Dynamic Periphery Display: Enhancing Pilot Decision Making in Simulated Flight

Holly Baiotto
Shamaria Engram
Mitchell Massey

Research Mentors:
Christina Bloebaum, Ph.D.
Elliott Tibor
Christopher White

Abstract

This project involves the development of a supplementary application for flight simulation training. The goal is to display critical engine information necessary for emergency recovery in order to improve students' decision making abilities. The interface synchronizes with an X-Plane flight simulator across a local User Datagram Protocol (UDP) network. The interface is grounded in design guidelines and research considerations from FAA Regulations, Gestalt Theory, Proximity Compatibility Principles, Feature Emergence, Component Arrangement, and Situational Awareness. The interface will aid students in the detection and correction of engine failures during simulated flight.

Introduction

Table-top flight simulators have revolutionized the way that pilots are trained, because they provide immersive, safe, cost-effective, and highly customizable flight experiences. A standard PC can be used to simulate a realistic portrayal of a piloting environment. A cross-platform example of one such flight simulator is X-Plane 10, developed by Laminar Research. Pilots select an aircraft, an airport, and environmental settings. They can perform procedure checklists, takeoff, flying, and landing exercises in a graphic representation of the real world. The simulation is designed to have practical features such as engine sounds, system failures, tower communication, and realistic physics.

However, table-top simulations, by nature of their PC implementation, do not recreate the tactile or proprioceptive experiences of actually being in a moving aircraft. Additionally, the layers of keyboard commands and mouse movements that must be learned add complexity to a pilot’s workflow of monitoring flight controls, engine gauges, and navigation systems. Thus, it can be deduced that novice simulator users have a substantial cognitive load when using a table-top system. On top of learning basic flight mechanics, piloting checklists, and radio tower communication standards, flight students must monitor the simulated aircraft and the hardware upon which the simulation is ran.

Other possible contributors to cognitive load include the standard analog gauge design in cockpits and instrument layouts that often differ across aircraft models. The typical analog gauge design is effective for acquiring current system readings, but dangerous system states could potentially be hard to interpret from these designs. System failure recognition and recovery are essential steps in emergency response. This report introduces a supplementary interface for table-top flight simulators that should decrease pilot emergency response time, therefore increasing the safety of the flight and the learning experience of flight students.

Background

Research has shown that flight simulator interfaces prove to be more effective when they are consistent in visibility, and when pilots can clearly recognize the purpose of a control panel (Panko & Panko, 1998). Pilots tend to prefer that indicators using the same system be grouped together (i.e., grouped engine system indicators and flight system indicators), so the grouping design principles of Gestalt psychology should be used to align panels with the most relevant system components (Endsley, 1988) .

For pilots and flight trainees, situation awareness (SA) is a critical goal, and the aforementioned design guidelines can help increase SA in a cockpit or flight simulator. Endsley (1998) summarizes the stages of SA (i.e., perception, comprehension, and projection) and process by which pilots automate decision making processes. The report suggests several design guidelines for optimizing pilots’ SA, such as minimizing verbal information requirements on short term memory. The other recommendations determine the placement of different types of information (Endsley, 1998).

Some implementation research has focused on making high fidelity simulators more cost-effective (Wu & Sun, 2014), while other research has sought to make a simulator’s training more transferable to a real aircraft (Taylor et al., 1999). However, there are few auxiliary interfaces with the purpose of enhancing decision making or situational awareness in simulated emergency situations. This report’s proposed interface will utilize these design recommendations to enhance the situational awareness of students in flight simulators, so that they can detect system failures, and therefore respond to them, more quickly and reliably.

An important foundation of the interface design is applied Gestalt Theory (Wertheimer, 1938). It predicts how humans will perceive different visual features, and is often interpreted by designers to establish clean and intelligent foundations for the layout and organization of a graphic display. Although there are many observations from Gestalt literature to consider, the most important pieces are summarized as laws or principles. More recently, researchers have explored the value of Gestalt theory in computer interface design. Chang, Dooley, and Tuovinen

(2002) used these principles in the redesign of an interface called WoundCare, which is a program that was developed to aid nursing student education. The students generally evaluated the new interface as more effective and easier to use than the old interface. ”The user evaluations indicated that all the identified Gestalt laws are beneficial for visual screen design and learning effectiveness” (Chang, Dooley, and Tuovinen, 2002).

Another design quality considered is emergence. Wickens & Carswell (1995) describes how different design aesthetics can make important information stand out or emerge. Designers should manipulate different design features based on the relationships between their different data pieces or interface items, or how proximal they are to each other. This kind of proximity is measured by perceptual (aesthetic) or processing (content complexity) similarity, and different aesthetic manipulations can create emergence. However, is important that design manipulations and feature groupings be context- or task-specific to op. In general, homogenous or singular manipulations (e.g. color to distinguish an item) produce more emergence or glanceability than mixed, heterogenous manipulations (e.g. color *and* shape, orientation, or extent). Homogenous emergent features can decrease the time requirements of search in a cluttered environment (Wickens & Carswell, 1995).

Design Methodology

Overview

This section describes the details of the content, placement, and implementation of the interface. Figure 1 shows a snapshot of the engine display.

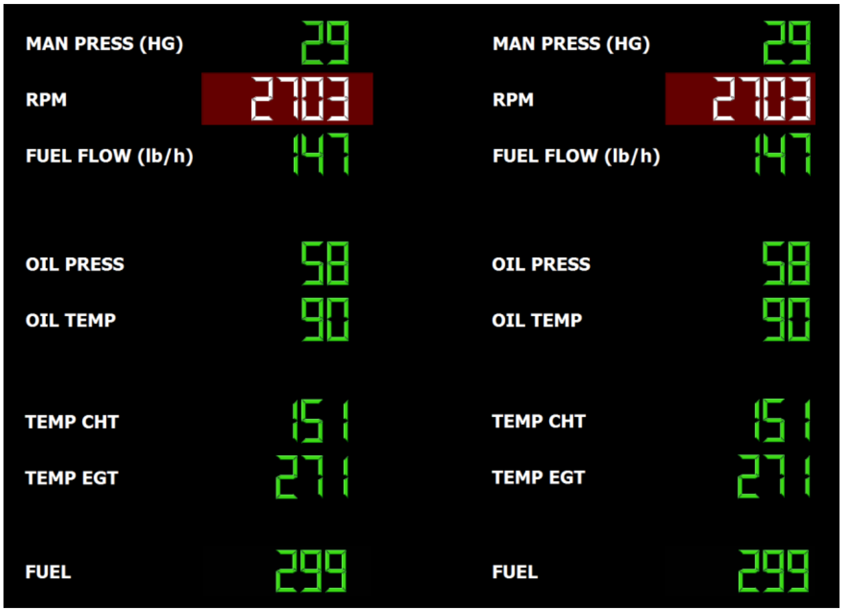

Figure 1. Snapshot of periphery engine display.

Gauges. The interface is implemented and prototyped for a Beechcraft 58 Baron aircraft (see Figure 2). The 58 Baron is a civilian aircraft with twin turbocharged piston engines. It was chosen because its interface could be easily adapted to a larger or smaller aircraft. The implementation focuses on the essential engine gauges (see Figure 3).

Figure 2. Beechcraft 58 Baron Aircraft.

Figure 3. Panel of essential engine gauges.

Color Coding & Peripheral Warning Cues. Figure 4 shows the color scheme as it appears on the interface. The engine display shows white in idle states, green when in safe zones, yellow when in acceptable but cautionary ranges, and red when at dangerous levels.

Figure 4. Implementation of color scheme.

Principles, Heuristics, and Guidelines from Research

FAA Regulations. To ensure that the interface is fully deployable in an aerospace classroom at a university or flight training facility, it is important to employ the policy standards determined by the Federal Aviation Administration (FAA). Current regulations across the span of the FAA's domain are electronically accessible under e-CFR (Federal Aviation Regulations, 2014). The Beechcraft 58 Baron is a personal aircraft that seats 4 to 6 people, with twin propellers; so the design of the interface falls exclusively under the regulations listed in Part 23- Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Airplanes. However, only the subparts dealing with Electronic Display Instrument Systems (§23.1311), Arrangement and Visibility (§23.1321), and Warning, Caution, and Advisory Lights (§23.1322) regulate the specifics of the periphery display.

The interface is in compliance with all federal aircraft regulations. It also contributes to X-Plane's more realistic simulation experience. Figure 5 shows an FAA certified tabletop simulator that could synchronize with the interface over UDP:

Figure 5. Table-top flight simulator.

Design for periphery displays. Matthews (2007) summarizes the literature surrounding glanceable displays for periphery use and multitasking. She explains that the goal for support displays in periphery roles is to make them "naturally glanceable" such that "visuals will be perceived automatically, without cognitive effort or learning...enabling quicker and easier intake of new information." Matthews elaborates on the relationship between bottom-up processing (i.e., raw perception) and top-down processing (e.g., cognitive strategies) as described by studies in attention theory and visual search (Wolfe, 1994; Julesz, 1984; Treisman & Gelade, 1980) and Gestalt theory (Wertheimer, 1938). Matthews supplements this with the idea that discriminability of features adds to a display's glanceability. This justifies our use of emergent features, which will be explained later in the report.

Gestalt organization. The interface adheres to the Gestalt laws that were most appropriate for this application. Table 1 shows 10 Gestalt laws from Chang, Dooley, Tuovinen (2002) and their relationship to the interface:

GESTALT LAW	CORRESPONDING INTERFACE FEATURES
Proximity	➔ Separate columns for left and right engine gauges. ➔ Vertical grouping combines
Similarity	➔ Rows contain the same gauge for the left & right engines ➔ All engine gauges and labels use the same fonts and color schemes ➔ All gauges show green until a reading is in a cautionary (yellow) or very dangerous (red) range
Pragnanz (good form)	➔ Digital displays with color show gauge readings and ranges in a minimalist form. ➔ Idle states of the engine appear white
Balance / Symmetry	➔ Symmetrical gauge organization: mirrored columns with identical label orientation ➔ Digital displays report whole numbers to reduce visual noise
Closure	➔ Vertical groups of gauge readings help users perceive rectangular layout of the left and right engine columns
Focal Point	➔ Flashing emergency alert centers attention to critical engine reading
Isomorphic Correspondence	➔ Gauge labels use same terminology as standard aircraft gauges (i.e., "Man Pressure" for manifold pressure)
Unity & Harmony	➔ Consistent color scheme and parallel column format keeps information unified
Simplicity	➔ Minimalist labels and digital display ➔ Sans-serif font ➔ No clutter
Figure - Ground	➔ High contrast background–text pair: white text on black background

Table 1. Gestalt Laws and their Implementation.

Interface design guidelines. In an FAA-distributed report on design guidelines for multifunction displays, Mejdal, McCauley, & Beringer (2001) combine findings from some critical research in interface design, including Component Arrangement (Sanders & McCormick, 1993), Proximity Compatibility Principles (Wickens & Carswell, 1997), and Emergent Features (Wickens & Carswell, 1997; Pomerantz, 1981). These principles guided the interface arrangement and feature set.

Component arrangement. The relationships between interface components is a critical consideration for usable designs. These relationships included critical importance, frequency of use, and patterns or sequences of use (Sanders & McCormick, 1993). The engine gauges on the developed periphery display are clustered according to these 3 criteria. See Table 2 for each gauge's criticality score, frequency rate, and sequence group number.

	Criticality	**Frequency**	**Sequence**
Manifold Pressure	Moderately Critical	Regular periodic check	1
RPM	Moderately Critical	Glance after periodic check	1
Fuel Flow	Moderately Critical	Glance after periodic check	1
Oil Pressure	Very Critical	Regular periodic check	2
Oil Temperature	Moderately Critical	Glance after periodic check	2
Exhaust Gas Temp (EGT)	Slightly Critical	Regular periodic check	3
Cylinder Head Temp (CHT)	Slightly Critical	Glance after periodic check	3

Table 2. Component Arrangement Rankings by Engine Gauge

Proximity compatibility principles. Wickens and Carswell (1997) wrote that there are four different levels of comparison to measure psychological (what he calls, "perceptual") distance. Essentially, if you compute or process two pieces of information along one of these levels (i.e., task, correlation, system, integration), then they belong in perceptual groups together. This is a similar concept to the Gestalt grouping law of similarity, except that it is a proactive design guide for placing non-obviously similar items together, rather than a description of how people will perceive obviously related objects. It builds off of the Gestalt law of proximity, defining the exact levels of similarity that determine proximal groupings.

For instance, oil temperature and oil pressure are grouped together because they are correlated readings for the same component in the engine. This is a more logical grouping than a hypothetical alternative where all temperature readings from different components (i.e., exhaust gas, cylinder head) are placed together. As another example, Manifold Pressure is the value that the pilot can indirectly manipulate to optimize RPM. Thus, as an integrated set, they are vertically grouped together for convenient reading.

Emergent Features. Design features were employed to increase the glanceability of the engine readings and distinguish critical differences between readings. Feature emergence is not a quality of any one gauge, rather it is how a gauge stands out against the background or the other gauges. The interface embraces the homogeneity of color to make the flashing red gauges at dangerous levels stand out amidst the safe green gauges.

Implementation

The interface was implemented using Qt Creator which is a cross platform C++ integrated development environment. The graphical representation of the interface was implemented by using the Qt GUI and form designer. The LCD numbers were then given functionality by communicating with X-Plane using User Datagram Protocol (UDP). X-Plane is set to send UDP data 20 times per second. However, this sample rate can be changed to the user's preference.

The data that is exported from X-plane and displayed on the interface includes: manifold pressure, revolutions per minute, fuel flow, oil pressure, oil temperature, exhaust gas temperature, cylinder head temperature, and fuel level.

Discussion

The development of the interface was constructed on the basis of literature research. The interface displays glanceable and accessible engine information for enhanced decision making. The periphery cues are components of situation awareness that will increase detection speed and recovery success. The interface quickly alerts the pilot to a potential situation, thus decreasing the time for an emergency response process.

Future Work

User Testing and Evaluation Research

The next step of this research is to test and evaluate the interface through user experimentation. The experimentation would be completed in an aerospace classroom at Iowa State University. Agent-based computational modeling could also be implemented to access the functionality of the interface.

Application and Expansion

If the interface is found to be effective, it could be commercialized for classroom environments. The interface could also be expanded to include other essential flight instruments, or be adapted to different aircraft. A further application could be to adapt the interface into a real-world cockpit for improved situational awareness.

Conclusion

It has been proposed that a dynamic peripheral display for flight simulation would increase decision making capabilities for aerospace students. The principles of Gestalt theory, feature emergence, and component arrangement, support this claim. These principles, as well as the design methods and implementation described in this paper, form the foundation for a functional, user-centered interface, which is predicted to increase the situational awareness of flight simulator pilots.

Acknowledgements

This material supported in part by the National Science Foundation Grant CNS-1156841.

References

Anglissano, L. (2013). Flight training cockpit: roll your own Sim: PilotMall's add-as-you-go tabletop flight simulator lets you create a custom training panel. The only thing missing is FAA approval. *The Aviation Consumer, 43, 15.*

Chang, D., Dooley, L., & Tuovinen, J. E. (2002, July). Gestalt theory in visual screen design: a new look at an old subject.

Electronic Code of Federal Regulations, § Part 23—Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes. Retrieved from http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=b24e1664c4bdb28711690c47b38fca6c&n=14y1.0.1.3.10&r=PART&ty=HTML#14:1.0.1.3.10.6

Endsley, M. R. (1988, October). Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 32, No. 2, pp. 97-101). SAGE Publications.

Julesz, B. (1984b). A brief outline of the text on theory of human vision. Trends in Neurosciences, 7(2). 41-45.

Matthews, T. (2007). Designing and evaluating glanceable peripheral visualizations. *Unpublished PhD, EECS Department, University of California, Berkeley*.

Mejdal, S., McCauley, M. E., & Beringer, D. B. (2001). *Human Factors Design Guidelines for Multifunction Displays*.

N, E., Jung, H., & Donaldson, J. (2007, August). Interaction gestalt and the design of aesthetic interactions. In *Proceedings of the 2007 conference on Designing pleasurable products and interfaces* (pp. 239-254). ACM.

Panko, R. R., & Panko, D. K. (1998, January). Where do you want to fly today? A user interface travel genre based on flight simulators. In *System Sciences, 1998., Proceedings of the Thirty-First Hawaii International Conference on* (Vol. 2, pp. 110-118). IEEE.

Senol, M. B., Dagdeviren, M., Kurt, M., & Cilingir, C. (2009, December). Evaluation of cockpit design by using quantitative and qualitative tools. In *Industrial Engineering and Engineering Management, 2009. IEEM 2009. IEEE International Conference on* (pp. 847-851). IEEE.

Taylor, H. L., Lintern, G., Hulin, C. L., Talleur, D. A., Emanuel Jr., T. W., & Phillips, S. I. (1999). Transfer of Training Effectiveness of a Personal Computer Aviation Training Device. *International Journal Of Aviation Psychology, 9*(4), 319.

Treisman, A. & Gelade, G. (1980). A feature integration theory of attention. Cognitive Psychology, 12. 97-136.

Wertheimer, M. (1938). Gestalt Theory. In Ellis, W.D. (Ed.), Source Book of Gestalt Psychology (362-369). New York: Harcourt, Brace and Co.

Wickens, C. D., & Carswell, C. M. (1995). The proximity compatibility principle: its psychological foundation and relevance to display design. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(3), 473-494.

Wolfe, J.M. (1994). Guided Search 2.0: A revised model of visual search. Psychonomic Bulletin & Review, 1(2). 202-238.

Wu, L. N., & Sun, Y. P. (2014, January). Development of a Low-Cost Flight Simulation Training Device for Research and Education. In *Proceedings of the 2nd International Conference on Intelligent Technologies and Engineering Systems (ICITES2013)* (pp. 445-452). Springer International Publishing.