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**15. SUPPLEMENTARY NOTES**

Requirement: AJM-FY20-5 - Integration of Touch-Based User Interfaces into Air Traffic Control Systems
The FAA Human Factors Design Standard has very limited guidance on touch-based user interfaces. Requirements are limited to basic parameters such as touch target size. Touch-based user interfaces are already beginning to appear on air traffic control systems, with individual program teams independently establishing program-level requirements. What is needed is a literature review and market research to identify best practices and existing standards, an assessment of applicability, and an update to the Human Factors Design Standard establishing requirements for FAA systems.


**16. ABSTRACT**

The objective of this effort is to identify human factors issues and generate guidelines and recommendations for updating the FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B], touch based user-interface (TUI) section. Technical tasks consist of conducting a literature review, a gap analysis with recommendations for future research and a guidelines generation report. The literature review included relevant scientific literature, industry documents, regulatory and guidance material, and user behavior to assess current state of touch-based user interfaces for ATC controls The gap analysis consisted of 1) summary of issues found in the literature review and an assessment of gaps in the current HFDS, and 2) recommendations for future research for human factors issues pertaining to touch that are not covered by the HFDS section 5.7.4.2 Touch Screens. This Guidelines Report extracts findings from analysis performed and provides preliminary recommendations for requirements and guidance updates to be included in future updates to the HFDS for touch-based user interfaces.



**17. KEY WORDS**

Air Traffic Control, touchscreen, multi-touch touchscreen, touch user interface, human factors, readability, reflections, luminance, touch target size, touch errors, touch gestures, latency, fatigue, display position, inclination angle, design, display system, FAA HF-STD-001B


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**Touch User Interfaces in Air Traffic Control: Final Guidelines Report with Recommended Updates for the FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B]**

**Honeywell NextGen Aviation Human Factors Research & Development**

**Honeywell Contract # DTFAWA-17-V-0004**
**Task 7: Update Human Factors Design Standard Section on Touch Screens**

**Prepared for the FAA**

**March 16, 2022**

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**Advanced Technology**
**Crew Interface Platform Systems**

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**Acronyms & Abbreviations**

| | |
|---|---|
| AC | Advisory Circular |
| ACM | Association for Computing Machinery |
| AEG | Aircraft Evaluation Group |
| AIAA | American Institute of Aeronautics and Astronautics |
| AIM | Aeronautical Information Manual |
| ANOVA | Analysis of Variance |
| ASI | Aviation Safety Inspector |
| ASIAS | Aviation Safety Information and Sharing |
| ARTCC | Air Route Traffic Control Centers |
| ASRS | Aviation Safety Reporting System |
| ATC | Air Traffic Control |
| ATCSCC | Air Traffic Control System Command Center |
| ATM | Air Traffic Management |
| ATP | Airline Transport Pilot |
| CFR | Code of Federal Regulations |
| cm | Centimeter |
| CPDLC | Controller-Pilot Data Link Communication (CPDLC) |
| CSCW | Conference on Computer-Supported Cooperative Work and Social Computing |
| CWA | Cognitive Work Analysis |
| DTIC | Defense Technical Information Center |
| DVI | Driver Vehicle Interfaces |
| EAP | Electroactive Polymer |
| EASA | European Aviation Safety Agency |
| EEG | Electroencephalography |
| EFB | Electronic Flight Bag |
| EMG | Electromyography |
| ERM | Eccentric Rotating Mass |
| FAA | Federal Aviation Administration |
| Fc | Foot Candle |
| FSDO | Flight Standards District Office |
| GUI | Graphical User Interface |
| HCI | Human Computer Interaction |
| HFDS | Human Factors Design Standard |
| HFES | Human Factors and Ergonomics Society |
| HMI | Human Machine Interface |
| Hz | Hertz |
| IASTED | International Association of Science and Technology for Development |
| ICAO | International Civil Aviation Organization |
| ICMI | International Conference on Multimodal Interaction |
| IEEE | Institute of Electrical and Electronics Engineers |
| IR | Infrared |
| ISO | International Organization for Standardization |
| IUI | Intelligent User Interfaces |
| LRA | Linear Resonant Actuator |
| min | Minute |

| | |
|---|---|
| ms | millisecond |
| MS | Microsoft |
| NACO | National Aeronautical Charting Office |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NextGen | Next Generation Air Transportation System |
| NTIS | National Technical Information Service |
| OTW | Out-the-Window |
| PCAP | Projected Capacitance |
| PIREP | Pilot Report |
| RTCA | Radio Technical Commission for Aeronautics |
| SARA | Speed and Route Advisor |
| SARDA | Spot and Runway Departure Advisor |
| SID | Standard Instrument Departure |
| SOP | Standard Operating Procedure |
| SPECOM | International Conference on Speech and Computer |
| STDEV | Standard Deviation |
| TRACON | Terminal Radar Approach Control Facility |
| TSC | Touch Screen Controller |
| TUI | Touch Based User Interface |
| UI | User Interface |
| US DOT | United States Department of Transportation |
| VSCS | Voice Switching and Control System |

## 1.0 Objective

The objective of this program is to identify human factors issues and generate guidelines and recommendations for updating the FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B], touch based user-interface (TUI) section. Technical tasks consist of the following:

- Literature Review of relevant scientific literature, industry documents, regulatory and guidance material, and industry standards (completed).
- Gap Analysis Report with Recommendations for Future Research (completed)
- Guidelines Generation Report with recommendations of updates to FAA HF-STD-001B
    - Draft Guidelines Report
    - Final Report

This report contains a preliminary set of guidelines and recommendations for the FAA to include in a future update to FAA HF-STD-001B. It is based on the on the results of the literature review and gap analysis.

## 2.0 Introduction

The first step towards updating the HFDS, which has been completed by Honeywell, was to produce a literature review report on TUIs for ATC applications. The second step, which has also been completed by Honeywell, was to produce a gap analysis report, in which the information from the literature review was cross-analyzed and compared to information already in the FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B]. The gap analysis included 1) a summary of issues found in the literature review and a cross check to see if those issues are adequately addressed in the FAA HF-STD-001B, and 2) recommendations for future research for human factors issues pertaining to TUIs that are not adequately addressed in the current the HFDS section 5.7.4.2 Touch Screens.

This current report extracts findings from analysis performed and provides preliminary recommendations for requirements and guidance updates to be included in future updates to FAA HF-STD-001B for touch-based user interfaces. Additional recommendations based on future research should be further elaborated on after that research is complete.

## 3.0 Preliminary Guidelines Recommendations

This section includes preliminary recommendations for guideline updates to FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B], touch based user-interface (TUI) section. The recommended guidance updates are intended to reduce the potential for human factors issues associated with the implementation of touch user interfaces into ATC operations.

The current HFDS for TUIs focuses on five main areas including luminance transmission, positive indication, display feedback, minimal parallax, and minimal specular glare. Honeywell recommends expanding these areas as well as incorporation of additional guidance not currently in the HFDS for use of TUIs. The section numbers from the HFDS are indicated below in parenthesis for reference.

Many TUIs are integrated with a display as a system (i.e., touch display). For specifications and standards, there are different schools of thought: 1) address touch displays similar to non-touch displays; 2) address only the touch screen itself. Separating the touch screen from the display does not take into consideration the impacts of the touch itself on optical properties and characteristics of the touch display as a system.

The recommendations below address the touch user interface as an integrated system of both display and touch (i.e., touch user interface display).

## 3.1 Touch User Interface Definition

*Recommendation – Update Definition*

Expanding the definition offers clarity. The first sentence is in the existing HFDS should indicate pointing by direct touch (as opposed to a gesture in the air).

**(5.7.4.1) TOUCH USER INTERFACE**

**Definition**

**Touch User Interface.** *A touch use interface (TUI), (e.g.,* touchscreen device*)* is an input device that permits users to interact with the system by pointing to objects on the display *via direct touch by fingertip or touch stylus on the surface*. Touchscreen control may be used to provide an overlaying control function to a data display where direct visual reference access and optimum direct control access are desired. [Source: MIL-STD-1472H, 2020; DOD-HFDG-ATCCS (DOD-HFDG-ATCCS V2.0), 1992]

**Multi-touch Touchscreen.** A multi-touch touchscreen device functions with one or more direct touch inputs. Multi-touch represents a set of interaction techniques that allow touch screen input with more than one digit and uses software that recognizes multiple, simultaneous touch points as opposed to a single touch point. [Source: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015]

This section applies to multi-touch touchscreen displays, and not to touch pad controls (e.g., touch pad on a laptop, etc.).

## 3.2 Readability

*Recommendation – Add section called Readability.* Subsections that apply to readability should be included in this section. An additional recommendation would be that 5.3.1.1 GLARE CONTROL be revised and be called 5.3.1.1 REFLECTIONS, and updated to include reflections from displays, specular reflection, diffuse reflections, and reflected glare to match MIL-STD-1472H, which concurs with how much of industry refers to these (e.g., Honeywell, etc.).

**(5.7.4.2) READABILITY**

High ambient lighting conditions pose challenges for touch user interfaces in reduced legibility of text display in bright sunlight, screen display scratches, and grease spots from fingerprints after heavy usage. To achieve readability of displays in high ambient conditions (see 5.7.4.2.1.5 below) touch user interface surfaces require special anti-reflective films or coatings [Source: MIL-STD-1472H section 5.2.1.4.1-f]. It should be noted that specular and diffuse specifications were set for displays *without* integrated touchscreens (see MIL-STD-1472H, section 5.2.1.4 Reflections and HF-STD-001B section 5.3.1.1 GLARE CONTROL); to obtain best readability; however, the presence of fingerprints pose a challenge to touch user interfaces for meeting the criteria.

### 3.2.1 Luminance

**(5.7.4.2.1) Luminance**

- **Luminance transmission.** Touch user interfaces shall have sufficient luminance transmission to allow the display to be clearly readable in the intended environment from the intended operating position. [Source: MIL-STD-1472H, section 5.1.3.1.2]

- 5.7.4.2.1.2 **Luminance control and contrast**. Touch user interface displays shall conform to requirements for displays but shall also have sufficient luminance and contrast to be usable under all expected ambient illumination conditions even in the presence of fingerprints. [Source: MIL-STD-1472H] Also see HF-STD-001B section 5.11.4.4.1.

- 5.7.4.2.1.3 **High ambient light**. Touch user interfaces installed in areas of high ambient light must be readable in that light environment, even in the presence of fingerprints.

  - 5.7.4.2.1.3.1 **High ambient outdoor.** Display contrast shall be more than 0.6 black: 1 white, up to a viewing angle of 60 degrees in an environment of 10.000 fc for touch user interfaces in the presence of fingerprints. [Source: Zeh, 1999]

  - 5.7.4.2.1.3.2 **High-ambient indoor (e.g., ATC tower, etc.).** Touch user interface displays shall be designed to be readable at 6,040fc. [Source: Wilson et al, 2007]

  - 5.7.4.2.1.3.3 **Worst case ambient light conditions.** Touch user interface displays shall be designed to function in ambient light levels of 50 fc -10000 fc [Source: Livada, B., 2019]

### 3.2.2 Reflectance

**(5.7.4.2.2) Reflectance**

Section 5.11.4.2 gives guidance for illumination for the workplace and specific tasks. There are two specific subsections that apply to touch user interface displays. Section 5.11.4.4 addresses glare from light sources, while Section 5.11.4.5 addresses reflected glare, which is of particular interest for touch user interface displays. Glare from surfaces which have oil, dirt, and debris from fingerprints exasperate issues with reflections. Testing in the intended environment is recommended for establishing cleaning/maintenance schedules to minimize reflections from fingerprints, oil, and contaminants.

- 5.7.4.2.2.1 **Minimal specular glare**. Touch-interactive devices should be selected and mounted to minimize specular glare caused from fingerprints. [Source: MIL-STD-1472H, section 5.1.3.1.11; DOD-HFDG-ATCCS V2.0, 1992]
- 5.7.4.2.2.2 **Specular reflections**. Touch user interface displays should be located such that light from an external source does not exceed 1.0 percent of the display luminance for a viewing angle of 30 degrees or less from the display normal even in the presence of fingerprints. [Source: MIL-STD-1472H, 2020, section 5.2.1.4.2]
- 5.7.4.2.2.3 **Diffuse reflections.** Touch user interface displays should be located such that light from an external source creating a diffuse reflection on a touch user interface display with fingerprints does not exceed 0.2 percent of the display luminance for a viewing angle of 30 degrees or less from the display normal or across the expected range of operator viewing angles, even in the presence of fingerprints. [Source: MIL-STD-1472H, 2020. Section 5.2.1.4.3]
- 5.7.4.2.2.4 **Visual quality.** Characteristics of touch-interactive devices shall not degrade visual display quality in a manner that impairs user performance. [Source: MIL-STD-1472H, 2020, section 5.1.3.1.5]
- 5.7.4.2.2.5 **Cleaning.** Touch use interface displays shall be cleanable without destroying the visual display or interaction. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; FAA AC 20-175, 2016]
- 5.7.4.2.2.6 **Cleanable without inadvertent touch.** Touch screens should be cleanable without causing inadvertent activation of functions. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; FAA AC 20-175, 2016]

## 3.3 Touch Target Size

*Recommendation – Add section called Touch Target Size.* Subsections that apply to size of touch active area should be included in this section.

### (5.7.4.3) Touch Target Size

Available standards and other research vary on specifications for target size and separation.

- 5.7.4.3.1 **Touch target size.** Touch target (active area) size and separation should be confirmed for use in relevant environment and location. Figure 1 describes target size and separation pictorially. Table 1 shows various recommended target size and separations.

**Figure 1. Target Size and Separation Diagram**

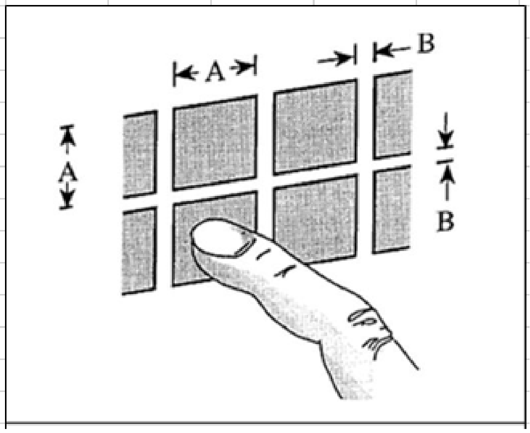



**Table 1. Touch Target Size and Separation**

| Source/Use | Touch Target Size (Actuation Area A) | Separation B | Resistance | Comments |
|---|---|---|---|---|
| MIL-STD-1472H Alphanumeric keyboards | Preferred 16 mm x 16 mm (0.63 in x 0.63 in) | 2.0 mm minimum to 6.0 mm (0.25 in) maximum | 250 mN (0.9 oz.) minimum to 1.5 N (5.3 oz.) maximum | For touchscreens that use a "first contact" actuation strategy, separation between targets shall be not less than 5 mm (0.2 in). For touchscreens that use a "last contact" strategy, separation between targets may be less than 5 mm (0.2 in), but not less than 3 mm (0.12 in) for applications other than alphanumeric / numeric keyboards. |
| MIL-STD-1472H Other Applications | 15 by 15 mm (0.59 by 0.59 in) minimum to 38 by 38 mm (1.5 by 1.5 in) maximum | 3.0 mm (0.12 in) minimum to 6.0 mm (0.25 in) maximum | 250 mN (0.9 oz.) to 1.5N (5.3 oz.) | |
| Honeywell Dodd, et al (2014, 2015) All applications | 13 mm x 13 mm (0.5 in x 0.5 in) minimum | 2.54mm (0.1 in) minimum | | For touch screen use under high vibration, (e.g., turbulence), hand stabilization is required for use with these target sizes. |
| ANSI HFES 100 All applications | Minimum 9.5 mm x 9.5 mm (0.4 in. x 0.4 in.) | 3.2 mm (0.13 in.) minimum | 0.25 to 1.5 N (0.9 ounce-force–5.4 ounce-force) | If the touch screen and the image plane of the screen are separated, the dimensions of the touch areas should be increased to avoid user performance |

| | | | | |
|---|---|---|---|---|
| | | | | degradation attributable to parallax problems.<br><br>The optimum touch-sensitive area depends on the application and required accuracy. |

[Source: MIL-STD-1472H, 2020; DOD-HFDG-ATCCS V2.0, 1992; ANSI HFES 100, 2007; Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015]

## 3.4 Touch Errors

*Recommendation – Add section called Touch Errors.* Subsections that apply to size of touch active area should be included in this section.

### (5.7.4.4) Touch Errors

The possibility of inadvertent touches by the user of touch user interface displays requires evaluation in the relevant setting and environment in which they are to be used.

- 5.7.4.4.1 **Inadvertent errors.** Target size, separation, and space around outsides of touch targets shall be of sufficient size to minimize inadvertent touch errors and failure due to unintended touch activation of the touch user interface display (see Table 1). [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

- 5.7.4.4.2 **Activate upon release.** For critical applications and functions, touch user interface displays should only activate upon release of touch (activate after lifting finger or stylus off touch sensitive surface). Users must be able to slide off touched target then release to avoid inadvertent activation of unintended target. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

- 5.7.4.4.3 **Visually distinguishable.** Emergency and critical buttons should be visually distinguishable. DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

- 5.7.4.4.4 **Critical Task Confirmation**. For critical tasks using touch input, a confirmation step with additional touch input shall be required to mitigate unintended or inadvertent activation. [Source: MIL-STD-1472H, 2020; Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

- 5.7.4.4.4 **Minimal parallax.** Touchscreen devices should be selected and mounted to minimize parallax issues. [Source: MIL-STD-1472H, 2020; DOD-HFDG-ATCCS, 1992]

    - The distance between the touch sensitive surface and the display surface should be minimized to reduce touch errors from parallax. [Source: Stammers & Bird, 1980]

- 5.7.4.4.5 **Viewing angle and touch user interface display position**. Touchscreen viewing angle and position shall be located such that the user is able to see what he or she is touching (i.e., adequate line of sight). [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

    - 5.7.4.4.5.1 **Touchscreen viewing angle.** See 5.7.4.2.10.1.

    - 5.7.4.4.5.2 **Vertical mounted touch displays.** Vertical touch user interface displays should not be used for installation/applications that require greater than 95 percent accuracy Touch user interface displays installed in vertical positions have higher fatigue potential and reduced accuracy. [Source: Honeywell: Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

    - 5.7.4.4.5.3 **Hand stabilization.**
        a) **Vibration environment**. Hand stabilization shall be provided on touch user interfaces that may experience movement and vibrations from the environment (e.g., turbulence or other vibrations). [Source: Honeywell, Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

        b) **Identification.** Surfaces or locations that users may use for hand stabilization shall be identified to help inform where on the display the gesture tasks can be performed most effectively. [Source: Honeywell, Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12), 2018]

## 3.5 Heads-down Time

Excessive heads-down time can create loss of focus of main task at hand, due to the fact users must look at the touch user interface display to interact with it. Insufficient data currently exists to prescribe specific timing, therefore special studies may be necessary for the particular system and task context. See Appendix B. Design Process Considerations.

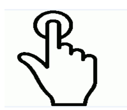
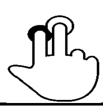
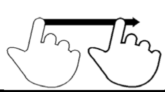
## 3.6 Touch Gestures

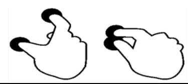
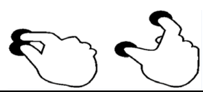
*Recommendation – Add section called Touch Gestures.* Subsections that apply to size of touch gestures should be included in this section.

**(5.7.4.5) Touch Gestures**

Common touch gestures include tap, double tap, long press (press & hold), drag (pan), select & drag (also known as drag and drop), swipe, pinch, spread and rotate, as shown in Table 2.

**Table 1. Common Touch Gestures**

| Name | Symbol | Description | Action |
|---|---|---|---|
| Tap |  | Briefly touch surface with fingertip. | Tap may be used to select a target or button (e.g., data entry, menu buttons). |
| Double Tap |  | Rapidly touch surface twice with fingertip. | Double tap may be used differentiate from single tap to mitigate inadvertent touch or accidental activation to select specific buttons (require 2 taps for specific targets). |
| Long Press |  | Touch surface for extended period of time. | Long press may be used to differentiate from single tap to mitigate inadvertent touch or accidental activation (e.g., power button). |
| Drag |  | Move fingertip over surface without losing contact. | Drag may be used to pan images (e.g., map) |
| Select & Drag |  | Select a zone target and move fingertip over surface without losing contact | Select & drag may be used to select a target and place in another area of image (e.g., drag and drop for questionnaires, targets, etc.) |

| | | | |
|---|---|---|---|
| Swipe |  | Very quick drag. | Swipe may be used to quickly dismiss an object or flip between pages or screens. |
| Pinch |  | Touch surface with two fingers and bring them closer together. | Pinch may be used to change magnification (e.g., zoom out). |
| Spread |  | Touch surface with two fingers and bring move them apart. | Spread may be used to change magnification (e.g., zoom in). |
| Rotate |  | Press surface with two fingers, long press with one of them and draw a curve in a clockwise or counterclockwise direction to rotate area/target. | Rotate may be used to rotate an image. |

[Source: Honeywell: Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.5.1 **Obscuration.** Gestures requiring more than two digits have greater potential to obscure touch targets and display information and shall not be used for critical operations. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

  - 5.7.4.5.2 **Gestures on vertical touch displays.** Gestures used for vertically mounted touch user interface displays shall be associated with touch targets that are greater than 0.5" x 0.5" to support finger pad actuation (instead of fingertip activation) to support improved touch accuracy (for projected capacitive touch technology, due to fingernails, callouses, and dry skin). [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.5.3 **High frequency use**. A touchscreen should not be the sole input means if the interface will be used to enter large amounts of data frequently [Source: MIL-STD-1472H, 2020]

- 5.7.4.5.4 **Sensitivity.** Fingertip contact with the touchscreen shall be able to actuate the control or input function. [Source: MIL-STD-1472H, 2020]

- 5.7.4.5.5 **Operational conditions**. Screen sensitivity shall match all expected operational modes including the use of gloves (e.g., gloved operations during flight or inclement weather). [Source: MIL-STD-1472H, 2020]

- 5.7.4.5.5 **Sustained interaction.** Touchscreens shall not be used for frequent actions over an extended duration of time (e.g., typing on a virtual keyboard or continuous target selection).
    - **Exception**. This requirement does not apply to small hand-held devices. [Source: MIL-STD-1472H, 2020]

- 5.7.4.5.6 **Display feedback.** Touch gestures shall provide visual feedback that the target is being touched. [Source: MIL-STD-1472H, 2020]

- 5.7.4.5.7 **Positive indication.** A positive indication of touch-panel activation shall be provided to acknowledge the system response to the control action. [Source: MIL-STD-1472H, 2020; DOD-HFDG-ATCCS, 1992]

- 5.7.4.5.8 **Disabled Areas.** Portions of the touch user interface shall have capability to be disabled for touch gestures to minimize inadvertent errors (e.g., multi-touch gestures such as drag/pan pinch and zoom, etc., shall not be able to inadvertently activate critical areas of display). [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.5.9 **Gesture type.** The gestures used on the touch user interface display shall be assessed for what touch gestures should be functional for the intended application. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.5.10 **Stabilization.** Hand stabilization shall be provided for touch user interfaces. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

## 3.7 Latency

*Recommendation – Add section called Latency.* Subsections that apply to latency and response time should be included in this section.

### (5.7.4.6) Latency

Latency is the delay between a finger touch on a touch screen and the feedback given. Latency involves the time needed to recognize the touch, processing time to interpret the input and response, the sampling rate from a touch sensor, and the time for the visual display to change (refresh rate).

- 5.7.4.6.1 **Display response time (latency).** Display response time should not be more than 100 milliseconds (ms). [Source: MIL-STD-1472H, 2020]

    - **Operational considerations.** A shorter display response time may be dictated by operational considerations; latency should be evaluated in a representative environment to ensure that (when informed by the displayed information), the representative users' human performance meets task requirements. [Source: MIL-STD-1472H, 2020]

- 5.7.4.6.2 **Feedback guidelines.** Guidelines for latency feedback are shown in Table 3. Feedback latency shall be tested and confirmed via evaluation in the relevant environment in which it will be used, especially in a high workload environment. [Source: Kaaresoja, 2016]

**Table 2. Guidelines for unimodal and bimodal latency feedback.**

| Type of Feedback | Visual (ms) | Audio (ms) | Tactile (ms) |
|---|---|---|---|
| Unimodal | 30 - 85 | 20 - 70 | 5 - 50 |
| Bimodal | | | |
| Visual-Audio | 95 | 70 | |
| Visual-Tactile | 100 | | 55 |
| Tactile-Audio | | 100 | 25 |

[Source: Kaaresoja, 2016]

- 5.7.4.6.4 **Display refresh rate**. Latencies shall be multiples of the current refresh rate. Display refresh rate strongly affects latency in touch devices. Touch input can register quickly but will not display until the display can redraw the image. 60 Hz displays are currently the norm for display refresh rate. [Source: Deber, et al., 2015]

## 3.8 Fatigue and Touch User Interface Display Position

*Recommendation – Add section called Fatigue and TUI position.* Subsections that apply TUI position as related to the user should be included in this section.

**(5.7.4.7) Fatigue and TUI Position**

- 5.7.4.7.1 **Touchscreen viewing angle.** Touchscreens shall be perpendicular to the user's line of sight while the user is in a normal operating position. [Source: MIL-STD-1472H]
  - 5.7.4.7.1.1 **Reduced viewing angle**. A reduced viewing angle, less than 90 degrees from horizontal, may reduce arm fatigue for frequent actions; however, changes to viewing angle shall be evaluated in relation to the negative impact on parallax, specular glare, and readability. [Source: MIL-STD-1472H]
- 5.7.4.7.2 **Inclination Angle.** Touch user interface displays should not be mounted at locations and vertical angles that cause hyperextension of the wrist, where users must flex their wrist to make greater contact with fingertip pad (for projected capacitive touchscreens, which requires conductivity to activate), and thereby increases propensity for fatigue. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.7.2 .1 **High angle.** Touch display installations with inclination angles ≥75° from horizontal should be assessed for user fatigue and workload when used for prolonged periods of time. [Source: Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- 5.7.4.7.3 **Accommodation.** See section 5.8.1.2.
- 5.7.4.7.4 **Reach.** In addition to below, see section 5.12.4.
  - 5.7.4.7.4.1 Users shall be able to reach and actuate all areas of the touch screen, including corners of the display. [Source: MIL-STD-1472H, 2020]
- 5.7.4.7.5 **Avoid full arm extension.** Touchscreens shall be located to avoid full arm extension. [Source: MIL-STD-1472H, 2020]
- 5.7.4.7.6 **Avoid upward reach**. Touchscreens shall be located to avoid upward reach. [Source: MIL-STD-1472H, 2020]
- 5.7.4.7.7 **Elbow support**. Elbow support shall be provided to minimize arm fatigue. [Source: MIL-STD-1472H, 2020]

## 3.9 Existing Human Factors Design Standard (HF-STD-001B) (2016)

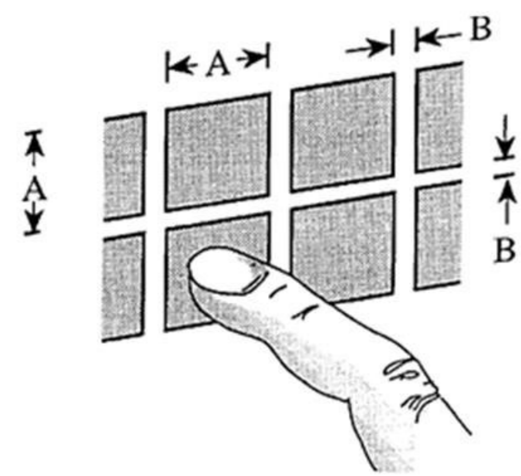
The current HFDS [FAA HF-STD-001B] for touch screens focuses on the five main areas including luminance transmission, positive indication, display feedback, minimal parallax, and minimal specular glare. This section includes the original language for reference purposes to show what is being updated.

- Human Factors Design Standard (HF-STD-001B) (2016)
  - TOUCH SCREENS
  - A touchscreen device is an input device that permits users to interact with the system by pointing to objects on the display. [Source: DOD-HFDG-ATCCS (DOD-HFDG-ATCCS V2.0), 1992]
    - **5.7.4.2.1 Luminance transmission.** Touch screens shall have sufficient luminance transmission to allow the display to be clearly readable in the intended environment. [Source: MIL-STD-1472G, 2012; DOD-HFDG-ATCCS, 1992]
    - **5.7.4.2.2 Positive indication.** A positive indication of touch-panel activation shall be provided to acknowledge the system response to the control action. [Source: MIL-STD-1472G, 2012; DOD-HFDG-ATCCS, 1992]

- 5.7.4.2.3 **Display feedback**. Display of user command or action feedback for touch panels shall appear immediate to the user. [Source: MIL-STD-1472G, 2012; DOD-HFDG-ATCCS, 1992]

- 5.7.4.2.4 **Minimal parallax**. Touch-interactive devices should be selected and mounted to minimize parallax problems. [Source: MIL-STD-1472G, 2012; DOD-HFDG-ATCCS, 1992]

Exhibit 5.7.4.2.4 Touch panel responsive area dimensions.




| | A<br>Size | B<br>Separation |
|---|---|---|
| Minimum | 19 mm<br>(0.75 in) | 3 mm<br>(0.13 in) |
| Maximum | 38 mm<br>(1.5 in) | 6 mm<br>(0.25 in) |

- **5.7.4.2.5 Minimal specular glare.** Touch-interactive devices should be selected and mounted to minimize specular glare. [Source: DOD-HFDG-ATCCS V2.0, 1992, MIL-STD-1472G, 2012]

## 4.0 Recommendations for Future Research

For completeness, this section includes the recommendations for future research from the gap analysis, which identified several areas which need further assessment to fully understand human factors implications of TUIs for ATC applications. Guidance about task-related compatibility and potential pros and cons of TUI use for specific applications is needed. Guidance is needed about how and where TUIs *should* be used as input devices, whether it be ATC towers, Terminal Radar Approach Control Facilities (TRACONs), Air Route Traffic Control Centers (ARTCCs), and the Air Traffic Control System Command Center (ATCSCC).

Recommended areas for future research to be used to inform additional guidance and updates to HFDS include:

- Touch Errors
- Heads-down Time
- Touch Gestures
- Touch Target Size
- Inclination Angle
- Fatigue and TUI Position
- Readability
- Seated Vs. Standing Operations and Use of Touch Screens
- Latency
- Implications of Task-Dependency on Input Method

*Touch Errors*

- Research is needed to assess errors caused from position of the TUIs with respect to working position (some position cause users to not be able to adequately see the screen they are interacting with).
    - Viewing angles need to be properly considered when designing working positions that include touch screen monitors.
        - Difficulty in seeing the monitors may exacerbated from reflections.

*Heads-down Time*

- Research on implications of direct versus indirect touch to interact with various displays and applications is needed (i.e., impact on heads-down time).

- Further research is needed to guide where TUIs should and should not be used in the 'system', including impact and issues with TUI and tactile (and where tactile input (keyboard and/or mouse).

    - Further assessment is recommended to fully understand the reasons for preference of a touch screen to a mouse for TFDM.

        - Is touch so compelling users are willing to risk being heads-down in an environment they need to be heads-up?

*Touch Gestures*

- Understanding which touch gestures should or should not be used in the ATC environment is recommended for further evaluation.

*Touch Target Size*

Available standards and other research vary on specifications for target size and separation.

- Touch target size (active area) should be confirmed for use in relevant ATC environment.
- Recommend further research to identify potential applications for the various size recommendations to examine task-related compatibility and potential pros and cons of use in particular applications.

*Inclination Angle*

- Recommend evaluation for various ATC installations and TUI positions for inclination angles.

*Fatigue and TUI Position*

- TUI and associated display positions and ergonomics is a potential issue with the use of TUIs in an ATC environment. Solutions for the body posture of the controller and integration of TUIs at appropriate height and angle need to be explored further.
    - There is a need to fully understand the domain of application when considering touch screen location. There may be locations TUIs should not be used.
    - The ergonomics of using touch in the various ATC installations and positions needs to be evaluated for implications of fatigue.

*Readability*

- Research needs to be done to further evaluate the impact of reflections from fingerprints in ATC high ambient light conditions.
    - The questions are: at what point does the surface contamination interfere with readability, and how often should the surface be cleaned?

- Research needs to be done to recommend a cleaning schedule/interval for removing oil and contaminants from the touch surface.

*Seated Vs. Standing Operations and Use of Touch Screens*

- Research is needed to provide guidance for the use of TUIs for both seated and standing user positions.
  - This includes researching implications from use of TUIs while using a sit-stand workstation, where users may vary position within the work shift.
  - Sit-Stand workstations where the TUIs are mounted in various positions need further assessment for implications of viewing angles as it relates to touch errors.
  - Evaluation should be conducted to assess the implications of TUIs mounted on adjustable articulating arms at the workstation. This includes investigating if TUIs are susceptible to movement and inadvertent touch activation.

*Latency*

- Guidelines for unimodal feedback and bimodal feedback latency should be confirmed via evaluation in a relevant ATC environment for interacting with electronic flight strips to inform whether these guidelines should be SHALL or SHOULD.

*Implications of Task-Dependency on Input Method*

Research is needed to assess implications of task-dependency on input method. An evaluation should be completed to determine the implications of task-dependency on input method to determine appropriate device use for various task types.

- TUI may have a more intuitive feel in terms of the interaction, particularly when accessing hierarchies or option menu items in a GUI. While touch screens may not take up as much workspace as a separate keyboard and pointing device with a display, there is also an obvious task-dependency that will help determine whether a separate physical keyboard and pointing device are to be provided. For data entry tasks of more than a few words, the keyboard would most likely be preferable. Frequent numeric entries would most likely be more suited to a numeric keypad. Forms that have multiple data entry fields could be exhausting to use with a TUI vs. a mouse or trackball, or simply using a keyboard Tab key. While a touch screen with virtual keyboard and numeric keypad could be used, performance would likely be slower and more error prone, as well as more fatiguing.

## 5.0 Conclusion

The review of scientific and technical data and literature on TUIs for ATC applications was used to inform and conduct a gap analysis, where the information herein was cross-analyzed and compared to information already in the FAA Human Factors Design Standard (HFDS) [FAA HF-STD-001B].

This report provides preliminary recommendations for requirements and guidance updates to be included in future updates to FAA HF-STD-001B for touch-based user interfaces. Additional recommendations based on future research should be further elaborated on after that research is complete.

This report includes many considerations to be used towards recommending updated guidance to reduce the potential for human factors issues associated with the implementation of touch user interfaces into ATC operations. This project directly supports including best-practice standards for ATC system development and integration of future systems that make use of touch-based user interfaces.

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## Appendix A. Known Standards for the Use of Touch-User Interfaces

This section includes a listing of standards literature pertaining to touch user interfaces.

International Organization of Standardization (ISO)

- EN ISO 9241-410 (2008) – Ergonomics of Human-System Interaction – Part 410: Design Criteria for Physical Input Devices
    - 

SAE International (previously known as Society of Automotive Engineers)

- SAE ARP 60494 (2019) - Touch Interactive Display systems: Human Factors Considerations, System Design and Performance Guidelines
- SAE AS8034c (2018) Minimum Performance Standard for Airborne Multipurpose Electronic Displays

Radio Technical Commission for Aeronautics (RTCA)

- RTCA DO -372 (2017) - Addressing Human Factors/Pilot Interface Issues for Avionics
- RTCA DO – 256 (2018) – Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps

Federal Aviation Administration (FAA)

- Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls Version 2.0 (2016)
    - AC 20-175 – Controls for Flight Deck Systems/FAA Regulatory and Guidance Material

- Human Factors Design Standard (HF-STD-001B) (2016)

Department of Defense Design Criteria – Human Engineering

- MIL-STD-1472H -Section 5.1 (2020)

    - 5.1.3.1 Touch screen controls for displays

    - 5.1.3.1.1.1 High frequency use. A touchscreen should not be the sole input means if the interface will be used to enter large amounts of data frequently.

    - 5.1.3.1.1.2 Luminance transmission. Touchscreens shall have sufficient luminance transmission to allow the display to be clearly readable in the intended environment (including from the seated position for the full range of users, if applicable) and meet the display luminance requirements.

    - 5.1.3.1.1.3 Positive indication. A positive indication of touchscreen actuation shall be provided to acknowledge the system response to the control action.

- 5.1.3.1.1.4 Display response time (latency). Display response time should not be more than 100 milliseconds (ms). A shorter display response time may be dictated by operational considerations. Any latency should be evaluated in a representative environment to ensure that it meets human performance requirements.

- 5.1.3.1.1.5 Impact on visual display. Characteristics of touch-interactive devices shall not degrade visual display quality in a manner that impairs user performance.

  - 5.1.3.1.1.7 Critical tasks. Where a touch screen control is used for a critical task, system response shall require an additional confirmatory action to ensure that the control actuation is intended.

  - 5.1.3.1.1.11 Parallax and glare. Touchscreen devices shall be mounted to minimize parallax issues and specular glare.

  - 5.1.3.1.1.12 Touchscreen viewing angle. When possible, touchscreens shall be perpendicular to the user's line of sight while the user is in a normal operating position. A reduced viewing angle, less than 90 degrees from horizontal, may reduce arm fatigue for frequent actions; however, changes to viewing angle shall be evaluated in relation to the negative impact on parallax, specular glare, and readability.

  - 5.1.3.1.1.13 Reach. Reach design for touchscreens shall meet the criteria in 5.1.3.1.13.1 through 5.1.3.1.13.5.

  - 5.1.3.1.13.1 Accommodation. Touchscreens shall be mounted to ensure the multivariate central 90 percent (95 percent preferred) of suitably clothed and equipped males of the target user population and the multivariate central 90 percent (95 percent preferred) of suitably clothed and equipped females of the target user population are accommodated. Unless otherwise specified (see 6.2), users shall be able to reach and actuate all areas of the screen, including corners of the display.

  - 5.1.3.1.13.2 Avoid full arm extension. Touchscreens shall be located to avoid full arm extension.

  - 5.1.3.1.13.3 Emergency controls. If emergency controls are located on touchscreens, the emergency controls shall be able to be reached by crewmembers with their harness or seat belt locked even if full arm extension is necessary.

  - 5.1.3.1.13.4 Avoid upward reach. Touchscreens shall be located to avoid upward reach.

  - 5.1.3.1.13.5 Elbow support. Where possible, elbow support shall be provided to minimize arm fatigue.

  - 5.1.3.1.13.14 Sustained interaction. Touchscreens shall not be used for frequent actions over an extended duration of time (e.g., typing on a virtual keyboard or continuous target selection). This requirement does not apply to small hand-held devices.

- 5.1.3.1.17 Dimensions, resistance, and separation

    - Touch screen button dimensions, separation distance, and resistance for *alphanumeric keyboards*.
        - Actuation Area: preferred 16 mm x 16 mm (0.63 in x 0.63 in)
        - Separation: 2 mm minimum to 6.0 mm (0.25 in) maximum
        - Resistance: 250 mN (0.9 oz.) minimum to 1.5 N (5.3 oz.) maximum

    - Touch screen button dimensions, separation, and resistance for *other applications*
        - Actuation Area: 15 by 15 mm (0.59 by 0.59 in) minimum to 38 by 38 mm (1.5 by 1.5 in) maximum
        - Separation: 3.0 mm (0.12 in) minimum to 6.0 mm (0.25 in) maximum
        - Resistance: 250 mN (0.9 oz.) to 1.5N (5.3 oz.)
    - Standard cotton flame resistant anti-flash gloves should add 5.0 mm (0.2 in) to each dimension of the actuation area.
    - Separation between targets should not be less than 5.0 mm (0.2 in) for touch screens that use a "first contact" actuation strategy.

Computer-Human Interface (CHI) Guidelines for Enterprise Information Display Systems (E-IDS) (2020)

American National Standards Institute (ANSI)

- ANSI/HFES 100 (2007)
    - https://www.xybix.com/hubfs/ANSI_HFES_100-200727E2.pdf?t=1508538849931

- ANSI/HFES 200 (2008) - Human Factors Engineering of Software User Interface
    - https://law.resource.org/pub/us/cfr/ibr/006/hfes.200.2.html#s9.3

Other Standards

- MIL-HDBK-759C (5.4 Controls and 5.4.6 touch screen controls for displays)

- NASA/SP-2010-3407 – Section 10.6.3

- ASTM F1166 13 Human-Computer Interfaces – 13.27 Input Devices

- Human Factors Criteria for the Design and Acquisition of Non-Keyboard Interaction Devices: A revision to Chapter 9 of the Human Factors Design Standard (June 2004) Ahlstrom & Kudrick
    - If task is repetitive and operation frequency is high, traditional keyboard should be used instead of touch pad or touch screen (HFCD and acquisition of keyboard interaction).

- Analysis of the Application of Touch Screen in Civil Aircraft Cockpit (Wang et al., 2019)

## Appendix B. Design Process Considerations

- **Impact of Sit vs. Stand Touch Workstation.** Testing shall be conducted for performance and error rates for both sitting and standing positions for the intended installation. Error rates and time on task while standing tend to be higher than those of sitting for small target sizes. (Source: Chourasia, et al., 2013]

- **Duration of task.** Tests shall be conducted to ensure duration of tasks do not induce operator fatigue. Direct input devices, such as touch screens, require direct input into the screen, which can lead to discomfort by increased reach of the arm. [Source: Stanton, et al., 2013; Honeywell: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]

- **Ergonomics**. The ergonomics of using touch in the various relevant installations and positions shall be evaluated for implications of fatigue. [Source: Stanton, et al., 2013; Gleeson et al., 2004; Shin & Zhu, 2011]

    - **Body posture and display position.** Body posture of the user and integration of multi-touch displays at appropriate heights and angle is required to be evaluated for reach, visibility, and fatigue for each type of installation and positioning. [Source: Stanton, et al., 2013; Gleeson et al., 2004; Shin & Zhu, 2011]

- **Test for heads-down time for data entry.**
    - Testing should be performed to determine if heads-down time when performing data entry using a touch keyboard poses risks to safety for intended application and installation. [Source: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018]
    - Alternate means for data entry should be provided for performing direct data entry tasks on touch alphanumeric keypads to minimize heads-down time. [Source: Whitfeld, Ball, & Bird, 1983]

- **Touch vs. tactile.** Designers shall evaluate where touch user interface displays should and should not be used for intended installations, and where tactile input (keyboard and/or mouse) must be required. Touch user interfaces installed in vertical line-of-sight positions can support reduced heads-down time but have higher fatigue potential and reduced accuracy (leading to greater propensity for touch errors). [Source: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018; Alapetite et al., 2013; Causse et al., 2014]

- **Direct vs. indirect touch.** Indirect touch should be evaluated against direct touch for effectiveness of reducing heads-down time, fatigue, and obscuration of touch target for intended installation and application. [Source: Dodd, et al., (FAA Contractor's Report: DTFAWA-10-A-80031), 2015; Dodd, et al., (Contractors Report F15-8200-HON, Task 8212 (FAA Task 12)), 2018; Alapetite et al., 2013; Causse et al., 2014]

- **Definition**
  - **Direct touch.** Direct touch involves interacting with an application by directly touching the surface.
  - **Indirect touch.** Indirect touch refers to a touch area on a separate touch-enabled surface, whether it be a touch screen or touchpad, which allows users to interact remotely with the display they are looking at.