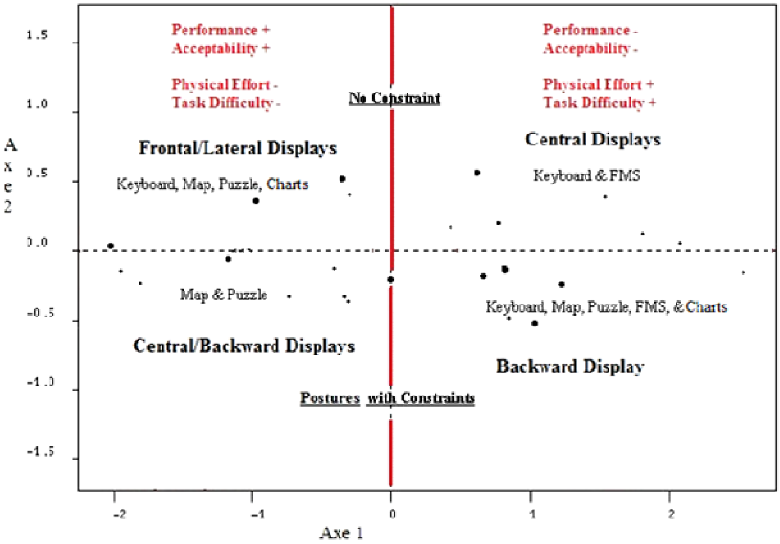


Fig. 7. Derived cloud of the posture/display/task mean points

PCA consists in building up a vector space of variables and a Euclidean space of individuals' points. Graphical representation (figure 7) summarizes results obtained from interpretation of vectors-variables' projection on axes 1 and 2 (84% of variance accounted) and from different configurations of individuals' mean points indexed with qualitative parameters (postures with or without constraints / display locations / type of tasks). Axis 1 describes opposition between performance/acceptability (figure 7, left +; right -) and physical effort/task difficulty (figure 7, left-; right +). Axis 2 represents the opposition between unconstrained (top) and constrained (down) postures. Best scores for performance/acceptability (left) are for frontal and lateral displays (keyboard, map, puzzle, Charts) and also for central and backward displays (map and puzzle). Opposite (right), backward (keyboard, map, puzzle, FMS, Charts) and central displays (keyboard and FMS) are less acceptable.

5 Preliminary Guidelines

Based on the results presented in this paper and in the former one [4], four categories of interactions have been defined according to the criteria of the Touch Interaction Area Model (table3). Some preliminary guidelines can be extracted from this applied model, for example: tasks with a high level of difficulty and gesture accuracy are to be performed preferentially on frontal or lateral displays; simultaneous action of both hands is possible but not recommended for some display locations due to postural constraints; if display locations imply upper limb elevation and postural constraints, duration should not be long due to muscular fatigue.

Table 3. Categories of interaction according to the touch screen locations

Type of criteria	Criteria	CAT1	CAT2	CAT3	CAT4
Human-Machine Interaction	Duration of the tactile task (D)	Long	Medium	Short	One time
	Frequency of the task (F)	Not tested			
	Repetitiveness of the task (R)	Not tested			
	Gestures and hands used (G)	All gestures	Gestures with both hand possible	One hand limited	Mono-touch only
	Task difficulty /accuracy (T)	Accuracy	Accuracy	No accuracy	No accuracy
Human physical capabilities	Working Posture (WP)	Preferential area	FR+50 with small constraints	FR+50 with constraints	FR+100 All postures
	Lateralization impact (L)	Low	High	Medium	Low
	Visual Control (VC) (field of vision & head movement)	α (30°) $\alpha+\beta$ (60°)	$\alpha/2+\beta$ (55°) $\alpha+\beta+\gamma$ (90°)	δ (90°) $2\alpha+\beta+\gamma$ (110°)	All degree of freedom
	Vibration impact (V)	Not tested			
	Touch screens location	Location not tested	Frontal/Lateral (D1, D3)	Central (D2, D4)	Backward (D5, D6)

This preliminary definition of the categories answers two types of question that can be addressed by cockpit layout and HMI designers:

- Where should the HMI be localized according to the type of interaction needs? Answer: If the HMI interaction requires: G = one hand gesture, T = gesture accuracy and D = medium duration, then the touch interaction area should be CAT2 (frontal or lateral) location.

- What types of interaction should be recommended for a system in a dedicated touch screen location?
  Answer: If the HMI is located on the central area, then interaction should be CAT3 (D = short duration, T = no gesture accuracy and G = limited to one hand gesture).

6 Conclusion

The Touch Interaction Area Model has proven to be worthy to define and give guidelines for design. Nevertheless, complementary studies with real operational tasks are needed to validate these new ergonomic rules in order to refine the nature of the tactile task, the gesture accuracy and also to study the impact of the frequency and the repetitiveness of the task in the model. Vibration effects such as those encountered in turbulence conditions need to be investigated to identify postural, upper limb and Human-Machine interaction disturbances. It will also be interesting to study if, an adapted training improves the way pilots interact with touch screen technology.

References

1. Shneiderman, B.: Touchscreens now offer compelling uses. In: Sparks of Innovation in Human-Computer Interaction. Ablex Publ., Norwood (1993)
2. Young, J.-G., Trudeau, M., Odell, D., Marinelli, K., Dennerlein, J.-T.: Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles. Work 41, 81–91 (2012)
3. Fuller, H., Tsimhoni, O., Reed, M.P.: Effect of In-Vehicle Touch Screen Position on Driver Performance. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 52, 1893 (2008)
4. Barbé, J., Chatrenet, N., Mollard, R., Bérard, P., Wolff, M.: Physical ergonomics approach for touch screen interaction in an aircraft cockpit. In: Proceedings of the Ergo'IHM 2012 Conference. ACM, New York (2012)
5. Ignazi, G., Mollard, R., Pineau, J.C., Coblentz, A.: Reconstitution en trois dimensions des aires d'atteintes du membre supérieur à partir de quelques données biométriques classiques. Cahiers d'Anthropologie 3, 93–117 (1979)
6. Mollard, R., Ressler, S., Robinette, K.: Database contents, structure, and ontology for World Engineering Anthropometry Resource - WEAR. In: Proceedings of the 16th Triennal World Conference of the International Ergonomics Association, July 10-14. The Netherlands, Maastricht (2006)
7. Benzécri, J.P.: Correspondence analysis handbook (Benzécri, J.P. Trans.). New-York: Dekker (Original Work published 1980) (1992)
8. Wolff, M.: Apports de l'analyse géométrique des données pour l'analyse de l'activité. In: Sperandio, J.-C., Wolff, M. (eds.) Formalismes de Modélisation Pour l'analyse du Travail et l'ergonomie, pp. 195–227. PUF, Paris (2003)
9. Le Roux, B., Rouanet, H.: Geometric Data Analysis. Kluwer Academic Publishers, Dordrecht (2004)