Human-Centered Design of the Enhanced Pilot Learning Interface for the Aviation Community

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A dissertation submitted to the College of Engineering and Science at

Florida Institute of Technology

in partial fulfillment of the requirements
for the degree of

Doctor of Philosophy

in

Human-Centered Design

Melbourne, Florida

December 2018
We the undersigned committee hereby recommend that the attached document be accepted as fulfilling in part the requirements for the degree of Doctor of Philosophy of Human Centered Design.

Human-Centered Design of the Enhanced Pilot Learning Interface for the Aviation Community
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Abstract

Human-Centered Design of the Enhanced Pilot Learning Interface for the Aviation Community.

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The purpose of this research is to introduce a new device to help pilots navigate aircraft manuals. This informational navigational tool is designed to improve learning by reducing the time it takes a pilot candidate to retrieve aircraft system information within an aircraft manual. The device is called the Enhanced Pilot Learning Interface, an Advanced Interactive Media. The research project is based on human-centered design and consists of participatory design, modeling and simulation, human-in-the-loop simulation (HITLS), and expert user experience. Additionally, a traditional research experimentation was conducted to collect supporting statistical data. Preliminary tests of four current professional airline pilots demonstrated an efficiency increase of 65.5% when using the Enhanced Pilot Learning Interface; when compared to state-of-the-art methods. The research experiment consisting of 38 pilots also confirmed an average efficiency increase of 63%. Further, pilot feedback was also very positive. Human-in-the-loop simulation of the prototype was conducted with good results. During human-in-the-loop testing, more emerging properties and system behaviors were discovered with the challenges incorporated into the final prototype. This was to address emerging properties and behaviors discovered during the research.
Acknowledgement

There are a number of very talented and wonderful people who have been involved in this research. The investigation of this project could not have been completed without their valuable work and input; this is participatory design. I wish to acknowledge them here:

Alexandre Lucas Stephane, Ph.D., FIT COE, for accepting my request to act as my advisor after significant life-events occurred during my time at FIT. His trust, patience, guidance, and support for my success are endearing and will never be forgotten.

Captain Charles William Connor, Ph.D., Delta Airlines and the U.S. Marine Corps, for taking me under his wing and his steadfast encouragement to continue my work. His unwavering support, weekly phone calls, and candor will be inspirational for many years to come.

Captain Stephen J. Cusick, JD, FIT COA and the U.S. Navy, for being my advocate, making valuable recommendations, and being there when I needed him most.

Michael Klenz, MS, FIT Aviation LLC., for allowing me to conduct research with his employees; a significant number of my research subjects. Without their participation, and his generosity, this work would never have been completed.

Captain Greg Fox, MS, Ph.D. Candidate, FIT Aviation LLC., for his unwavering support, his never-ending recruitment of research subjects for this project, his guidance, and late-night discussions that kept me going.
Captain Peter Dunn, MS, Braniff, Midway, United and the U.S. Air Force, for his brotherly devotion, support, encouragement, and fabulous sense of humor; without you Pete, Sir Lawrence would still be in the desert!

Dennis K. Ledford, MD, USF, for his recommendation, as my physician, to pursue my new career as a designer; a vocational rehabilitation project as a replacement for my first career choice which was lost due to medical issues. Additionally, for his guidance and support in dealing with chronic illness. Without his guidance, my road to repossession could have been much more complicated.

Captain Thomas E. Johnson, BS, Ozark, PSA, US Air, US Airways, for his life-long support and his assistance in developing EPLI.

Manali Desi, MS, FIT HCDIA, for her support and assistance in developing the MS Wireframe for the first EPLI prototype.

2nd Lt. Antoine Rambrue, MS, French Air Force, for his support and assistance in developing software for the second EPLI prototype.

Natasha Rao, MS, FIT HCDIA, for her support and assistance in developing EPLI.

Varun Krogaonkar, MS, FIT HCDIA, for his support and assistance in developing EPLI.

Michael Mitchel, MS, KSA, for his support and assistance in developing EPLI.

Thomas Eskridge, Ph.D., FIT COE, for his support and assistance in recruiting a software team for the third and fourth EPLI prototypes.

Ian Dillion, FIT COE, for his support and assistance in developing software for the third and fourth EPLI prototypes.

Melissa Manley, FIT COE, for her support and assistance in developing software for the third and fourth EPLI prototypes.
Christian Maurno, FIT COE, for his support and assistance in developing software for the third and fourth EPLI prototypes.

Gaetano Saltalamacchia, FIT COE, for his support and assistance in developing software for the third and fourth EPLI prototypes.

Sebastian Boulnois, Ph.D., FIT COE, for his tireless help in the formatting of this document. He made the chore much easier than it could have been. Additionally, for his help with Excel and suggestions for building graphs and other images, enhancing the tangibility of theories presented in the paper for the reader.

Katherine Hess, for critical editing skills. I very much appreciate her expertise.
Dedication

This research is dedicated to the following individuals who have had a major impact on my life and, if not for their influence, this research would never have occurred. Their names appear in chronological order of “first-life-meeting-influence”:

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<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Carol Lucia, AT&amp;T, Boeing (Mother)</td>
<td>Coach Jack Mashin, Grossmont College</td>
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<td>Gladys Carlson (Grand Mother)</td>
<td>Coach Bob Larsen, Grossmont, UCLA</td>
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<td>De Vere Carlson (Grand Father)</td>
<td>Coach Jim Peabody, Grossmont College</td>
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<td>Sharon Hofferber (Aunt)</td>
<td>Gale Vavra, San Diego City Schools</td>
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<td>Gene Hofferber (Uncle)</td>
<td>(Foster Mother)</td>
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<td>Robert E. Lucia, Convair, Rohr, Boeing</td>
<td>Dr. Jay Vavra, San Diego High Tech</td>
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<td>David Nations, Universal Studios</td>
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<td>Jan Nelson, PSA ALPA Secretary</td>
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<td>F.A. Pat Blakley, PSA, US Airways</td>
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F.A. Sherry Martin, PSA, US Airways
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Cpt. Doug Streed, PSA, US Airways
Cpt. Pete Muellner, PSA, US Airways
Cpt. Andy Misner, PSA, US Airways
Cpt. John Crawley, PSA, US Airways
Cpt. Dave Sheridan, PSA, US Airways
Cpt. Ford Tbidaux, PSA, US Airways
Cpt. Sully Sullenberger, PSA, US Airways
Cpt. Mitch Inman, Continental
Cpt. Kevin Wilson, MESA, Piedmont, US Airways, AMR
Cpt. Klem Brooks, SkyWest
Cpt. Fred Dale, PSA, US Airways
Cpt. Bruce Sheetz, PSA, US Airways
Cpt. Travis Major, PSA, US Airways
Cpt. Roger Riolo, PSA, US Airways
Cpt. Doug Arthur, Chief Pilot, PSA
Cpt. Raul Caseras, PSA, US Airways
Paula Martin, PSA, US Airways
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Cpt. Nick Stanger, PSA, USA Airways
Margy Newman, PSA, US Airways
Margo Ceballos, PSA, US Airways
Cpt. Paul Peterson, US Airways
Cpt. Carl (Bud) Wiser, US Airways
Cpt. Scotty Clark, US Airways, AMR
Cpt. Sidney Clark, Chief Pilot, US Airways
Mack Fulwyler, Ph.D., SeQ Ltd.
Carol Fulwyler
Cpt. Don Mentzner, Eastern, FSI
Cpt. Dave Lipsey, FSI
Cpt. Ken Diffée, COEX, AMR
Kenneth Ledford, MD, USF
Ken Penkai, FL Voc Rehab
Professor Kelvin Faison, MS, PHSC
Professor Anita Mukerjee, MS, PHSC
Professor Eric Spaziani, Ph.D., PHSC
Professor David Chapman, MS, PHSC
Master Chief Ray Hall, U.S. Coast Guard
Asst. Dean Ernie Rogers, MS, LU
Professor Steve Marks, Ed.D., OSU
Professor Jon Loffi, Ed.D., OSU
Professor Chad Depperschmidt, Ed.D.
OSU
Professor Steve Cusick, JD. FIT COA
Cpt. Pete Dunn, MS, United
F.O. Fred Brier, Elite
Professor/F.O. Ken Stackpool, Ph.D.
FIT, PSA
Cpt. Bill Connor, Ph.D., Delta
Cpt. Greg Fox, Ph.D. Candidate, FIT
Dan Miller, FL Voc Rehab
Professor Guy Boy, Ph.D. FIT
Special Dedication

When I first began the endeavor to complete the necessary requirements for acceptance into a Ph.D. program, including the completion of a BS and MS, there has been one individual who has remained a paramount advocate in helping me through this arduous task. She has been patient, loving, supportive, endearing, and understanding. She has moved with me from university to university, never once complaining. I could never have undertaken the workload without her and, therefore, I would like to make a special dedication to her; the best little Pal, my Black Labrador, ILIA. She has been my faithful companion through it all.
Glossary

**Accelerators:** Are user interface elements that allow the user to perform frequent tasks quickly. Examples of accelerators include: function keys, command name abbreviations, and ICONS.

**Accommodation:** According to Piaget, the modification of schemas so that information inconsistent with existing schemas can be integrated or understood (Rathus, 2008).

**Affordance:** A relation between an object or an environment and an organism that, through a collection of stimuli, affords the opportunity for that organism to perform an action.

**AFGS:** Auto Flight Guidance System:

**AEV:** Anthropological Endogenic Variation

**AIM:** Advanced Interactive Media: Products and services on digital computer-based systems which respond to a user’s actions by presenting content such as text, moving image, animation, video, audio, games, etc.

**AOM:** Aircraft Operating Manual: A book containing the information required to safely operate the aircraft.

**AR:** Augmented Reality: an enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device (such as a smartphone camera) (Merriam-Webster).

**Assimilation:** According to Piaget, the inclusion of a new event into an existing schema (Rathus, 2008).
**ATP:** Airline Transport Pilot: The highest level of aircraft pilot certificate. Those certified as Airline Transport Pilots are authorized to act as pilot in command on a scheduled air carrier's aircraft under CFR 14 Part 121.

**Attitude:** An enduring mental representation of a person, place, or thing that evokes an emotional response and related behavior (Rathus, 2008).

**Automatic Processing:** Information processing that occurs without conscious attention, as in well learned skills (Hawkins, 1997).

**Automaticity:** The ability to accomplish things without occupying the mind with low-level details, allowing it to become an automatic response pattern or habit. It is usually the result of learning, repetition, and practice.

**Cache:** In computing, a cache is a component that stores data so future requests for that data can be served faster; the data stored in a cache might be the result of an earlier computation, or the duplicate of data stored elsewhere.

**CFA:** Cognitive Function Analysis: Is a methodology supported by a mediating tool for the human-centered automation of safety-critical systems. It is based on a socio-cognitive model linking the artifact being designed, the user’s activity, the task to be performed, and the organizational environment. Cognitive functions can be allocated to humans or machines. They are characterized by their role, context definition and associated resources (Boy, 1998).

**Chunking:** The grouping together of many items by the mind, after which they can be remembered as a single item; according to Rathus, a chunk is a stimulus or group of stimuli that is perceived as a discrete piece of information (Rathus, 2008).
**CID:** Computer Integrated Documentation: A CID is context-sensitive and includes a hypertext database, a knowledge-based management and maintenance system, and a user interface. A CID provides navigation in hyperspace, acquisition of indexing knowledge, generation and maintenance of a large documentation, and relation to other work (Boy, 1991).

**CNS:** Central Nervous System: The part of the nervous system which in vertebrates consists of the brain and spinal cord, to which sensory impulses are transmitted and from which motor impulses pass out, and which coordinates the activity of the entire nervous system (Merriam-Webster).

**Cognitive Compatibility:** The degree of consistency, congruency, and mapping between tasks on the one hand, and internal mental processes, knowledge, and expectations on the other (Taylor, 1996).

**Cognitive Quality:** The conformance of a system with the specified cognitive requirements (Taylor, 1996).

**Cognitive Variation:** The different ways people mentally process sensations, perceptions, memories, intelligence, language, thought, and problem solving (Rathus, 2008).

**Concept:** A mental category that is used to class together objects, relations, events, abstractions, or qualities that have common properties (Rathus, 2008).

**Creativity:** The ability to generate novel and useful solutions to problems (Rathus, 2008).

**CRM:** Crew Resource Management: The focus on the proper crew response to threats to safety and the proper management of crew error (Tullo, 2010).

**CSS:** Cascading Style Sheets: is a style sheet language used for describing the presentation of a document written in a markup language.
DM: Decision Making: The act or process of deciding something especially with a group of people (Marriam-Webster).


EFB: Electronic Flight Bag: is a device that allows flight crews to perform a variety of functions that were traditionally accomplished by using paper references (NBAA, 2018).

Emotion: a state of feeling that has cognitive, physiological, and behavioral components (Rathus, 2008).

FAA: Federal Aviation Administration: The United States national authority with powers to regulate all aspects of civil aviation (FAA).

FAR: Federal Aviation Regulation: The regulations prescribed by the FAA governing all aviation activities in the United States. They are a part of Title 14 of the Code of Federal Regulations (FAA).

FCOM: Flight Crew Operating Manual: A guideline for operators to develop their own Standard Operating Procedures, in accordance with applicable requirements. This source document incorporates aircraft manufacturer guidance on how to use the systems on board the aircraft for enhanced operational safety, as well as for increased efficiency (Airbus, 2018).

Fight or Flight Response: An innate adaptive response to the perception of danger (Rathus, 2008).

FMA: Flight Mode Annunciator

FMS: Flight Management System

**Functional Analysis:** A systematic study of behavior in which one identifies the stimuli that trigger problem behavior and then reinforces it (Rathus, 2008).

**GA:** General Aviation: General aviation is all civilian flying with the exception of scheduled passenger airline service (AOPA, 2018).

**GAO:** Government Accountability Office: An independent, nonpartisan agency that works for Congress. Often called the "congressional watchdog," GAO examines how taxpayer dollars are spent and provides Congress and federal agencies with objective, reliable information to help the government save money and work more efficiently. (GAO, 2018).

**GEM:** Group Elicitation Method: A brainwriting technique augmented by a design support system for constructing a shared memory (Boy, 1996).

**Graphical User Interface:** Provides its user a "picture-oriented" way to interact with technology. A GUI is usually a more satisfying or user-friendly interface to a computer system (WhatIs.com, 2018).

**Granularity:** is the extent to which a material or system is composed of distinguishable pieces or grains. It can either refer to the extent to which a larger entity is subdivided, or the extent to which groups of smaller indistinguishable entities have joined together to become larger distinguishable entities (Boy, 2011).

**Habituation (Habit Capture):** Occurs as a result of a warning display being frequently activated in conditions which require no corrective action; it reflects a system design fault (Hawkins, 1997).

**HCD:** Human Centered Design: The design of dynamic systems of production transport or services that integrate both human operations and decision or command algorithms (Millot, 2014).
HITLS: Human-in-the-LOOP Simulation: A simulation model of a system, e.g., airplane, air traffic control center, emergency management plan, or military operation developed for the purpose of training people. Trainees and researchers interact with the visual simulation model for the purpose of observing and learning system interaction behavior.

HMS: Human Machine Systems: Explores integrated human/machine systems at multiple levels and scales and includes areas such as human-machine-interaction; cognitive ergonomics and engineering; assistive/companion technologies; human-machine modeling, testing, and evaluation; and fundamental issues of measurement and modeling of human-centered phenomena in engineering systems.

Homeostasis: The state of dynamic equilibrium of the internal environment of the body that is maintained by the constant processes of feedback and regulation in response to external or internal changes (Taber, 2018).

HSI: Human System Integration: an interdisciplinary technical and management process for integrating human considerations with and across all system elements, an essential enabler to systems engineering practice. Human activity considered by HSI includes operating, maintaining, and supporting the system (Boy, 2011).

HTML: Hypertext Markup Language: The set of markup symbols or codes inserted in a file intended for display on a World Wide Web browser page. The markup tells the Web browser how to display a Web page's words and images for the user. Each individual markup code is referred to as an element (but many people also refer to it as a tag). Some elements come in pairs that indicate when some display effect is to begin and when it is to end.

ICAO: International Civil Aviation Organization: Is a specialized agency of the United Nations. It codifies the principles and techniques of international air navigation and fosters
the planning and development of international air transport to ensure safe and orderly growth (ICAO, 2018).

**Interface:** Consists of the set of dials, knobs, operating system commands, graphical display formats, and other devices provided by a computer or a program to allow the user to communicate and use the computer or program (Whatis.techtarget.com, 2018).

**ID:** Interaction Descriptor

**IND:** Integrated Navigational Document: Computerized document with contextually linked Interface Objects and Interaction Descriptors that provide enhanced system information retrieval for users.

**IO:** Interface Object

**IOE:** Initial Operating Experience

**IT:** Information Technology: The use of computers to store, retrieve, transmit, and manipulate data, or information, often in the context of business or other enterprise.

**JavaScript:** Is a high-level, dynamic, untyped, interpreted run-time language. It has been standardized in the ECMAScript language specification. Alongside HTML and CSS, JavaScript is one of the three core technologies of World Wide Web content production; the majority of websites employ it, and all modern Web browsers support it without the need for plug-ins.

**JMP (“Jump”):** Computer program for statistics

**Learning:** (1) According to behaviorists, a relatively permanent change in behavior that results from experience. (2) According to cognitive theorists, the process by which organisms make relatively permanent changes in the way they represent the environment
because of experience. These changes influence the organism’s behavior but do not fully determine it (Rathus, 2008).

**Long Term Memory**: The type or stage of memory capable of relatively permanent storage (Rathus, 2008).

**M (Mean)**: Also known as the arithmetic average, is computed by adding all the scores in the distribution and dividing by the number of scores (Gravetter, & Wallnau, 2010).

**Meaningful Learning**: Is opposed to rote learning and refers to a learning way where the new knowledge to acquire is related with previous knowledge (Novak, 2011b).

**Memory**: the process by which information is encoded, stored, and retrieved (Rathus, 2008):

- **Episodic Memory**: Memories of events experienced by a person or that take place in the person’s presence
- **Semantic Memory**: General (factual) knowledge, as opposed to episodic memory
- **Working Memory**: capacity to hold information long enough to use it, like RAM in a computer
- **Procedural Memories**: learned actions; i.e., walking, running, and procedural practice:
- **Prospective memory**: Memory to perform an act in the future, as at a certain time or when a certain event occurs
- **Implicit Memories**: Memory that is suggested (implied) but not plainly expressed; the things people do but do not state clearly

**MFD**: Multi-Function Display: A small screen interfaced with a configurable keyboard or display. It is used to display information to the user in numerous configurable ways.
**Motivation:** What drives or induces a person to behave in a particular fashion (Hawkins, 1997). It reflects the difference between what a person can do and what he/she will do in a particular set of circumstances.

**N (Population):** The set of all the individuals of interest in a particular study (Gravetter, & Wallnau, 2010).

**n (Sample):** A set of individuals selected from a population, usually intended to represent the population in a research study (Gravetter, & Wallnau, 2010).

**Operant Conditioning:** A simple form of leaning in which an organism learns to engage in behavior because it is reinforced (Rathus, 2008).

**Participatory Design:** Is an approach to design attempting to actively involve all stakeholders (e.g. employees, partners, customers, citizens, end users) in the design process to help ensure the result meets their needs and is usable (Boy, 2011).

**Perception:** The process by which the senses are organized into an inner representation of the world (Rathus, 2008).

**PFD:** Primary Flight Display: The pilot’s primary reference for flight instrument information (found in aircraft with electronic flight instruments). A PFD combines the information that many electromechanical instruments used to display into one single display reducing pilot workload and enhancing situational awareness.

**Phenomenology:** The study of structures of consciousness as experienced from the first-person point of view. The central structure of an experience is its intentionality, its being directed toward something, as it is an experience of or about some object (Stanford, 2003).

**Positive Reinforcer:** A reinforcer that, when presented, increases the frequency of an operant (Rathus, 2008).
**RAM:** Random Access Memory: Computer hardware that stores the operating system (OS), application programs, and data that are in real-time current use; the OS, applications, and data are kept in the RAM for quick retrieval by the computer processor. RAM is also known as the main memory of a computer.

**Recall:** Retrieval or reconstruction of learned material.

**Recognition:** In information processing, the easiest memory task, involving identification of objects or events encountered before (Rathus, 2008).

**Resilience:** The ability of a system or an organization to recover from disturbances at an early stage, with minimal effect on dynamic stability (Hollnagel, Woods, and Leveson, 2008).

**Retrieval:** The location of stored information and its return to consciousness; the third stage of information processing (Rathus, 2008).

**Robustness:** The ability to withstand or overcome adverse conditions (Hollnagel, Woods, and Leveson, 2008).

**RS:** Research Subject: A person who decides to participate in a research study. This is completely voluntary. The RS helps the researcher or research institution evaluate questions he/she wants to study. An RS can quit the study at any time.

**SA:** Situational Awareness: A term used to describe a person’s awareness of their surroundings, the meaning of these surroundings, a prediction of what these surroundings will mean in the future, and then using that information to act.

**Semantic Distance:** The measure of how close or distant the meanings of two units of language are. The units of language may be words, phrases, sentences, paragraphs, or documents. The semantic distances between words (or more precisely, between concepts)
can be used as fundamental building blocks for measuring semantic distance between larger units of language. The ability to mimic human judgments of semantic distance is useful in numerous natural language tasks including machine translation, word sense disambiguation, thesaurus creation, information retrieval text summarization, and identifying discourse structure (Mohammad, and Hirst, 2006).

**Sensemaking:** Refers to how we structure the unknown, so we are be able to act within it. Sensemaking involves developing a reasonable understanding, concept, or a mental map of an everchanging environment and testing this understanding with others, via data collection, action, and conversation. Once identified, one refines or abandons the concept, depending its credibility (Ancona, 2012).

**Sensitive Dependence:** In chaos theory, the butterfly effect is the sensitive dependence on initial conditions in which a small change in one state of a deterministic nonlinear system can result in large differences in a later state (Zeeman, 1976).

**Schema:** A way of mentally presenting the world, such as a belief or expectation, that can influence perception of persons, objects and situations; according to Piaget, a hypothetical mental structure that permits the classification and organization of new information (Rathus, 2008).

**SHCDIA:** School of Human Centered Design, Innovation, and Art (It became the COE’s Department of Human Centered Design).

**Short-term Memory:** The type or stage of memory that can hold information for up to a minute or so after the trace of the stimulus decays; also called working memory (Rathus, 2008).
**Symbology (Symbolic System):** Used in the field of anthropology, sociology, and psychology to refer to a system of interconnected symbolic meanings.

**SNS:** Sympathetic Nervous System: The branch of the autonomic nervous system that is most active during the fight or flight reaction.

**SOP:** Standard Operating Procedure: A set of instructions that describes all the relevant steps and activities of a process or procedure (IBM, 2017).

**STEAM:** The educational approach to learning that uses Science, Technology, Engineering, the Arts, and Mathematics as access points for guiding student inquiry, dialogue, and critical thinking. The end results are students who take thoughtful risks, engage in experimental learning, persist in problem solving, embrace collaboration, and work through the creative process. These are the innovators, educators, leaders, and learners of the 21st century.

**TCAS:** Traffic Alert and Collision Avoidance System: A family of airborne devices that function independently of the ground-based air traffic control system and provide collision avoidance protection for a broad spectrum of aircraft types. All TCAS systems provide some degree of collision threat alerting, and traffic display (FAA).

**TUIO:** Tangible User Interface Object: An open framework defining a common protocol for use with multi-touch surfaces that optionally support tangible object recognition (Intuiface, 2018).

**Uncertainty:** Within the decision-making agenda of training, uncertainty can arise in the following ways:

- Incomplete information
- Inadequate understanding of available information
Undifferentiated information (equally attractive or unattractive alternatives)

The latter may also be related to uncertainties regarding decision making. Incomplete information can be determined objectively. However, undifferentiated alternatives and inadequate understanding are sources of uncertainty caused by an interaction between different characteristics of a decision made, the environment a decision is embedded within, and the decision-maker, him/herself. Because of these differences, occasionally only incomplete information can be well-defined as uncertainty, while the other two are considered under a different category like ambiguity (Grote, 2009).

**Unitization**: (psychology) the configuration of smaller units of information into large coordinated units.

**Usability**: Applies to all aspects of a system that a user interacts with (Nielsen, 1993). This includes conception, design, development, and implementation, as well as operational, and maintenance procedures. Additionally, usability is the ease of use and learnability of a human-made object such as a tool or device (Nielsen, 1993). In software engineering, usability is the degree to which a software can be used by specified consumers to achieve quantified objectives with effectiveness, efficiency, and satisfaction in a quantified context of use.

**Variability, (Anthropologic)**: Human variability is the range of different values which can be characteristically measured for human beings, be it physical or mental. These differences can be inconsequential or significant, temporary or permanent, voluntary or involuntary, congenital or acquired, genetic or environmental. In other words, everyone is unique; based on their genetics, education, culture, social environment, etc. (inter-individual variability).
Furthermore, each person is subject to variability that results from transient factors such as: fatigue, health condition, psychological state, and ageing (Boy, 2013).

**VBS:** Visual Basic Script: is an Active Scripting language developed by Microsoft that is modeled on Visual Basic. It is designed as a "lightweight" language with a fast interpreter for use in a wide variety of Microsoft environments.

**VNC:** Vestibular Nuclear Complex: Human perceptual balancing mechanism.

**VR:** Virtual Reality: An interactive computer-generated experience taking place within a simulated environment, that incorporates mainly auditory and visual sensory stimulation, but also other types of sensory feedback like haptic (tactile).

**WL:** Workload: The relation between the function relating the mental resources demanded by a task and those resources supplied by the human operator (Parasuraman, Sheridan, and Wickens, 2008).

**WSAS:** Wind Shear Alert System: A computer that identifies the presence of wind shear.
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Chapter 1
Introduction

During the last several decades, aircraft automation has been granted more authority allocation in the flight station. The intent has been to reduce the number of required pilots, lessen pilot workload, enhance aircraft and system performance, and enhance safety (Sánchez, 2007; Hawkins, 2010; Salas & Maurino, 2010; Cusick, Cortés, & Rodrigues, 2017). Therefore, automation has been allocated increased authority over time. Because of this human-system interactive evolutionary maturation, the role of the pilot has shifted from that of a manual operator to a manager of automation. Additionally, to accommodate the two-pilot flight station, the operation of systems and their interaction has also become increasingly automated. During normal operations, automation is a powerful tool that normally operates well (Telfer & Moore, 1997). During normal operations, the flight crew monitors the automation and ensures the flight management system, along with the other systems of the aircraft, are behaviorally compliant with the inputted commands the flight crew have programmed into the automation. However, in times of abnormal or emergency situations, automation does not operate well, and the pilots must operate the aircraft and its systems manually. It is during these times that the pilot and co-pilot must pay careful attention and ensure proper management of the aircraft and its systems and the systems interaction.

While automation was intended to reduce pilot workload and enhance safety, auto-flight systems require a deep understanding of their operational management and constant
vigilance monitoring during the many different environmental flight conditions; these are complex multi-agent systems operating in a constantly changing environment. Therefore, proper in-depth education and training of the flight crew is required to safely operate these complex machines. Numerous diverse conditions exist within the many different operational environments: normal, abnormal, and emergency conditions. Procedural and non-procedural operations of a complex transport category aircraft are multifaceted and dynamic. Profiles of normal operations consist of standard operations during a normal flight. Abnormal profiles include system malfunctions that require rule-based decision making (e.g. standard operating procedures and checklists), choice-based decision making (e.g. two potential threats exist and the correct one must be identified), and creative-based decision making (e.g. an unstable situation that was not “planned for” has occurred and the flight crew must rely on their experience, training, education, and skill to develop a procedure which regains stability or reduces the consequences of the unstable situation) (Kline, 1993b; Kline et al., 1993, Cannon-Bowers, Salas, & Pruitt, 1996; Zsambok & Kline, 1997; and Orasanu, 2010).

It should be noted that automation has caused problems in the ability of pilots to make creative decisions, i.e., loss of situational awareness, monitoring inefficiency, increased mental workload, and, occasionally, the inability for a pilot to revert to manual control, otherwise known as automation surprise (Telfer and Moore, 1997). Emergencies are life-threatening situations and can require creative decision making in addition to the rule and
choice-based procedures. Additionally, there are many different phases of flight in which these nominal and off-nominal scenarios can occur. The different phases include:

- Passenger boarding, preflight, and deplaning
- Engine starting, after engine start, and pre-taxi
- Taxi and before-takeoff
- Takeoff, after-takeoff, and climb
- Cruise
- Descent, initial approach, final approach and landing
- After landing, taxi, engine shutdown
Chapter 2
Background and Significance

This section describes the purpose for this research and why it was conducted. An introduction to aviation pilot training and other relative factors that needed to be considered are presented, and: scholarly papers and texts are cited and referenced to support the subject areas presented. This dissertation describes how pilots currently read, study, find information, and how they formulate “what-if” questions for preparation of procedural training. These current pilot training topics are generated from the author’s 33-year career as an airline flight engineer, first officer, captain, ground school instructor, simulator instructor, flight instructor, and university adjunct instructor teaching human factors, crew resource management, and aviation law. Finally, an outline of the author’s research, questions, and methods is presented; based on current technology issues generated from the author’s education, experience, and expertise.

2. About Airline Pilot Training and Associated Topics

Within the airline domain, there are two types of training:

— Systems Training (Declarative Knowledge) includes:
  - Systems knowledge
  - Systems integration knowledge (how the systems interact)

— Procedural Training (Procedural Knowledge) includes:
  - Normal flight operations
  - Abnormal flight operations
• Emergency flight operations

Systems training occurs in the classroom and during home study (Figure 1).

Procedural training occurs in several different training artifacts (Figure 1):

— A home mockup using flight station panel posters
— A flight-training device (FTD, non-motion)
— A full-motion 3-axis flight simulator

During simulator training, the pilots continually rehearse scenarios that help them develop and enhance their expert skills. Such training helps to influence and enhance constructive behavior during emergencies to offset risk mitigation during unwanted events and allows the pilots to regain stability. This occurs because practice helps pilots to act in a reflexive, natural, and instinctual manner (Ericsson, Krampe, and Tesch-Romer, 1993; and Nokes, Schunn, and Chin 2010). Cognitive resources acquired during simulator training become
automatic over time during procedural practicing; this is known as automaticity (Logan, 1985; and Salas and Maurino, 2010).

For a pilot candidate to transition to the simulator and begin procedural training, they must complete their systems training. Systems training prepares the candidate to begin acquiring the declarative knowledge required to succeed in the simulator. Without systems and systems interaction knowledge, it is impossible for the pilot in training to succeed in the simulator because they lack the deep systems knowledge essential for performing all of the required procedures adequately.

At present, no commercial aircraft, no matter how advanced, is safe to operate without a competent crew (Jensen, 1995; Chappelow & Elshaw, 2006; Dismukes, et al, 2010; Salas & Maurino, 2010; and Cusick, Cortés, & Rodrigues, 2017). The FAA requires a minimum number of flight hours (1,500 total flight hours of experience) and certifications (Commercial, Instrument, Multi-engine, and Airline Transport Pilot (ATP)) for a person to qualify and become an airline flight crew member (FARS 121.433, 434, 437, 439, and 443, 2017). Additionally, the FAA requires a minimum number of training hours, specific tasks, satisfactory standard operational performance, and recurrent training for each aircraft type (FARS 121.403, 407, and 409, 2017). These requirements involve a significant amount of education. This minimum experience is necessary for a pilot to develop the essential skills one must possess to safely interface with a modern complex transport category aircraft (Ericsson, Krampe, and Tesch-Romer, 1993; Hawkins, 1997; Dismukes, 2010; Salas & Marino, 2010; and Cusick, Cortés, and Rodrigues, 2017). Therefore, a great deal of training must take place before a pilot can act as a flight crewmember. Additionally, crews must embrace a deep knowledge of the aircraft systems and understand how those structures
interact during normal, abnormal, and/or emergency scenarios (Nielsen, 1993; and Hawkins, 1997; and (FARS 121.403, 407, 409, 433, 434, 437, 439, and 443 2017).

3. Knowledge Transference: The Current Methods

Current knowledge transference methodologies of aircraft systems and systems integration are extremely cumbersome to work with and require large amounts of time. These methods currently consist of paper and digital (electronic flight bags, or EFBs) knowledge transference methodologies (Figure 2, Figure 3). Current methodologies make it difficult for new-hire pilots to find the right information at the right time. Through combining “meaningful learning” and an advanced ineractive media (AIM), the author has creatively conceptualized and developed what I believe to be an improved method. These new technologies were not available until recently.

Figure 2. Paper Based Training Documents.
4. **Knowledge Elicitation: How Pilots Develop Mental Skills**

Historically, pilots in command (captains) gain experience while performing co-pilot duties. They learn from the more experienced pilots as they work together as a crew. On average, it takes approximately eight to ten years for a person to fully develop the necessary skills to qualify and act as a pilot in command, i.e., the captain (Ericsson, 2006; Ericsson, 2009; and Beuke, 2011). Unfortunately, within the next decade, most of the current airline pilots will retire (Aviation Week and Space Technology, 2015; Harmon, 2016; Ostrower, 2017; APA, 2017; and the Bureau of Labor and Statistics, 2018). Most retirees will be captains. In 2014, the U.S. Government Accountability Office (GAO) reported that employment projections suggest the number of pilots to be hired during the next decade will be between 1,900 and 4,500 pilots per year which is consistent with the airlines’ reported expectations for hiring.
over the same period” (U.S. GAO, 2014). If we take the high end of the average, 4,500 pilots, and divide that number by 365 days in a year, then 12 pilots a day would need to be trained, certified and ready to “fly the line” (a term the airlines use for pilots and flight attendants flying revenue lines of flying) in order to replace these pilots. This number is only for retiring pilots, not for projected growth, a number that has not been estimated. However, Boeing and Airbus project building 33 thousand aircraft between now and 2033. The two manufactures stated these aircraft were for growth and not the replacement of aging aircraft. With five crews (10 pilots) per aircraft, it would mean that there are 330,000 additional pilots the GAO does not account for. These numbers indicate that there will be a tremendous strain on the amount of pilot resources available. Further, it can be assumed there will be a great deal of training required to support the required number of pilots that will be needed to address the coming pilot shortage.

The FAA has distributed information about this concern and is looking for solutions to mitigate the potential threat of an airline pilot shortage. One of the potential mitigations could be found in enhanced training; if we could reduce the time required to acquire systems knowledge, could that time be reallocated to enhance procedural training and boost the performance of a pilot’s simulator training? If this was accomplished, could less experienced people be added to the pilot resource?

To address this concern, I have considered Novak’s “meaningful learning”, in combination with an AIM I call EPLI. Could this new training platform potentially reduce current temporal requirements for airline pilot systems knowledge transference? The main goal of EPLI is to improve the efficiency of systems, systems interaction, and procedural learning through emerging technologies that support the increased interactive effectiveness of
meaningful learning. Novak cited Ausubel’s assimilation theory of meaningful learning. In 1963, Ausubel published solid theoretical work on the distinction between learning by rote versus learning meaningfully (Novak, 2010, 2011a, and 2011b). According to Ausubel, when someone learns by rote, there is no effort to relate new ideas with existing knowledge schemas. Therefore, the new ideas fail to be incorporated into longterm memory. In the context of meaningful learning, an individual integrates new information with existing cognitive structures (Novak, 2010). In this way, new ideas and concepts are stored into longterm memory and easily retrieved later. This process helps an individual to establish an integrated framework of concepts and propositions which are hierarchically organized into a given domain of knowledge. This is how individuals build expertise, through a process of continuous meaningful learning. This process can be broken down into the different ways in which humans have learned how to interact with their environment since infancy. This is known to psychologists as assimilation and accommodation (Rathus, 2008).

4.1. Assimilation and Accommodation

As infants and children, people learn to integrate with their environment through cognitive development. Through assimilation and accommodation an individual develops a pattern of action, or a mental structure, involved in acquiring or organizing knowledge; this pattern of action is called a schema (Rathus, 2008). When we experience a new stimulus, we respond through either a reflex or existing habit; such a response is known as assimilation.

When assimilation occurs, humans experience a stimulus and react to it. This process results in the development of the schema (a pattern of action or mental structure involved in acquiring or organizing new knowledge) (Rathus, 2008).
When a new stimulus is experienced, it cannot be assimilated with pre-existing schemas as none exist to incorporate the new information? In such a case, assimilation cannot be achieved, and the brain must accommodate for such a new stimulus.

Accommodation allows an individual to transform existing schemas to incorporate new events (Rathus, 2008). Accommodation is applicable when new experiences, situations, or stimuli cannot be integrated into existing schemas. Accommodation helps build new schemas based on the new stimulus. In this way, one can perceive, process and react to future associative stimuli accordingly.

During their training, pilots are continually exposed to multiple stimuli. Some can be assimilated while others are accommodated. They rely on their patterns of schema; developed through previous experience, training, and aeronautical knowledge; to process different stimuli and incorporate them with pre-existing schemas to organize the new knowledge into newly developed schemas where they are stored into memory.

4.2. Memory

According to Rathus and Carter, there are five different kinds of memory: episodic, semantic, working, procedural, and implicit, the definitions of which can be found in the glossary of this dissertation (Rathus, 2008; and Carter, 2009).

For the purpose of this research, I am concerned with episodic, working, and procedural memory.

Episodic memory involves content of previous original experiences. Working memory maintains a plan of action while utilizing items from another part of the brain that will eventually be a part of that plan. Procedural memories allow automatic motor actions previously learned; they are used in recall. However, they are typically unconscious (Carter,
This is known as muscle memory (muscular proprioception) which is instilled through procedural practice; the muscles remember where specific switches, levers, and handles are located without the need for direct visual input.

Only experiences giving rise to unusually prolonged and/or intense neural activity become encoded as memories (Carter, 2009). It takes up to two years to consolidate the changes that create a long-term memory but, once encoded, that memory may remain available for life. Long – term memories include events from a person’s life (episodic memories) and impersonal facts (semantic memories). Together, these are termed “declarative memories,” since they can be recalled consciously (“declared”). Procedural (body) memories and implicit (unconscious) memories may also be stored in long-term memory (Carter, 2009).

Regarding memory, it is important to understand that once an individual learns or experiences something in a specific state of mind or environment, or while concurrently experiencing a sensation or perception, the brain can subsequently recall that sensation or perception more readily when the individual later experiences a similar situation. This can cause one to revert in their actions automatically and unconsciously (Connor, 1985; and Hawkins, 1997). People are particularly susceptible to such phenomena during times of high work load and/or stress (time compression) (Connor, 1985; Jenson, 1995; Hawkins, 1997; Cheung, 2004; Carter, 2009; and Baldwin, 2012). Hawkins explains that when a specific pattern of behavior has been established (a conditioned response, Pavlovian response), it can be problematic to abandon it (Hawkins, 1997). Such an action could be extremely dangerous if it is no longer appropriate as a person could move a switch or press a button at the wrong time, or in the wrong direction. This is important to remember as it is applicable to the
potentiality of unwanted physical outputs on the part of people. We must now look at how memory influences a pilot’s situational awareness (SA) and decision making (DM).

For a pilot to develop, establish, and enhance situational awareness, they must incorporate several aspects of memory. The brain utilizes working memory to assess, process, and act in the existing environment. To employ working memory, the brain must access and incorporate episodic memory and semantic memory (Rathus, 2008; Carter, 2009; and Kiss, 2013).

Because episodic memory consists of reconstructions of past experiences, sensations, and emotions, a pilot’s episodic memory would consist of experiences, sensations, and emotions garnered through their time operating an aircraft or simulator.

Semantic memory involves factual knowledge. For a pilot, this would include aviation didactics: aircraft limitations, performance, systems, and systems interaction; procedures including: normal, abnormal, and emergency procedures; FARs, etc. Working memory is the capacity of the mind to hold information just long enough to use it, like RAM in a computer (Carter, 2009). This allows a pilot to perceive, process and act on stimuli in real time; i.e., what he/she is environmentally experiencing in real-time. Working memory maintains a plan of action while utilizing stored episodic and semantic memories as a part of the total plan.

Therefore, it would be reasonable to infer that as pilots’ gain experience, their knowledge increases, and their episodic and semantic memory knowledge schemas should also increase. As episodic and semantic schemas increase, the pilot’s working memory has more information available for processing and interpreting related threat and error information
while operating an aircraft. This affords the experienced pilot with enhanced cognitive performance. Therefore, because experienced pilots have more developed schemas, the inference is that they should be able to perceive, process, respond and confirm errors and threats more efficiently and accurately, using less cognitive resources, and improve their situational awareness and decision making. This can allow them to deal with unwanted events more efficiently and augment the probability of a positive outcome. By comparison, on the other hand, using the same inference, a less experienced pilot with reduced episodic and semantic memories would be expected to have more limited situational awareness, on average. This could lower their ability to handle an unwanted event lowering the probability of a positive outcome.

In short, more experienced pilots can determine and mitigate threats and errors in a more efficient manner, using less cognitive resources than do less experienced pilots (Hawkins, 1997 and Tullo, 2010). This allows expert pilots to perceive a new stimulus, process it, and respond accordingly with enhanced efficiencies, better accuracy, and more quickly than less experienced pilots (Kiss, 2014).

4.3. **Cognitive Variation**

Assimilation and accommodation are uniquely specific to each distinctive individual. To predict how a person would behave under certain circumstances, one would have to measure all the variables associated with schema development over a person’s lifetime. Of course, this is not possible due to the complexity of this unique anthropological cognitive variation. Therefore, such an endeavor to make long-range prediction of human behavior is insuperable.
Thus, when certain behavior is needed to provide system stability during the emergence of unwanted events, procedural training and operational documentation should be created to afford users operating in extreme environments with natural and instinctive behaviors. This is needed for positive responses to emergent anomalies, particularly during periods of high work load, short temporal components, high stress, and fatigue (Connor, 1985; Jensen, 1995; and Caldwell, 2006).

4.4. **Developing Positive Schemas**

Through the repetition of simulator training, assimilation and accommodation instill schema patterns that permit people to perceive, process, decide and act in reflexive behavior patterns (Rathus, 2008). Jeanne Piaget (cognitive psychologist, 1896-1980) believed that “true intelligence” involves adapting to the world through a smooth and fluid balancing of assimilation and accommodation processes (Rathus, 2008).

Piaget’s accommodation mechanism states that, knowledge accumulates in memory following an iterative process. Therefore, through the actions developed during procedural training, positive knowledge schemas are developed that can be articulated and reshaped to enhance emergent anomaly resilience and robustness. This is particularly important in respect to temporal limitations during an emergency where high-work-load and limited available time are a factor (Connor, 1985).

4.5. **Deep Knowledge**

Today’s complex aircraft, their associated systems, and automation require a deep understanding of the systems, their operations, and how they interact with one another, particularly during system failures. Telfer explains that when one is acquiring such knowledge, “[s]uccess in a relative difficult task requires relating new and old knowledge,
spending extra time finding out more information about the topic, being absorbed in learning about the topic and wanting to understand the information. Further, the assessment of the more difficult topics focusses upon problem solving, judgement, and decisions” (Telfer, 1993, pp. 124). Airline pilots require deep knowledge to safely operate the modern complex airliner. According to Telfer, pilots are extremely proficient at adjusting and coping with changed circumstances. They are surface oriented learners well trained at setting personal goals, reviewing material, testing their individual current knowledge about systems, procedures, aircraft performance and developing summaries to update their current knowledge (Telfer, 1993). However, Telfer goes on to explain that such deep learning approaches can be encouraged by allowing the learner to experiment with training devices which help pilots realize a degree of metacognition, the awareness or analysis of one's own learning or thinking processes (Merriam-Webster, 2018). Telfer and Moore describe deep learners as individuals who reflect on potential problem scenarios and spend time discovering subject matter that can help them resolve such complicated situations (Telfer & Moore, 1997). Pilots develop solutions by asking themselves “what-if” questions and then searching the plethora of system information to find solutions to those what-if questions. This is how pilots develop deep knowledge and their expertise and skills. In my experience, I have often marveled at how pilots have found solutions to unexpected scenarios given in the simulator, during training. Pilots often confer with one another about potential solutions to a specific what-if questions they could not personally resolve. In this way, there is a consensus among many different individuals and a solution is collectively found. Individuals develop deep knowledge by asking specific what-if questions and then find a solution, individually or collectively.
Finding these collective solutions and transferring current knowledge requires an inordinate amount of time to sort through the relevant information. If that time could be reduced, it is possible that it could benefit deep knowledge and support enhanced decision making.

5. The Variables Involved

There are numerous variables that must be considered. In this section, I describe many of the variables I have discovered during my career as an airline pilot, instructor, educator, designer and during the progression of this research.

5.1. High Work Load/Short Temporal Component: Time Compression

Different people have different levels of experience, education, and skills; and different ways of perceiving, processing, deciding and acting on information. There are many different complex sources of variation in workload demand, as shown in figure 4 (Telfer & Biggs, 1988; Jensen, 1995; Baldwin, 2012). Workload demand fluctuates with the different task functions that occur over time and with the different phases of flight, i.e., takeoff and landing versus cruise flight. Workload is further complicated by the operator’s personality and the way they respond to tasks or personal demands (Telfer & Biggs, 1985; and Salas, Bowers, & Edens, 2001). This response can be further affected singularly or in combination with multiple tasks, which increase the challenge of the agent to properly assess workload. Figure 4 demonstrates the relationship of workload and performance.
Because of these multidimensional influences, disassociation between the tasks and required actions to meet those tasks can occur, leading to an overload situation that affects the person’s cognitive abilities (Connor, 1985; Jensen, 1995; Hawkins, 1997; Dismukes, Benjamin, and Loukopoulous, 2007; and Dismukes, 2010). Therefore, normal decision-making performance can deteriorate when workload is too high or available time is critical.

5.2. **High Stress (Emotion)**

When a pilot experiences an anomaly during flight, the sympathetic nervous system (SNS) automatically induces hormonal activity that will increase heart rate, blood pressure, and activate other physiological changes (Chappelow, 2006). Personally, I have experienced this anomaly and it takes considerable effort to ignore these symptoms and manage the situation at hand.
Gawron declares that emotions can reduce a pilot’s ability to resist spatial disorientation (Gawron, 2004). The SNS response can influence what a person sees through a phenomenon known as paradoxical cognition. Experts form mental representations (knowledge schemas) to address specific actions during times of high cognitive load (Dror, 2011). As experts modify their mental representation, through experience, education, and training, they form efficient cognition mechanisms that become automatic and have a high level of rigidity. While these representations afford the user the ability to quickly identify and resolve the majority of conflicts, there are occasions where this ability leads to an error (Jensen, 1995; Salas, Bowers, and Edens, 2001).

SNS hormonal activation can induce paradoxical cognition. This means the individual can degrade in performance, leading to tunnel vision and biases. This occurs because corticosteroids (stimulated by the SNS) can inhibit cognitive function (Marieb, and Hoehn, 2010). Through adaptation, the user will utilize his/her automatic mental representations to adjust to the situation. This is further enhanced with task loading and time compression (Connor, 1985; and Jensen, 1995). These factors can lead to reliance on automatic processing, repetition, and habit capture.

### 5.3. Automatic Processing, Repetition, Habit Capture, & Expectation

"Automatic processing" (highly practiced skills that become automatic over time) is mentally established during the repetition of training over a long period and has the advantage of being fast, efficient, and making minimal demands on cognitive resources (Salas & Maurino, 2010). However, Salas and Maurino claim that while automatic processing is normally highly reliable, it can become less reliable when there is a change in
normalcy; i.e., a person’s attention can become diverted when initiating a task (Salas, & Maurino, 2010).

When individuals intend to divert from a normal step in a habitual procedure, they are vulnerable to what is known as “habit capture” (Salas & Maurino, 2010). Habit capture occurs when a person has repeated the same task over and over many times, and they acclimatize to the same procedure. However, when there is a change in the procedure, they unconsciously perform the old procedure. If a pilot does not pay careful attention, they may be in danger of reverting to the habitual step rather than performing the intended and correct one.

Expectation occurs when an individual is expecting a certain outcome based on previous experience. An example would be, setting an old decision height altitude during an instrument landing when the altitude was changed during a revision. Such a scenario could place the aircraft in danger of hitting an object on the ground prior to landing. Another example would be expecting the same taxi clearance assigned during the last flight, but the controller gave different instructions. Therefore, automatic processing, repetition, habit capture, and expectation can influence an individual to revert in performing actions they have procedurally practiced during an emergency when the action is not wanted.

5.4. **Cognitive Unitization**

The process of developing expert cognition tools induces unitization, which occurs when new entities and neural processing cause normal cognitive components, once perceived separately, to fuse together (Dror, 2011). This creates a new schema that can be used later, known as “chunking” or “lumping”. This is how neural processing provides cognitive
optimization for expert cognitive information processing needed for expert domain performance (Connor, 1985).

However, there is a caveat. As the brain develops these expert cognition capabilities, there are several limitations that can cause degradation of performance. Studies have shown that brains of experts who have developed such expertise have increased grey matter volume located in the posterior hippocampus (Dror, 2011). To accommodate this extra posterior volume, Maguire et al found less grey matter in the anterior hippocampi of these brains (Maguire et al, 2006). Although the experts with these brains are knowledgeable about spatial relationships, they were limited at forming and retaining new associations related to visual information. These types of tradeoffs appear in other expert domains (Dror, 2011). Other studies have suggested that while developing neural representations of visualization occurs for experts, other existing structures are suppressed in the process.

5.5. Perception

Perception is greatly influenced by what the brain believes about objects and movements previously experienced in an environment, and what it expects the properties of those objects and movements to be (Rathus, 2008; and Carter, 2009). By the time an individual perceives, processes and responds/acts to a stimulus, different components of the body’s sensing and processing systems are involved (Hawkins, 1997, Carter, 2009; and Marieb & Hoehn, 2010). Therefore, memories of previous perceptual experiences, such as practicing scenarios during simulation, play a strong role in influencing a person’s perception, especially when cognitive resources are limited, and the results are seen in the user(s) behavior(s).
5.6. **Vestibular Nuclear Complex and Muscle Memory (Muscle Proprioception)**

The perceptual inputs for human balance are visual (the eye), vestibular (the inner ear), proprioceptive (muscle memory), and various modes of memory (Monesi, 1980; Harding and Mills, 1983; Gawron, 2004; Carter, 2009; and Marieb & Hoehn, 2010). These variables are incorporated into the vestibular nuclear complex (Figure 5) that perceives, processes, decides, and sends signals to the central nervous system (CNS) for appropriate skeletal muscular reaction to maintain balance homeostasis. Collectively, the vestibular nuclear complex (VNC) responds to stimuli from the following inputs to maintain equilibrium: the eyes, inner ear, and the muscles of neck, limbs, and trunk (Marieb & Hoehn, 2010). Figure 5 shows the VNC. This system is extremely complex and sensitive dependent on initial conditions of episodic and procedural memories.

It is important to understand that these outputs are reflexive in nature, which is colloquially known as “muscle memory”. Balance receptor stimulations bypass the cerebral cortex (where cognition and other special sense perceptions occur) and travel directly to the vestibular nuclear complex located in the brain stem (Marieb & Hoehn, 2010). This is how humans establish the ability to reach for and place an appendage on a specific switch, knob, or lever in a specific location without looking. The VNC sends the signals to the CNS for appropriate muscle memory. However a problem arise if the inputs deliver conflicting information.
Visual perception is the primary input for balance. This allows pilots to override the other sensory perceptions when experiencing vestibular issues such as Vertigo or Coriolis. When there is an issue with the visual input, like nystagmus, visual perception can be overridden by the vestibular apparatus (Baldwin, 2012; Cheung, 2004 and Gowran, 2004). There are other additional attractors that can cause instability of the VNC, such as: high work load, short temporal component (time compressions), high stress (emotion), and cognitive deficits influenced by poor memory, fatigue, illness, and blood chemistry (drugs, alcohol, pathogenic infection, or abnormal hormonal stimulation) (Caldwell, 2006). Therefore, it is important to instill proper training methods that support natural and intuitive behavior when the VNC overrides cognition. To overcome the above variables and build resilience and robustness to offset associated unstable events related to those variables, procedural training must be practiced. Before procedural training can be practiced, pilots must have deep knowledge of the systems and their interactions.
6. Technical Aviation Systems Requiring Deep Knowledge

In today’s aviation environment, the flight crewmember is subject to a multitude of human anatomical, physiological, psychological, and psychosocial variables that can affect their performance and impede their decision-making processes; this can increase the propensity of human error. Fatigue, stress, circadian dysrhythmia, flying long hours at high cabin altitudes with reduced blood oxygen saturation, and career/family stressors are just a few of the human factors affected by today’s aircraft technologies (Jensen 1995; and Caldwell, 2006). There are several aerospace technological advancements that require specific education and training. If the education and training are of poor quality, the physiological boundaries of the human component can limit situational awareness, decision making, and, therefore, appropriate actions (Hawkins, 1997; Telfer & Moore, 1997; Sánchez, & Ballesteros, 2007). Novices can be at a disadvantage when making decisions because they lack the deep knowledge of experts (Chi et al, 1988; Klein, 1998; Ericsson, et al, 2006; Ericsson, 2009). The following are aviation systems requiring deep knowledge for the enhancement of system stability resiliency and robustness, and the mitigation of risk.


The modern Auto Flight Guidance System (AFGS), also known as an auto pilot, requires rigorous aircraft automation operations classes to transfer methods for understanding all the functions of an AFGS. Mandatory procedures must be clearly detailed into company flight operations manuals. Procedures require pilots not only turn the automation on, but maintain continual automation update situational awareness. These procedures require the flight crew
(both the captain and the first officer) to maintain constant monitoring, cognitive processing, evaluation, and verification methods to ensure the machine is conforming as requested by the inputs inserted by the crew. The information is compared with the crew inputs and the flight mode annunciators (FMAs) by both pilots. Additionally, there should be further verification by the monitoring of flight instruments and verbal updates by the crew to ensure the FMAs are presenting the correct information. I call these verification methods “Critical Triangles of Agreement”.

The pilots must maintain constant communication with each other to verify the aircraft is performing in the appropriately selected parameters. These methods are termed “mental models,” and “feedback-loops.” Verification is further enhanced through mode annunciators that provide visual conformation of the mode selected.

The process of utilizing mental models and feedback loops helps to:

— Prevent human complacency and boredom
— Reduce fatigue
— Enhance situational awareness and decision making
— Increase safety
— Reduce human psychological limitations and error such as:
  • Over Load
  • Fixation
  • False Hypotheses
  • Cognitive Processing

The Flight Management System (FMS) is designed to enhance the human interface with the AFGS.
The Primary Flight Display (PFD) and Multi-Function Display (MFD) provide a pictorial view for pilots to reference their geographical position. In addition, pilots need to use navigational charts and navigational aids to continually update their geographical position cognitively and verify PFD/MFD information. This is to maintain situational awareness of where they were, where they are, and where they will be.

If pilots do not develop these techniques, they can be susceptible to spatial disorientation which influences perceptual illusion during flight operations, specifically, during approach procedures. The efficiencies of these new technologies improve threat recognition, communication, CRM, and situational awareness. They also reduce illusions, false hypotheses, and mental fatigue. Therefore, these technologies are significant in further reducing human physiological and psychological limitations and require deep knowledge.

### 6.2. Warnings, Alerts, and Indicators

Seventy percent of aircraft accidents result from communication errors affecting CRM (Kanki, B., Helmreich, R., & Anca, J., 2010). This includes errors resulting from false hypotheses generated from misidentification of a threat. False hypotheses can result from lack of warning devices not incorporated into the machine which can impede the human-system-interface. This not only leads to a misunderstanding of a problem but can also influence a crew to remain on a “continued path of error.”

Some of these warnings are:

- Engine/APU fire
- Wheel-well fire detection
- Cargo fire
- High cabin altitude
• Duct overheat
• Low hydraulic Pressure
• Take-off configuration
• Stall
• Fuel imbalance

These different warning systems are composed of visual, aural, and tactile elements providing pilots with three types of human sensory perception to include in their situational assessments, enhancing threat detection.

The industry has also fashioned “Rule-based” standard operating procedures to enhance positive outcomes. Warning systems and SOPs help to conserve cognitive resources through training by inducing memories that are stored into somatic memory (factual and procedural knowledge) and used in combination with episodic memory (assimilated knowledge schemas developed through previous experience); working memory (perceptions of the current environment and situation) then utilizes procedural and somatic memory to resolve current threats. Therefore, the pilot can perceive a threat, process it, evaluate it, act upon it and re-evaluate it through a feed-back-loop process with great cognitive efficiency. This increases cognitive ability and reduces risk of human limitations. Therefore, warning technologies and SOPs facilitate cognitive function and have increased aviation safety.

6.3. Terminal Collision Avoidance System (TCAS)
TCAS has prevented mid-air collisions. North America (the U.S., Canada, and Mexico) has not experienced a mid-air collision since the operational use of TCAS began in the early 1990s. In order to use TCAS proficiently, a pilot must have a good understanding of how the system works.


6.4. **Wind Shear Alert System (WSAS)**

Also, developed in the early 1990s, after several accidents and incidents involving wind shear (a sudden change in direction and velocity of airflow over the wing), aircraft and airport wind shear detection warning systems were developed and have helped to mitigate wind shear accidents. Humans lack the perceptual ability to discern or predict wind shear. Therefore, pilots needed a system that could detect and warn them of an impending wind shear.

In addition, improved procedures during wind shear recovery have also helped to prevent wind shear accidents. The airport wind shear warning system provides early detection to flight controllers; allowing airport operations to adjust accordingly and provide early warning detection advisement for inbound flights on approach and flights preparing for departure.

The on-board wind shear warning detection also allows for early detection giving the crew immediate recognition; training provides “Rule Based” procedures for wind shear recovery further enhancing safety. There have been no wind shear accidents since the wind shear warning and procedures have been introduced; at least none that I know of.

**A Final Word on Warning Systems**

The key to these warning systems is “information transfer” which is crucial in problem solving situations because the resolution of the problem relies on gathering and communicating pertinent information for the purpose of taking steps in the mitigation of the threat (Kanki, B., Helmreich, R., & Anca, J., 2010). Without the deep understanding of these systems, resilience and robustness in mitigating associated risks would be less than optimal.
6.5. **Merger, Consolidation, Fleet Integration Issues**

The combination of different fleet types can make the operation multiple types of aircraft too complex for the human component; this is deleterious in mitigating associated physiological and psychological limitations. The differences in instrumentation, auto flight systems, engines, and other different fleet variables are just too complex.

Automation is a wonderful tool that can enhance pilot performance and mitigate accidents. However, there must be proper training in place to accomplish the transference of the knowledge needed to operate such complex systems. The multifarious cockpit differences in a fleet resulting from merger/consolidation differences can promote error.

These errors are related to human factors issues such as:

— Habit capture: Doing something so often that it is performed during a time when it is not warranted

— Repetition: Turning a switch in one aircraft influences an individual to turn the switch in the same direction in a new aircraft type. However, in the new aircraft, the switch moves in the other direction

— Automaticity: A procedure becomes sub-conscious and the individual is not aware of it

— Expectation: Expecting a certain outcome based on previous experience

These are cognitive issues related to human psychology. Because of these human confines, if crews are to enjoy the benefits of automation across many different aircraft types, and differences among the same type, their training must include deep knowledge of the operation of the different fleet idiosyncrasies. Further education is needed to demonstrate how habit capture, repetition, automaticity and expectation generated in the normal
operations of one aircraft, can affect actions and performance of an individual operating a new aircraft.

7. **A Problem with Current Airline Pilot Training**

In today’s airline industry, current paper and digital knowledge transference methodologies are complex and make it difficult for students to find and cognitively encode the deep knowledge required to understand the related system information. Searching for this information increases the time required to find the associated material. The number of systems, systems interactions, auto flight management, procedures, warnings, rules, and requirements commercial airline pilots need to study are extensive.

The Aircraft Operating Manual (AOM) or Flight Crew Operating Manual (FCOM for Airbus) is a governmental certified document. Flight crews, airline operations management and other planning staff use the AOM/FCOM for operations and planning. Although there have been significant advances in aircraft design, aircraft manual format has remained basically the same. Manuals are presented to flight crew candidates via a “classic” paper document, or as an electronic document (electronic flight bag, or EFB) (Ramu, 2002). The EFB was intended to reduce the search and retrieval time for information. However, while there has been some reduction in time finding system information, the EFB has many limitations in saving time. Indeed, my research has found that paper is actually faster when retrieving information. This will be articulated later. The AOM/FCOM plays a significant role in flight crew training. It also serves as a reference for training material. My objective is to investigate the opportunities for articulating a new advanced interactive media in which aircraft operations and training are more intuitive and knowledge acquisition is enhanced.
7.1. **Paper Manuals**

Paper-based manuals (Figure 6) consist of system, procedural, performance, limitations, checklist, and other documentation which is organized into several books consisting of many chapters, and the relative lined logic is read via physical pages, indexes, and tabs. Paper manuals require a great deal of time to discover specific information, because a user must sort through a plethora of material to find that specific information. Further, depending on the specific information, one must look through many different manuals to find the relative material. While studying, this can require a student to continually search through information to find an answer, often forgetting what they were looking for when they started the search. They can also become distracted with the data that exists within the manual. Further, revisions are mandatory and require a great deal of time to revise which occurs weekly. With electronic documentation, these properties will no longer exist, and new properties have to be defined.
7.2. Electronic Flight Bags (EFBs)

EFBs (Figure 7) consist of the same system, procedural, performance, limitations, checklist, and other documentation as do the paper manuals. They simply exist in PDF format with some limited contextual linking and a three-level limitation. EFBs are also organized into several books consisting of many chapters, and the relative lined logic is read via electronic display. EFBs also require a great deal of time to discover specific information. This is also because a user must sort through a plethora of information to find that specific information.
As with paper manuals, one must look through many different electronic manuals to find information. The difference is instead of physically picking up the manuals and turning the pages, one must select the appropriate manual (i.e., volume 1, 2, or 3) tab and then select the appropriate chapter. The only difference is one is searching for information through a PDF format. There are some limitations to the EFB format: The search engine runs through every associated word in the volume, there is no link to the main page, and one must scroll to find information. Also, when using the search engine, the individual does not know where they are, geographically, in the manual. Situational awareness is lowered, as a result. The one feature all pilots like about EFBs is the ease with revisions. What used to take hours can now be accomplished in minutes by simply downloading the new revision into the EFB. However,
while studying, the EFB is no faster at retrieving information then paper documents. EFBs also require that a student continually search through information to find an answer. Sometimes, as a simulator instructor, I have found that candidates were not procedurally prepared. This usually occurred because they had lost time trying to find system information during their systems study phase of training. I.e., there was less time available for procedural study and, therefore, they lacked the necessary procedural knowledge needed to succeed in the simulator. I.e., they spent so much time preparing for the oral examination that they lost time allocated for their procedural studies.

This is a problem because time is lost during the simulator training as it is reallocated to teach procedural study time which should have been practiced prior to the first simulator session. This costs the airlines a great deal of money.

While major advances have been made in simulation technologies, the improvement in knowledge transference method formats have remained unchanged (Ramu, 2002). Further, EFB manuals are limited to just three levels, meaning there are only three levels of a manual that are contextually linked together; usually limited to a system index with no linking between systems.

Additionally, many candidates do not study the correct material because they do not have the basic understanding of what needed to be studied. This is particularly relative for new hire pilots and pilots transitioning from older antiquated aircraft to new more automated aircraft. The minimum skills were lacking because there was no previous experience to help them transition to the newer equipment. I.e., no previous experience to help in their preparation.

As a result, I have considered the following: “Is it possible that current materials and manuals used by airline pilots and pilot educators could be outdated? If so, have current technologies
evolved enough that a new knowledge transfer format could be developed and used to
enhance pilots’ training, and, if so, how?”

Ericsson tells us that expert performers attain their superior performance by acquiring
complex cognitive mechanisms and physiological adaptations through extended deliberate
practice (Ericsson, 2009). A new platform could be developed to reduce the time required to
find systems knowledge and afford the extra time to be reallocated to deliberate procedural
practice. It should be noted that the EFB was intended to reduce information retrieval (Ramu,
2002). However, it has been my experience and the experience of many fellow pilots that
EFBs are not faster and, in fact, they are more difficult because the users are lost,
geographically, as they of do not know where the information is located. In my research
comparing paper and EFB methods to EPLI, the data shows that paper is actually faster than
EFBs at information retrieval, on average. This is discussed in chapter 6.

8. Considerations for a New Learning Platform

When designing a new and enhanced learning platform, I needed to recognize, understand
and address the following considerations:
— The initial inputs of human learning;
— The systems requiring deep knowledge; and,
— Many over variables described above.

This knowledge was needed to afford system resilience for sensitive dependency. As a
result, HCD methodologies were used to consider the human component and propose the
definitions of potential design drivers for achieving system goals.
This required using usability engineering; participatory design with all actors, especially the experts within the domain (i.e., pilots); and modeling and simulation to test, verify, and observe any unforeseen emergent properties.

Additionally, I needed to understand human cognitive functions and how they are affected within the human component of the human-system-interaction (HSI). For this paper, specifically, due to the complexity of human perceptional mechanisms, it was of particular importance to consider how anthropological learning occurs during training and how that prelude to flight operations influences individuals during operational phases. The flight environment can influence these vitally important systems when adding vertical and angular acceleration moments to horizontal acceleration moments. If these systems are not considered with a comprehensive understanding, the users could be inserted into an emergent anomaly beyond their ability to stabilize, because of sensitive dependence. To discover the main areas of concern for the new AIM, I first had to develop a flight station function analysis.

9. Cognitive Function Analysis

Human-system integration in today’s highly multifaceted aircraft flight station is the main focus in this section. To understand the complex environment that exists for commercial flight crews, and their associated needs for reduced operational risk, I developed an abstract structural design for needed systems, subsystems, and systems integrations using a cognitive function analysis. There was a need to define and apply plausible scenarios that exist in today’s commercial aviation domain that would be used during HITLS. In defining physical functions and cognitive functions that are applicable, Boy’s Cognitive Function Analysis
was applied (See Appendix A). Once I identified the functions along with their tasks, roles, and allocation, I was able to generate a high-level synopsis of the system information needed for study. This promoted the establishment of a comprehensive design structure for EPLI.

In order to enhance EPLI, a cognitive functional analysis was performed to understand the:
- Tasks
- Roles
- Context and Resources
- Actions

A cognitive function analysis is an important element when allowing for authority allocation between the human, the machine, interactive inputs, and the human-machine integration. This provides an analysis of the sequentially in-depth abstract functions, general functions, and physical functions that may occur. Initially, I developed a subsequent iterative modeling process utilizing 4 expert airline pilots and scenarios during modeling and simulation for analysis of potential activity patterns to discover needed functions for EPLI.

9.1. Complexity, Socio-technical Stability and Flexibility

Complexity results when operating within multi-agent systems. This is because of the multiple links occurring between the agents. Multi-agent systems that are highly connected behave like biological systems (Mitchell, 2009); there appears to be intelligence behind the actions of such systems. Multi-agent complexity can be expressed in terms of a number of problems to be solved at a given time. In terms of a socio–cognitive perspective, complexity should also be considered with capacity. A socio–technical system is dynamic as it is continually adapting to achieve its ends and react to changes in itself and its environment.
Therefore, in consideration of multi-agent complexity and socio-technical stability, design should consider potential constraints on behavior to ensure safe operations. The system should also continue to operate safely as changes in adaptions occur over time, i.e., as new elements are discovered, an iterative process should allow for changes to be made to the system artifact that address the needs of the newly discovered elements. This increases the maturity of the product. Therefore, flexibility is needed to address emergent anomalies that occur in non-linear complex environments like aviation. This is known as the ease of modification of a contract between two or several agents in real – time (Boy, 2011).

Flexibility assessments should guide cognitive function allocation in both resource and context spaces. When capacity increases, complexity and uncertainty will also increase (Grote, 2009). Therefore, to manage increasing complexity, and uncertainty associated with increasing systems integration, we need to design systems that have the right balance for human-system integration (Grote, 2009, and Boy, 2011). Therefore, I had to consider the users’ needs in the systems design of EPLI. This was accomplished working with other airline pilot experts.

### 9.2. User Needs

It is extremely difficult to predict how different individuals will behave when emergent anomalies express themselves. This is due to the complexity of human variation. Under the HCD philosophy, when designing systems, designers should consider the needs of the users; this is known as holism (Boy, 2013). In order to meet this requirement, designers need to understand how people perceive, process, decide, act, and follow through. For enhanced system maturity to exist, it is important to recognize the cognitive functions of people within
the context of the cultures they operate within; social, professional, organizational, and educational (Card, 1986; Nielsen, J., 1993; and Boy, 2013).

Anthropological endogenic variability defines the way people perceive information. How information is presented or displayed can influence cognitive functions of people and how they behave within their context of cultures. Anthropological endogenic variability is extremely complex (Hollnagel, Woods, and Leveson, 2013). Therefore, to enhance human interaction with computer systems, Phenomenology, the study of human behavioral experience within the world (Belvedere, 2007), needs to be applied to understand how people act in a world with pre-existing meaning and purpose. This allows the identification of appropriate interactive devices to provide the user with natural and intuitive actions for positive system stability reclamation. Therefore, contextual information must be provided to the users in the form of standard operating procedures. This contextual information must be clear and concise so that all users know who will do what, and when they will do it, when an emergent anomaly occurs.

### 9.3. **Nominal and Off-nominal Context**

Context can be nominal which includes normal operations that are stable within the operating envelope. Context can also be off-nominal, which includes abnormal and emergency circumstances. These types of conditions can evolve into unstable scenarios if:

- Appropriate measures are not taken
- If a false-hypothesis of the true situation is not recognized in a timely manner
- If a poorly designed procedure drives a crew down a path of continued error

Off-nominal situations require re-prioritization of procedures, checklists, communications, and re-delegation of duties, responsibilities, accountability and control. This is why crews
need to know who will do what and when they will do it. Therefore, to enhance cognitive resources during off-nominal situations, crews must have proper training, supervision, and organizational management. These variables are decomposed into cognitive functions which can be further deconstructed into other parallel cognitive functions distributed to other agents through the act of delegating authority when the cognitive functions of one agent become overwhelmed (Boy, 2013). This is the premise of crew resource management (CRM); aviate, navigate, communicate, and delegate when it is needed, and in that order. In this regard, a cognitive function analysis was performed with the intent of identifying cognitive functions and the associated resource spaces and context spaces (Boy, 1998) to influence proper acts on the part of the operators and the systems. I developed declarative configuration-driven scenarios for needed resources and procedural event-driven scenarios for the different contexts that could be conceived, and elicit others form different experts. By conscripting the expertise of fellow pilots and their education, experience, and training to elicit potential cognitive function networks, I consulted with experts within the airline domain and also in the general aviation arena.

9.4. Experts
When considering a potential artifact’s maturity and its functionality, sustainability, and maintainability, a designer should attempt to elicit expert experience feedback from users in the domain that they are studying (Boy, 1998, 2011). In order to provide the best way for users to accomplish tasks, one must utilize the correct interaction techniques along with the hardware and software elements associated with the input device. Resolution and accuracy are required to address the right amount of information noise. This was particularly important with the interface design of EPLI, a lack of information may cause the user to misinterpret
the information, leading to a false hypothesis. Too much noise and the users could have difficulty formulating a clear and concise understanding. This could require extra time to perceive, process, decide, act, and perform a feedback analysis of the correct action needed, or they could be prejudiced by subjectivity if the information is too vague. Typically, when emergencies arise, time is not available for a lengthy decision-making process. The right balance is needed for quick and efficient cognition leading to natural and intuitive actions. Expert users can reduce the amount of iterative experimental analysis through the identification of the correct information level needed. By utilizing professional airline pilots and instructors in performing my identification of cognitive functions, I was able to identify resources needed for EPLI.

9.5. **Resources**
Cognitive functions empower people and machines with the necessary control to execute tasks (Boy, 1998). Cognitive and physical resources are required, such as cognitive functions themselves. A resource is anything that is required in order for a function to occur. On the physical side, certain things must be available, and on the cognition side, there are other elements. For example, a warning light that warns the flight crew of a duct overheat would require the availability of many different resources in order for the light to illuminate, including:

- The engine must be operating
- Electrical power must be established
- Sensors must be located within the ducting
- A preset value must be tripped
- Hardware and software are required
A human must be available to witness the light and do something about it
The human must have training for understanding and applying appropriate actions
Operational documentation must exist to present appropriate checklists to accomplish the appropriate actions
All of these resources and more must be met or the functions cannot be achieved.

10. TASKS and SYSTEMS

10.1. Tasks
Potential risks must be identified and measured to ensure appropriate flexibility and resilience. There are a multitude of tasks which must be maintained while operating a modern aircraft:
- Aircraft maintenance
- Automation use, monitoring, and non-compliance mitigation
- Communications
- Economic stability
- Monitoring instruments, displays, and indications
- Navigation management
- Pilot fatigue, health, and circadian rhythms
- Proper training
- Terrain awareness and clearance maintenance
- Traffic avoidance
- Security
- Systems, systems within systems, and systems integration
- Weather
Commercial aviation is a particularly complex purview and, therefore, system design must involve the understanding of the different system functions, human cognitive functions, and the integration and shared authority allocation between them and the associated tasks for humans and machines. Additionally, evolutionary changes that emerge during different phases of flight, changes in system performance, unforeseen anomalies, and anthropological issues such as visual and auditory illusions need to be identified and understood (Kiss & Stephane, 2016). The system must afford provisional flexibility in resolving such emergent events at the earliest possible moment (Hollnagel, Woods, and Leveson, 2010). Context must be addressed, and scenarios developed for nominal and off-nominal (abnormal and emergency) situations. This is needed for determining the associated function allocations needed as the context of a given situation changes. For EPLI the focus was on the discovering the appropriate systems, limitations, procedures, and checklists needed.

### 10.2. Systems

Twenty systems requiring cognitive and physical function analysis were identified (Table 1). Within those systems, another 870 cognitive and physical functions were discovered. Those functions required a further breakdown into their associated context, roles, and tasks which totaled 11,077 (Table 1).
Table 1. Functions, tasks, roles, and resources analysis.

<table>
<thead>
<tr>
<th>SYSTEMS</th>
<th>FUNCTIONS</th>
<th>TASKS</th>
<th>ROLES</th>
<th>RESOURCES</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR/ENV</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>505</td>
<td>643</td>
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<tr>
<td>ANTI-ICE/RAIN</td>
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<tr>
<td>AUTO FLIGHT</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>300</td>
<td>444</td>
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<tr>
<td>COMM</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>159</td>
<td>246</td>
</tr>
<tr>
<td>ELECTRICAL</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>452</td>
<td>587</td>
</tr>
<tr>
<td>ENGINES</td>
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<td>65</td>
<td>65</td>
<td>382</td>
<td>577</td>
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<tr>
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<td>304</td>
<td>385</td>
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<tr>
<td>FLIGHT CONTRLS</td>
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<td>51</td>
<td>51</td>
<td>576</td>
<td>729</td>
</tr>
<tr>
<td>FLT INSTS/DSPLYS</td>
<td>114</td>
<td>114</td>
<td>114</td>
<td>1120</td>
<td>1462</td>
</tr>
<tr>
<td>FLT MGT/NAV</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>FUEL</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>464</td>
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<tr>
<td>HYDS</td>
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<td>598</td>
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<tr>
<td>LDG GEAR</td>
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<td>56</td>
<td>56</td>
<td>448</td>
<td>616</td>
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<tr>
<td>OXYGEN</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>NC</td>
<td>42</td>
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<tr>
<td>WARNS/CAUTS/ADVIS</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>2,236</td>
<td>2752</td>
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<tr>
<td>FLT CRW SEAT BELTS</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>Not Completed</td>
<td>36</td>
</tr>
<tr>
<td>FLT DECK EMG EQPT</td>
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<td>15</td>
<td>15</td>
<td>Not Completed</td>
<td>45</td>
</tr>
<tr>
<td>LIGHTS</td>
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<td>85</td>
<td>85</td>
<td>170</td>
<td>425</td>
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<tr>
<td>TOTALS</td>
<td>870</td>
<td>870</td>
<td>870</td>
<td>8212</td>
<td>11077</td>
</tr>
</tbody>
</table>

These cognitive and physical functions for the aircraft flight station consist of the following categories and are listed in detail in the cognitive function analysis presented in appendix A.
11. Conclusions

Cognitive work analysis provided the right amount of in-depth abstract functions, general functions and physical functions occurring within system environments needed to be inserted into EPLI. A subsequent iterative modeling and simulation process utilizing scenarios for analysis of potential activity patterns was needed in order to establish intuitive functions. In regard to modeling, cognitive work analysis can model the physical environment along with the associated affordances and restrictions, including the organizational affordances and constraints. Contextual design was applied with the intent of developing perspective models of jobs, roles and resources to enhance contextual linking for EPLI which was initially presented in the form of a CMap (Figure 8).

Figure 8. Initial CMap generated from CFA for EPLI.

The CMap generated a list of systems EPLI (Figure 9).
1. CHECKLISTS
   a. Normal
      • Safety & Power On
      • Originating/Receiving
      • Before Engine Start
      • After Engine Start
      • Before Takeoff
      • After Take Off
      • Preliminary Landing
      • Landing
      • After Landing
      • Parking & Securing
   b. Abnormal
      • Air Conditioning
        • Pack
        • Pack Trip Off
        • Zone Temp
        • Equipment Cooling
        • Electrical
        • Bat Discharge
        • Drive
        • Elec
        • Loss of Both Engine Driven Generators
        • Source Off
        • Standby Power Off
        • TR Unit
        • Transfer Bus Off
        • Fuel
        • Low Pressure
        • Filter Bypass
        • Pneumatics
        • Bleed Trip Off
        • Dual Bleed
        • Duct Overheat
        • Pressurization
        • Alternate
        • Auto Fail
        • Manual
        • Off Schedule Descent
   c. Emergency
      • Engine Failure Flameout
      • Engine Overheat
      • Engine Fire Severe Damage Separation
      • Single Engine Preliminary Landing
      • Single Engine Landing
      • Aborted Starts
      • Start Valve Open
      • Loss of Thrust on Both Engines
      • Airspeed unreliable
      • InFlight Start
      • Smoke or Fumes Removal
      • Electrical Smoke or Fire
      • APU Fire
      • Excessive Cabin Altitude
      • Passenger Evacuation
      • Runaway Stabilizer
      • Uncommanded Yaw or Roll/Jammed Rudder

2. LIMITATIONS
   a. Operational
   b. Weights
   c. Speeds
   d. Air Systems
   e. Autopilot/Flight Director
   f. Electrical
   g. Hydraulics
   h. Engines/APU
   i. Flight Controls
   j. Flight Management/Navigation
   k. Fuel
   l. Landing Gear

3. PANELS
   a. Overhead
      • Air Conditioning
      • Electrical
      • Fuel
      • Pneumatics
      • Pressurization
   b. Forward
   c. Center

4. POP UPS
   a. Fuel
   b. Air Conditioning
   c. Pneumatics
   d. Pressurization
   e. Electrical

5. SCHEMATICS
   a. Fuel
   b. Air Conditioning
   c. Electrical
   d. Pneumatics
   e. Pneumatics T
   f. Pressurization

6. SYSTEMS NARRATIVE
   a. Air Conditioning
   b. Electrical
   c. Fuel
   d. Pressurization
   e. Pneumatics

7. FLOWS
   a. Safety & Power On
   b. Originating/Receiving
   c. Before Engine Start
   d. After Engine Start
   e. Before Takeoff
   f. After Take Off
   g. Preliminary Landing
   h. Landing
   i. After Landing
   j. Parking & Securing

Figure 9. EPLI System List generated from CFA.
The EPLI System List was then used to generate a software structure for the EPLI interface and EPLI contextual linking (Figure 10).

![Diagram of EPLI System List](image)

**Figure 10. Contextual Linking Software Structure for EPLI.**

The CFA was needed to identify and understand the different contextual patterns of activity to establish the main visual and tactile interface of EPLI (Figure 11).
Figure 11. The main visual and tactile interface of EPLI.
Finally, it should be noted that for a fully functional prototype of EPLI, it would require all of the systems discovered via the cognitive functional analysis. Additionally, it would have to include: limitations, performance, procedures, checklists, etc. However, with the EPLI test prototype, only five systems were used to prove the concept: fuel, electrical, air conditioning, pneumatics, and pressurization. Five systems requiring cognitive and physical function analysis were identified for EPLI totaling 1,856 items.
Chapter 3
Research and Design Methodology

In this chapter, I discuss and explain the different research and design methods that I used to address and design an interface that would meet the needs of my research hypothesis. My methods were determined through the Human-Centered Design concepts learned during my required Ph.D. coursework:

— Advanced Interactive Media
— Cognitive Engineering
— Cognitive Function Analysis
— Complexity Science
— Life Critical Systems
— Organizational Design and Management
— Modeling and Simulation.

There were many different methods used. I describe them for the reader in this chapter. Using HCD philosophies, current approaches can be enhanced using simplicity, natural affordance, visualization, accelerators (icons vs. tabs or indexing), activities, context, and the right amount of granularity into current technologies, providing a system that is well understand (Boy, 2013).

Superior ergonomically designed inputs were considered for human anatomical and physiological variation. System design goals are to reduce repetition, minimize force, and enhance natural and neutral agent behavior through integrated useful cues (Shaer & Jacob, 2009; Card & Moran, 1983).
The system I designed needed to affect user attitudes to afford positive motivation. Attitude embodies methods of accomplishing tasks and actions within a specific context. These and other goals can be addressed via means of transferring static paper documents into a contextually linked system; between visual icons and system information for quick recognition and rapid information retrieval.

1. The Need for an Airline Pilot’s Mental Model

To create such as system, I developed what I call Integrated Navigational Documents (INDs). INDs contextually link Interaction Descriptors (INDs) and Interface Objects (IOs) of the AIM. INDs transform static paper-based information into actively changing content, influencing user attitudes to appropriately meet challenges throughout dynamic system changes (Shaer & Jacob, 2009; and Card & Moran, 1983). This is a mental model I established for pilot training as an experienced airline pilot and instructor who wanted to develop a structure that would allow users to ask specific “what if” questions during their study time. These questions allow pilots to formulate how systems integrate and, therefore, how the failure of one system will affect the operation of other systems during an emergency. It is this style of self-study that allows pilots to establish deep knowledge of the systems, systems integration, and how system failures affect the overall performance of an aircraft during abnormal and emergency procedure, building resilience and robustness for safety and stability.

Thus, I have designed and built a prototype AIM which is a Tangible User Interface Object (TUIO). A TUIO supports a Human-Machine Interaction (HMI) with multi-touch surfaces that optionally support tangible object recognition (Intuiface, 2018). The AIM/TUIO is
called the Enhanced Pilot Learning Interface (EPLI). EPLI is a tablet that incorporates INDs to enhance pilot retrieval times of the following information: systems, alerts, procedures, flows, checklist usage and philosophies, and other procedures found in aircraft manuals.

EPLI is intended for airline training platforms to enhance aircraft system retrieval times. However, EPLI was also designed to meet the needs of novice users. The main goal is to improve flight safety by assisting pilots in training for nominal and non-nominal situations; from the beginning of training through certification. This is achieved through the improved comfort and efficiency achieved through people interacting with this AIM/TUIO device.

2. Human-Centered Design Methodologies

HCD methodologies consider the human component and suggest design drivers for achieving system goals (Boy, 2011). This requires:

— Usability engineering
— Participatory design
— Group Elicitation Methods (GEM)
— Brain writing
— Rapid prototyping
— Modeling and simulation
— Human-in-the-Loop Simulation
— Others

Further, designers need to consider the systems, organizations, and people holistically for understanding all the associated technological, organizational, and anthropological variables within the domain studied, including:
— The system itself (the technology)
— The organizational management (organization)
— The users (people)

Today, computational modeling allows designers to create scenarios implemented into software for HSI analysis within virtual environments (Shaer & Jacob, 2009). This advanced technology further affords development of an entire system, from the beginning, with testing and verification, through the scenario-based design in association with modeling and simulation. This process allows validation of the multi-agent system behavior via an iterative prototyping process (Figure 12).

Figure 12, Iteration Process of Prototype Enhancement for System Maturity (Adapted from Boy, 2011).
2.1. **Usability Engineering**

Usability engineering is based on the following four techniques (Nielsen, 1993):

— User and task observation: Achieved via observations made of the user interacting with an artifact during HITLS and specific scenarios

— Scenarios: Provide a predetermined path for testing the user’s interactions with an artifact

— Simplified thinking aloud: Testing one user at a time and asking them to provide verbal communication of their thought processes during the testing

— Heuristic evaluation: According to Nielsen, a small set of broader heuristic guidelines including:
  
  - Simple and natural dialog: Dialog should not contain irrelevant information
  
  - Speak the users’ language: Dialog should be expressed in words, concepts, and phrases that are familiar to the user
  
  - Minimize the users’ memory load: Instructions for system use should be easily visible or retrievable
  
  - Consistency: There should be no ambiguity of different words, situations, or actions, i.e., the meanings should be consistent
  
  - Feedback: Always keep the user updated and informed via appropriate feedback at the appropriate time
  
  - Shortcuts: Accelerators – unseen by the novice – can speed up the interaction for the expert user and inexperienced user
  
  - Good error messages: Should precisely indicate the problem and provide a viable solution
• Prevent errors: The system should aim to prevent the occurrence of problems
• Help and documentation: Should be easy to find and focus on the user’s task and list concrete steps to be carried out

Usability is known by several terms: Computer-human interaction (CHI), Human-computer interaction (HCI), user-centered design (UCD), man-machine interface (MMI), human-machine interface (HMI), operator-machine interface (OMI), user-interface design (UID), and human factors (HF) (Nielsen, 1993).

Usability basically helps to discover the overall acceptability of computer system based on a combination of social acceptability and practical acceptability. However, usability is determined via the evaluation of whether the system can be used to achieve some desired goal or goals.

2.2. Participatory Design

Participatory design employs the cooperation of skilled experts; in this case, airline pilots and general aviation (GA) pilots. It involves the specific domain studied and allows designers to ruminate and create a mature system that interfaces with many different individuals that operate within a complex environment (Boy, 2011, 2013, and no date).

Complexity results from variation of the human component. This is because different individuals perceive, process, decide, and act in different ways. This variation makes it difficult for one to predict Human-System Integration (HSI) behavior. This is due to the significantly diverse emotions, education, experience, and training that exists with the many different human agents involved; hence the difficulty in prediction. Participatory design allows the designer to work with the experts from the beginning of the artifact development.
The participants afford the designer with concepts and ideas that are specific to the users’ needs; this helps the designer evaluate system design requirements and solutions.

### 2.3. Group Elicitation Method and Brainwriting

The Group Elicitation Method (GEM) is used to elicit different viewpoints from various domain experts in cooperation with scientific, technological, engineering, artistic, and mathematics (STEAM) professionals (Boy, no date). During a GEM session, a classification method facilitates the elicited viewpoints into a structure of concepts. When used with GEM, brainwriting promotes the designer’s ideas on paper by sharing these ideas between the participatory designers. Brainwriting sessions engender new ways of thinking about users’ needs. Understanding user needs is important for HCD because awareness of how users behave when interacting with a system increases system maturity. Skilled experts can then visualize the high-level concepts that participatory members generate from this information and apply those ideas to their expert knowledge and facilitate the concept categorization phase (Boy, 2013; and Shaer, & Jacob, 2009). Experts are highly qualified with experience in real-world operations and they can validate, or invalidate, the abstraction side of the creatively developed group concepts. This is important because it reduces the scenario-based Human-in-the-Loop-Simulation (HITLS) process, saving time, resources and money. Therefore, GEM and brainwriting are two very effective methods for developing new HCD artifacts with a high level of maturity before product delivery, enhancing comfort, safety, and efficiency. This was very beneficial in developing EPLI as the GEM sessions conducted helped to enhance solutions for design. Four airline pilots were instrumental in discovering elements to be added to EPLI. The intent was to enhance the system prototype.
2.4. **Rapid Prototyping**

During the modeling phase, a closed-loop simulation process can be run to produce and collect experimental data which can be analyzed for validation of:

— Intended system interaction

— Re-design of the system during development

— Enhancing AIM intuitiveness

Through this iterative process, designers can redesign the system to mitigate problems before the creation of a physical prototype. This is called “Rapid Prototyping” (Figure 12) and addresses issues arising from uncertainty and ambiguity.

Thru rapid prototyping, the following can be significantly enhanced for high maturity before delivery and operational phases, reducing ambiguity and uncertainty:

— System re-design

— Modification of:
  
  • People
  
  • Practices
  
  • Profiles

— The re-defining of other necessary systems which should be included

Some of the different problem aspects are:

— Visual

— Logical

— Dynamics

— Human-System Interaction (HSI)

— Intuitiveness
— Many others

Also, we need to be creative and think outside the box when considering the following (Grote, 2009):

— User needs
— Usability
— Uncertainty

Rapid prototyping is accomplished via observing the HSI during modeling and simulation in combination with scenarios. It helps to increase the identification of the following:

— Selective attention and interpretation
— Lack of defined actions and procedures for emergent anomalies
— Incomplete information in organizational documentation
— Inadequate context, preventing the right information at the right time
— Inadequate contextual linking
— Too much rigidity
— Increased ambiguity

The above-mentioned variables can reduce adaptation for instability recovery and increases the amount of uncertainty landscapes within a system’s operational environment (Grote, 2009).

Therefore, when considering EPLI, I wanted to conceptualize a system that would be complimentary and match the needs of:

— The people
— The environment
— The organization
— The technology

This was achieved through identifying and selecting the proper context within the:

— Operational documentation
— Procedures
— Training

2.5. Creativity

Selecting the proper context required designing from the outside-in. To achieve this, I needed to use creativity to generate ideas and concepts. My creative goal was to consider new existing technologies and combine them to create a system that meets the goals and ambitions for reducing the complexity of searching through large amounts of information in order to find specific wanted information. In this way, sensemaking practices were developed and incorporated into the design and uncertainty was reduced.

2.6. Sketches and Story Boards

To promote and enhance my creativity, conceptions, and design thinking (Meinel and Leifer, 2011), I incorporated “storyboarding” (drawings, cartoons, interactive media, etc.) (Shaer, & Jacob, 2009) in the development of the design. These visual aids helped to enhance visual thinking between myself and the participatory individuals during GEM sessions. These further elicited ideas, affording tangibility of the shared ideas and concepts (Boy, no date) between the participants. Using these processes, I conceived the needed scenario-based design to be incorporated into modeling and simulation for testing and validation of the system. This led to the first drawings for the concept of EPLI (Figure 13).
2.7. **CMaps for Design**

Concept maps are used as tools to represent and organize knowledge. CMaps consist of participatory-ideas of concepts and propositions linked together for hierarchal representation; from the most general and most inclusive concept, to the most specific and least general concept (Novak, 2011). When developing a CMap, the hierarchical structure is context dependent. The context helps to determine key concepts for the construction of the preliminary CMap. The rank order of the key concepts form the development of the hierarchical structure of the required components for a mature functioning prototype (Novak, 2011). For EPLI, I used a CFA to discover the variables that would need to be included and then inserted them into the CMap for identifying the structure which was later used to develop the software structure. To construct the preliminary EPLI CMap, “post-its” were used and placed on a whiteboard with the information from the CFA as a collective
means to move concepts around in an easy fashion. The CMap development helped to reduce difficulty within the iterative process of moving concepts together and linking narrative statements, images, ICONS, schematics, checklists and other components of EPLI. Additionally, the CMap allowed for the moving of groups of concepts during the map restructuring. This information provided a graphical presentation of interrelated CFA concepts providing a good integrating context of the required structures needed for EPLI. A classification method facilitates the elicited viewpoints into a structure of concepts, providing a high level of maturity before product delivery, enhancing comfort, safety, and efficiency (Boy, no date). For the EPLI CMap, see Figure 14. For an expanded view of the CMap, please refer to appendix C.

Figure 14. EPLI CMap.
2.8. **Expert Knowledge/User Experience (UX)**

When considering EPLI, there was a need to elicit expert experience feedback from users in the domain studied. In this case, airline pilots and general aviation (GA) pilots. To provide the best way for users to accomplish tasks, one must utilize the correct interaction techniques along with the hardware and software elements associated with the input device. Resolution and accuracy were required to address the right amount of information noise. Too little information and the users’ may subjectively interpret the information leading to a false hypothesis. Too much noise and the users could have difficulty formulating clear and concise understanding as extra time could be required to perceive, process, decide, and act. Typically, when emergencies arise, time is not available for a lengthy decision-making process. Therefore, the right balance is needed for quick and efficient cognitive functions. Expert users can reduce the amount of iterative experimental analysis needed to determine the amount of useful information and enhance the right amount of information noise. I was able to conceptualize many of the needed aspects to make EPLI functional and consult with other experts, using participatory design, GEM, and modeling and simulation scenarios. This process helped to ensure that my concepts matched those of other experts. This iterative process enhanced the maturity of EPLI.

2.9. **Scenario Based Design, and Modeling and Simulation, Human-In-The-Loop Simulation**

Modeling and simulation allows a researcher/designer, in association with scenario-based design simulation, to test and verify potential anomalies of systems, the users, and the interactions between the agents and the system. This modeling and simulation investigation allowed me to generate the correct conceptual tools to share the realized ideas and concepts
of EPLI and develop a better understanding of the overall desired context. The goal was to use this process to stay focused on the purpose of the artifact and the goal was achieved.
Chapter 4
Conceptual Development of a Generic Architecture for an Enhanced Pilot Learning Interface (EPLI)

In this section, I will describe EPLI in accordance with:

— Initial design
— Iterative prototypes

Additionally, I will discuss how the design of EPLI results from the integration of several technologies using an efficient model developed by my advisor describing those technologies in accordance with (Stephane, 2013):

— Content
— Content presentation
— How users interact with the content

The content was reformatted from static Boeing 737 documents (system contextual information, system schematics, systems images, panel images, checklists, etc.); they were created by me and then placed into the interface. The presentation was developed by contextually linking Interactive Objects (IOs) as symbolic icons with Interactive Descriptors (IDs), creating what I call INDs or Interactive Navigational Documents (See figure 20 on page 93). The INDs are then presented in the tablet. Essentially, INDs are accelerators. The interaction occurs when the user views the tablet and then selects the desired system information through tactile touch of the screen. What the user sees is the INDs, which were created using Microsoft Word in the original prototype. What the user does not see is the contextual linking, created by using a Micro Soft Power Point Wire Frame. Content,
presentation, and interaction are discussed in greater detail in section 2 of this chapter. Once the content, INDs and wireframe were generated, I worked to contextually link the items that needed to be linked. This was accomplished through modeling and simulation and testing 4 airline pilots using the initial wireframe prototype. A second prototype was begun; however, the software designer was a French Air Force Academy Cadet and was not able to complete the software prior to his return to France. Therefore, a third prototype was developed, using a software team of FIT undergraduate students. 38 airline and general aviation pilot research subjects tested the third prototype. A fourth update is currently underway which will improve the speed of EPLI further. However, there will not be enough time between now and the defense to test the last prototype.

1. Designing EPLI

In conceptualizing, designing, and producing EPLI, I worked with other airline pilots, other designers, two software teams, and employed user engineering along with my experience and understanding of how the users’ cognitive functions apply. The goal was to accelerate user-system interaction and enhance the Human System Integration (HSI). I wanted to promote the necessary actions to motivate users to perform in natural and intuitive ways (Nielsen, 1993). By using accelerators, it was my hope that the user would feel inspired to feel a direct manipulation of EPLI (Shaer & Jacob, 2009; and Card & Moran, 1986). This would allow expert users direct manipulation for specialized interaction (Nielsen, 1993). Additionally, it was important to ensure EPLI would strengthen simplicity and familiarity for the user. In this way, the complexity of current navigation systems might be reduced, to enhance learning by increasing information acquisition through the reduction of system
information retrieval. Reducing the amount of time it takes to find system information allows the user to conserve cognitive resources and study more information. There was a need to understand many variables before the initial design of EPLI could move forward.

1.1. Affordance
An affordance is an environmental property inspiring appropriate actions by people who are appropriately-equipped to deal with emergent phenomena. Devices should inspire people to act in the right way at the right time through natural and intuitive emotive inspiration (situation pattern awareness); developed through procedural training and operational documentation consisting of appropriate contextual validity. Such devices should have interfaces that match corresponding users’ situation patterns. An affordance has different values; they are:

— High Affordance: The more the interface affords natural and appropriate human–machine interaction, the less procedures are required to learn the system

— Low Affordance: The more the interface is non-specific, the more the user needs guidance to interact with the system. In other words, the vaguer something is, the more subjective it becomes and requires an experienced user to help the novice perceive low system transparency

Therefore, EPLI needed to support users with a high affordance to enhance the desired actions. Thus, I needed to consider semantic distance and the relations of the meaning of expressions in the way the system was designed (Sayed, Hacid, and Zighed, 2008). To accomplish this, I needed to incorporate ways in which the context supported the users’ conception of their desired tasks (proper decision making for example).
1.2. **Context**

To avoid ambiguity, false hypotheses, complacency, uncertainty, and incoherence; context needs to be considered. This is an important consideration, particularly within the context of the systems and how they integrate during operations within a continually changing environment in which the context associatively also changes according to system needs (Boy, 1998, and Grote, 2009). The more ambiguous something is, the more subjectively it will be interpreted. A person who is left to interpret a vague description of a task can be influenced by subjectivity and may misinterpret the intended meaning (Telfer & Moore, 1997; Ericsson, et al, 2006; Hollnagel, Woods, & Levison, 2006; Ericsson, 2009; Leveson, 2011; and Hollnagel, et al, 2011). This can lead to confusion, misunderstanding, or a false hypothesis. Therefore, in determining appropriate actions to meet changing scenarios, I needed to identify and understand the correct context. If I did not accomplish that, it is possible that contextual ambiguity could be causal in destabilizing communications between the user and his/her interaction with EPLI.

Under the auspice of user-system interaction, context is one of four basic elements that affect user experience. It refers to the social, cultural, political, linguistic, and economic factors which enhance user experience. Context can be defined by the relationships between objects, including:

- Verbal context
- Social context
- Historical context

These influences are termed environmental factors and they influence the other three basic elements:
— The user
— The system
— The interaction (activity)

To prevent ambiguity, misunderstandings, lack of focus, imprecision, uncertainty, and incoherence, context analysis and elicitation must be considered under HCD design practices (Boy, 2011, 2013; Grote, 2009; and Shaer & Jacob, 2009). Context patterns were used to categorize activities to meet task allocations including:

— The task
— The space
— The time

Proper context for EPLI was analyzed and elicited to enhance the performance of contextual knowledge within EPLI, i.e. the way context was formally represented and elicited in the interface itself.

Therefore, the context-sensitive structure of EPLI documents follows the classifications incorporated into meaningful domain-dependent categories for improved operator situational awareness and decision making. Because abnormal operations are time pressured, pilots need appropriate contextual training to simulate procedures that provide natural and intuitive actions to improve the cognition of quick perception, processing, deciding, acting, and feedback mechanisms (Hollnagel, Woods, and Leveson, 2010). This is needed to prevent slow action recovery methods (Telfer and Biggs, 1988). Therefore, context-sensitivities of such procedures and training were developed into operational documentation and procedural training. Moreover, in the future, EPLI could be used as an onboard context-sensitive information system (OCSIS) which could also be used to display useful information for
operators when they need the right information at the right time. Together, these context sensitive formats are useful for enhancing situational awareness, problem-solving, decision making and appropriate actions to mitigate unwanted anomalies (Reason, 2008, and Hollnagel, et al, 2011). Additionally, for EPLI, the context needed to address system evolutionary changes that occur during:

— The different phases of flight
— The different changes in system performance

This is needed to enhance provisional flexibility in resolving emergent events. For this, Scenario-based design was utilized. Scenario-based design provides a way to develop descriptions of how people accomplish tasks; these descriptions are than used as representations for design (Carroll, 1995). During the design stage, scenarios incorporated with modeling and simulation of four airline pilots for system behavior analysis, provided methods that elicited solutions for the observable anomalies which were then articulated, appropriately, into the right context of the operational documentation and procedural training. Then the changes were made and incorporated into EPLI. This enhanced the context pattern matching for contextual changes that occurred within the environment of system operations. These elements are inserted into the training for efficient means of operator learning.

### 1.3. Learnability

To enhance the learning of novice users (GA Pilots), EPLI needed to:

— Be easy to interact with
— Promote intuitive decisions and actions
— Provide a sense of meaningful interaction that is enjoyable to the user
These system attributes needed to enhance motivation and attitude in positive ways. It is important that these HCD considerations are employed in the design of an AIM (Nielsen, 1993). The goal is to develop a highly learnable system that provides the user with interactive proficiency and efficiency in a short temporal period, reducing cognitive load and increasing cognitive resources which can be utilized in further learning through associated time savings (Nielsen, J., 1993). For a graphical display of this concept, please see Figure 15.

![Learning curves for novice and expert](Adapted: Nielsen, 1993)

**1.4. Meaningful Learning**

According to Novak, meaningful learning inspires an individual to develop a combined context of concepts and propositions that are hierarchically organized into a prearranged domain of knowledge (Novak, 2010). Skilled experts gain expertise and knowledge over time via a process of continuous meaningful learning that occurs during education, practice, training, experience, and real-world system operations (Telfer & Moore, 1997; Ericsson, et
al, 2006; Ericsson, 2009; Novak, 2010; and Salas & Maurino, 2010). Concerning education (e.g. ground school, procedural training, and simulation), meaningful learning provides individuals with a sense of control in how they acquire knowledge. This emotive learning helps people use the knowledge gained to problem solve and facilitate future meaningful learning (Novak, 2010, 2011a; and Nielsen, L., no date).

Compared to rote memory practices, meaningful learning enthuses an intrinsic motivation to learn more (Novak, 2011b). This type of attitude provides an individual with greater cognitive resources for positive physical actions when experiencing adverse situations. Also, because meaningful learning is established in long-term memory, knowledge is generally retained longer which also enhances future creative thinking for novel problem solving.

There are five elements to this type of learning (Figure 16):

1. Learner
2. Teacher
3. Knowledge
4. Context
5. Evaluation of knowledge transfer (HITLS testing)
EPLI is designed to enhance informational navigation by allowing the learner to select desired information rather than scanning for it. This process decreases the user’s information retrieval time. EPLI contains the same knowledge as current navigational tools, i.e. aircraft manuals. However, the time to find information with EPLI has proven to take considerably less time than current manuals. The intent behind EPLI system design is to provide users with enhanced temporal resources for improving knowledge acquisition. I.e., the learner has more time available for studying extra material as less time is needed to find information.

1.5. User Needs
When designing or redesigning human-interactive systems, designers should consider the needs of the users. This is holism (Boy, 2013). To meet this requirement, I needed to understand how people perceive, process, decide, act, and follow through when learning and making decisions during their studies. Socio-dynamics must also be weighed. For EPLI to be a high-valued system, enhanced maturity was required. Therefore, it was important to
understand a pilot’s education, training, schema development, and their behavior within the context of the social cultures they operate in, including (Card, 1986; Nielsen, 1993; & Paletz et al, 2009):

- Professional
- Organizational
- Educational

I also had to appreciate and consider how people perceive information that encourages the development of the above-mentioned variables. This is known as anthropological endogenic variability (AEV) and it is very complex. This required the study of Phenomenology.

### 1.6. Phenomenology

Phenomenology is the study of human behavioral experience within the world (Belvedere, 2007). To enhance human-system-integration (HSI) with a computer system like EPLI, phenomenology needed to be applied. This was to understand how pilots act in a world with pre-existing meaning and purpose, such as is the case within the commercial airline domain. In this way, EPLI was enhanced to provide the user with natural and instinctive affordances for system stability. There were two areas of interest: Social computing and tangible computing.

#### 1.6.1. Social computing

Social computing considers the social skills and aspects of people within a social setting in which the systems are used. User actions during system interfacing are dependent on embedded relationships of associated education, procedural training, experience and other activities that vary with the influence of cultural aspects affecting their interaction with systems (Belvedere, 2007). Therefore, these dynamics needed to be understood as I wanted
to design EPLI as a mature system that would interface properly with the human component. I consulted with other airline pilots within the airline social setting during modeling and simulation of the first prototype.

**1.6.2 Tangible Computing**

Tangible computing considers peoples’ physical and tactile skills. The tangible computing goal is to afford people the use of embodied systems for unconscious interaction with computers embedded in physical objects (Belvedere, 2007). This is to help people enhance their system interaction through the afforded natural and instinctual endogenic behavior influenced within AIM devices. This was achieved with the INDs. Combined, the two provide increased affordances for positive, HSI behaviors. Therefore, the goal of an AIM like EPLI is to embody the HSI into the environment, enhancing the overall human-system interaction (Boy, 2011). There needed to be concise representation, so the user could easily navigate the device for correct information retrieval. Thus, simplification was considered and applied because simplicity can reduce the capricious complexity of individuals interacting with current knowledge transference methods (i.e., cognitive variation).

**1.7. Simplicity**

There are many different complex sources of variation in workload demand, see Figure 17 (Baldwin, 2012). Of course, workload demand varies with different task roles and how they change over time, particularly during different contextual changes of a mission. Perception of workload-complexity is influenced by operator personality and the way he/she responds to task demands and their evolutionary changes. Therefore, simplifying the current manual navigational process was considered.
Figure 17. Mental workload and performance graph (Baldwin, 2012).

Within the context of dynamic complex socio-technological systems, such as commercial airline operations, users have different levels of experience, education, and skills. To enhance HSI, users should feel their actions are directly manipulating the system naturally (Shaer & Jacob, 2009). This provides a subjective feeling about the system itself, providing an enjoyable experience. Context patterns can help categorize activities to meet task allocations including: the task, the space, and the time (Boy, 2011, 2013; Shaer & Jacob, 2009).

Additionally, context–sensitive documents can integrate domain categories for enriched operator situational awareness and decision–making, also known as “naturalistic decision-making” (Klein et al, 1993). This is to provide natural and intuitive actions via augmented cognition for quick perception, processing, decision-making, action, and appropriate feedback mechanisms. Additionally, as Woods and Sarter point out, if an interface design
does not possess adequate diagnostic information, the user can be led astray and travel down a path of false hypothesis (Woods & Sarter, 1998). This can increase the complexity and encourage “automation surprise”. Consequently, another goal of EPLI was to develop intuitive recovery actions.

Interpretation of human sensory perceptual and cognitive processing limitations was considered, i.e., estimating the appropriate amount of information to be transferred and the presentation of that information. I.e., the right amount of information at the right time. The appropriate goal was to simplify the complexity of current manuals by reducing the users’ cognitive efforts required to interface and interact with a system (Nielsen, 1993). This required:

- Reducing repetition
- Minimizing force
- Enhancing natural and neutral postures
- Increasing useful cues

This was accomplished by limiting the amount of information presented on the displays, affording simplicity for enhanced recognition.

Simply stated, the intention of simplification was to improve:

- Learnability
- Efficiency
- Memorability
- Subjective satisfaction
- Reduce errors.

Therefore, the main goals of the interface were:
• Reduce user cognitive load
• Enhance procedural and system location memory
• Increase system SA and DM
• Provide sense-making for the user
• Increase information density
• Enhance natural affordance
• Enhance system recognition

1.8. Usability
System usability can influence a user’s goals and needs. It is possible to elicit two different and concurrent sets of results, influencing the user’s perception. In other words, a person’s subjectivity can lead the individual to interpret the wrong set. This can lead to ambiguity, misunderstanding, uncertainty, or a false hypothesis when performing an activity in a specific context (Nielsen, 1993; Grote, 2009; and Salas, Bowers, & Edens, 2001). Also, perception can be influenced by what a person believes about objects and their movements through previous experience, or perception can be influenced by a means of memories from previous training scenarios during practice and simulation. Such memories can enthuse a strong role on user performance and behavior, especially when cognitive resources are limited, as they are during time compression (Connor, 1985; and Jensen, 1995).

One of the most dangerous aspects of human error is the false hypothesis (Reason, 1997; Hawkins, 2010; and Salas & Maurino, 2010). Moreover, when a pilot experiences an anomaly during flight, the sympathetic nervous system (SNS) automatically induces hormonal activity that will increase heart rate, blood pressure, and other physiological changes (Marieb & Hoehn, 2010). It can take significant effort to disregard these symptoms
in an effort to manage the situation at hand. Gawron declares that emotions can reduce a pilot's’ ability to resist spatial disorientation (Gawron, 2004). The SNS response can literally influence what a person can see through a phenomenon known as paradoxical cognition; the individual can degrade in performance as they can become cognitively impaired through what is termed as tunnel vision and biases (Cheung, 2004; Gowran, 2004; and Baldwin). Usability is measured relative to certain users and certain tasks. For high valued system maturity to exist, ambiguity, misunderstandings, lack of focus, uncertainty and incoherence need to be prevented. This is because abnormal and emergency operations are time pressured and pilots need appropriate contextual information to provide natural and intuitive actions (Connor, 1985). This is to improve cognition for quick perception, processing, deciding, acting, and feedback mechanisms. The goal is to develop intuitive recovery methods (Hollnagel, Woods, & Leveson, 2008). Also, if a lack of defined actions and procedures for emergent anomalies exists, or incomplete information within organizational documentation exists, or the wrong information is displayed at the wrong time, an increase in ambiguity can exist, and the number of uncertainty landscapes within a system’s operational environment can also increase (Grote, 2009). Therefore, context-sensitive procedures should be augmented with defined operational documentation and procedural training.

When certain behavior is needed to provide system stability during the emergence of unwanted events, contextual information should display useful information with the right information, at the right time, and in the right format during training scenarios (Nielsen, 1993). Context sensitive formats are useful for enhancing situational awareness (SA), problem-solving, decision making (DM), judgement, and appropriate actions to regain
system stability when emergent anomalies occur. Additionally, the context needs to address system changes which occur during:

- Different phases of flight
- Evolutionary task management changes
- Changes in system performance
- Unforeseen anomalies
- Anthropological issues, such as visual and auditory illusions

EPLI had to be able to change with the context of specific “what if” questions generated by the user and, as a result, afford provisional flexibility in resolving these different questions which are generated during learning and training.

Therefore, the interface had to be:

- Easy to interact with
- Promote intuitive decisions and actions
- Provide a sense of meaningful interaction that is enjoyable to the user

The goal was to develop a system that provided the user with interactive proficiency and efficiency in a short temporal period. According to Nielson, this reduces cognitive load and increases cognitive resources that can be utilized in further learning through associated time savings (Nielsen, J., 1993).

Usability is based on system acceptability, including (Nielsen, J., 1993):

- The overall acceptability
- Social acceptability
- Practicable acceptability
To ensure that EPLI addressed all the needs and requirements of the users, I needed to determine the following:

• The users’ tasks
• The desired system goals
• The anthropometrical, perceptual, cognitive, cultural, social, and attitudinal characteristics
• The entire spectrum of the intended users (novice, casual, and expert)
• System learnability, efficiency, memorability
• Possible errors
• Subjective satisfaction (is the system enjoyable to work with)
• Natural affordance
• The user’s knowledge of the task domain addressed by the system

Nielsen states that the multiple components of usability are associated with the following five usability attributes (Nielsen, J., 1993):

• Learnability
• Efficiency
• Memorability
• Errors
• Satisfaction (pleasant to use)
2. **Content, Presentation, and Interaction**

In this section I discuss, in more detail, the content, presentation and interaction utilizing a model developed by my advisor (Stephane, 2014).

My intentions were to develop a new advanced interactive media (AIM) and simplify natural dialog and visualization to create an active interface to enhance meaningful learning.

There were five areas of concern:

1. Analyze the desired user actions and identify steps they go through to accomplish those tasks (How they study systems, in this case)

2. Create an agent model that could simulate those actions: This was accomplished using a CFA and working with other expert pilots along with using my own experience learning and teaching systems as an airline pilot and instructor. These processes allowed me to create a “pilot’s mental model” of learning for the application of asking “what-if” questions to gain deep knowledge of systems and their integrations

3. Design contextual links for IDs and IOs to make the model work: They form the functionality of the INDs (See figure 20 on page 93).

4. Design an information display that would simplify HSI for superior navigation across different system learning domains

5. Contract with a software team to build the applicable software for the INDs

In conceptualizing an HCD AIM/TUIO device to assist pilots in learning, I employed user engineering, participatory design, and combined my experience and understanding of how the users’ cognitive functions apply. Working with other expert pilots and utilizing my experience as an airline captain and simulator instructor, I was able to reflect, conceive, and
integrate a cognitive function allocation analysis for the initial development of the new AIM (See appendix A). The analysis inspired the following concepts for EPLI.

EPLI’s introductory realization required the following:

— CONTENT
  
  • Associated language: 737 aircraft manuals with appropriate:
    * systems
    * schematics
    * checklists
    * flows
    * performance
    * flash cards
    * limitations
    * procedures

  Note: the 737 content was not copied/pasted into the documentation. The content was re-written in simpler contextual format yet describing the same important information. Additionally, all text, images, checklists, flash cards, and other relative information inserted into EPLI were created by me. All documentation was reformatted from current 737 system information.

— PRESENTATION
  
  • Interaction Descriptors (IDs)
  • Interactive Icons (IOs)
  • Integrated Navigational Documents (INDs): The navigational pages contextually linked via IDs and IOs (See figure 20 on page 93)
— INTERACTION

- Input system (tactile touchscreen; Microsoft Surface Pro 3)
- Contextual links (IOs + IDs = INDs = Contextual Links)
- Desired system interaction
- Reduce manual information retrieval complexity

2.1. Content

I used a power point wireframe for the first prototype. This required creating 36 slides and inserting index boxes that were assigned the appropriate slide numbers to simulate contextual linking of associated systems, and checklists. For this I used 737 panels, narrations, images, and checklists. For examples please see Figure 18.

![Figure 18. Contextually linked wireframe slides.](image)

2.2. Presentation

For Presentation, I utilized an interactive touchscreen tablet, Microsoft Surface Pro 3, with the wireframe slides as visual icons of virtual system schematics, systems controls and indications, and other operational documentation; i.e., checklists, flows, and
limitations. This allowed the users to navigate the system through useful visual ques made up of text boxes that were contextually linked to system information, simulating INDs, for the visualization. This was to prove the concept; the goal was to reduce system complexity and enhance the simplicity and familiarity of the systems, systems operations, task operations, and checklist usage. The intent of using familiar icon symbology is to provide transparency with the main goal of obtaining the highest affordances for operators to easily navigate the device platform for quick recognition of system information retrieval. This makes the use of EPLI tangible to the operator, enhancing system affordance.

2.3. **Interaction**

For interaction I chose the Microsoft Surface Pro 3. There were different reasons for the selection of Microsoft:

— Any software developed for the tablet could be used with a lap top, desk top or android

— Microsoft is more affordable then Apple; therefore, available to economically less advantaged individuals

— It had a touch screen

— Lightweight

— Compact

— Good graphics

— Was on sale (I paid for the tablet)

— My advisor recommended a tablet that was easily available to people
3. Goals

Some goals were to accelerate user-system interaction and improve Human System Integration (HSI). This was to encourage the needed actions for motivating users to perform in natural and intuitive ways. Further, the interactive touch screen was necessary for the enhancement of HSI. The tactile interaction of the touch screen also inspires the user to feel a direct manipulation of the apparatus (Shaer & Jacob, 2009; and Card & Moran, 1986). Additionally, there was a requirement to ensure the system would support simplicity and familiarity for the user. This was to decrease the complexity of the current navigation systems; to enhance learning by reducing the time it takes for information retrieval, increasing information acquisition.

Another goal was to reduce the amount of time it takes a user to retrieve information. If so, a user could use that valuable resource for the reallocation of more study material. Additionally, if I could make the information easier to find, than less cognition would be needed on the part of the user, affording the user with increased mental resources, reducing mental fatigue which should also allow the user to study extra material. Another goal was to make EPLI enjoyable to work with. If the interface was enjoyable to work with, then an emotive factor could influence a user to study more as the device would be fun to work with. It was conceivable that there was a potential to enhance knowledge acquisition 3-fold, when the interaction style is simple and easy to use, cognitively undemanding, and enjoyable, access to meaningful information is facilitated and knowledge acquisition enhanced (Boy, 2017). Superior ergonomically designed inputs were developed to reduce repetition, minimize force, and enhance natural and neutral agent behavior through integrated useful cues (Shaer & Jacob, 2009; Card & Moran, 1986). The design effort was focused on keeping
this model simple, consistent, and concise for users to grasp navigational functions while utilizing as little cognition as possible.

4. **Integrated Navigational Documents (INDs): More on Presentation and Interaction**

As stated earlier, the above-mentioned goals can be addressed via the means of transferring static paper documents to what I call Integrated Navigational Documents (INDs). INDs are generated via the contextually linked Interaction Descriptors (IDs) and Interface Objects (IOs) of the AIM/TUIO. INDs transform the current static paper-based information into actively changing content, through Computer Integrated Documentation (CID), and, therefore, provide contextual changes as the operational environment evolves during study time (Boy, 1998), or during training scenarios. In this way, INDs influence user attitudes accordingly for the dynamic system functionalities; this provides affordance of the user’s mental cognition to anticipate required actions influenced by the inputs of the AIM (Shaer & Jacob, 2009; and Card & Moran, 1983).

INDs need to actively change the intent of the documents and their use as the context of the continually evolving dynamic environment changes during study, training or system use (Boy, 1998, & 2013). In this way, through practice with the AIM/TUIO, a person can simply touch an interactive IO that is contextually linked between documents (IDs) to locate desired information, during simulated dynamic situational change, and develop cognitive schemas of physical system location and desired actions to stabilize the system in the real world in an efficient and safe manner, particularly when a limited temporal component is involved (Jensen, 1995). In other words, the IOs and IDs of the INDs produce active documents during study and training, affording the operator with imprinted visual and mental cues to accurately
and quickly solve “what-if” questions during real world study/training. Textual descriptions are less efficient in developing these affordances as they cannot convey the associated emotive aspects that active descriptors can.

There are several areas the INDs contribute to system design:

— An IND provides visualization during modeling and simulation to provide tangibility of human-system interactions

— An IND provides useful and natural cognitive impressions within the user to enhance document content comprehension

5. **Human-In-The-Loop Simulation (HITLS) Testing**

A preliminary phase of testing was conducted to prove the concept and estimate the possible reduction of time spent finding information using this device. Four highly experienced airline captains were asked to find the information related to two different system warning lights, using:

— The paper method

— The digital method

— The EPLI prototype

The results of the HITLS show an average 65.5% diminution of the time needed to access information, compared to the paper and digital forms (Table 2, next page).
Table 2. Results of the preliminary tests for EPLI.

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<td>EPU vs. PAPER</td>
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<td>EPLI vs. PAPER</td>
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<td>EPLI vs. DIGITAL</td>
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</table>

6. Conclusion

As it was only a preliminary test, the sample was not large enough to give significant results, and several groups with different aeronautical backgrounds would have been necessary for complete results. However, the results show the validity of the concept, since highly experienced pilots are the most efficient with traditional learning material, given that they are used to working with them. But this first prototype was very limited and had to be improved for further testing.

Because the first prototype was a wireframe, the possibilities offered by the initial testing were very limited. However, the concept was proven. The testing of EPLI with professional airline pilots proved there is increased efficiency with the link-based navigation system, i.e., INDs. Thus, the research subjects saved time retrieving system information. However, the complexity of adding new documents and maintaining updates makes it extremely difficult to create other types of accelerators. It was, for example, not possible to add some features that would further augment the navigation method further; such as the use of a search engine, or a way to go back to the previous page by a simple click.
Furthermore, the way the wireframe is created makes it very difficult to maintain and modify EPLI. This is because when adding just one new slide, it would involve an excessive amount of time to modify every slide individually, as the new slide would change the linking of all the icons. This would be a tedious and expensive process as the links would have to be updated carefully to make sure they navigated to the appropriate contextually correct slide. Updating the content of the system would be very arduous, time consuming and expensive.

Aircraft manual updates usually occur on a weekly basis. Therefore, using a wireframe is not feasible, sustainable or maintainable.

Consequently, a second prototype needed to be developed using software which could support the above-mentioned problems and several other requirements to further prove the feasibility, sustainability, and maintainability of the EPLI concept, and make available the improved navigation and new learning tools desired. First, investigation with a person that possessed some software knowledge, as I had no education in this field, demonstrated that possible software applications for a functional prototype would need to feature hypertext links that directly integrated the narratives, schematics, checklists, and other associated documents. This was to ease the navigation between the systems. The improved prototype also had to include several amended functions that were conceived during the initial testing of the first prototype:

- A search engine
- Interactive menus
- The ability to return to the previous page
- An advanced feature for the user to write notes and create flash cards
Another important aspect needed for the developmental iteration of the second prototype conception was the requirement for the ease of maintainability and modification of continual updating and upscaling, i.e., revisions. This feature is needed because improvements will have to be applied after testing, and the content of the manuals is regularly updated by scheduled carrier corporations; this is because the manufacturer, the airline, and regulatory entities (the FAA, EASA, ICAO, etc.) continually generate revisions which deal with safety issues. These variables generated the need for me to search out, find, and work with software experts in a participatory fashion. This would also require the need to iterate several prototypes in developing a fully functional EPLI; all of which is described in Chapter 5.
Chapter 5
Design and Development Schedule of a Functional EPLI Prototype

As a young new-hire pilot for Pacific Southwest Airlines (Acquired by US Air in 1988) in 1987, I personally discovered how time-consuming it was to learn the in-depth material required to act as a second-in-command of a four-engine aircraft; the Bae-146. I was literally studying from 6:00 am until 1:00 am the following morning every day, seven days a week, for 3 months (This included ground school, simulator training, and initial operating experience (IOE)). This study load was not a burden for me as I had dreamed of being an airline pilot since I was a very young boy. In fact, I was highly motivated and determined to do whatever was necessary to succeed in the training. After all, every pilot who had come before, or would thereafter, had to endure the same task load. It was just part of the job, and everyone knew it. With that said, it was not until 28 years and 12 transport category aircraft later, that I began to question the methods used to retrieve system information. This consideration became even more apparent when teaching Turkish Airline Pilots the A320 systems in 2015. In my entire career, I had never come across a manual that was so problematic and arduous to use in finding system information. Airbus could learn a lot from Boeing, McDonnel Douglas, Lockheed, Embraer, British Aerospace, Fokker and others. Fortunately, that was the same year that I began my quest to earn a Ph.D. in Human-Centered Design. That was the year I identified my thesis problem statement and began developing EPLI, i.e., the year I began my design thinking research (Meinel and Leifer,
2011). Figure 19 shows the time line/schedule for this research in the design and development of EPLI. In other words, the rapid-prototyping schedule of EPLI.

Figure 19. EPLI iteration development time frame.

1. The First Prototype

EPLI took several years to develop (Figure 19). In the beginning, I had to address usability for novice pilots and expert pilots. It was necessary to consider the “new-hire” student and the experienced airline pilot. I had to conceptualize, design, and create inputs (visual icons) with high affordance to enhance the desired novice actions in addition to the actions of an
expert. To address semantic distance, I considered the relation of the meaning of expressions in the way I designed the system. This was required to incorporate ways in which the context supported the users’ conception of their desired tasks (proper decision making as an example). Further, I had to explore whether EPLI could deliver the concepts and distinctions within the airline training domain. There needed to be concise representation, so the user, novice and expert, could easily navigate the device for correct information retrieval. Thus, simplification was considered and applied because simplicity can reduce the complexity of interacting with EPLI.

I also had to develop a new document system which could contextually link the different domains of study in an advanced jet transport category aircraft manual. This led to using the IOs and IDs in combination with Computer Integrated Documents for the development of the Integrated Navigational Documents. Again, INDs allow static documents to actively change accordingly to the evolutionary dynamic changes that occur during cognitive scenarios of different situations generated by “what if” questions that pilots consider during systems integration study (Kiss, 2017). In this way, pilots develop intuitive safety protocols by asking these mental “what if” questions during different stages of flight with different scenarios they mentally conceive. This is to provide stability resolution for possible unwanted events that might occur. INDs provide a dynamically context sensitive format that provides the user with quick answers to contextual “what-if” scenarios, as the user sees fit. This also provides the user with an enjoyable sense of descriptive interaction with the device, i.e., a feeling of control over the system rather than submitting to control of the system. In other words, they feel in control of their study time, enhancing their attitude and
motivation. Further, this allows the user to become an information selector rather than an information sorter (Connor, 1985).

Once the concept of EPLI was defined, the first prototype needed to be developed and then tested in order to verify the validity of the theory; EPLI could save pilots time in retrieving system information. Additionally, testing was needed for observing the users interacting with the system and to gather feedback from the users. Because I had no programming background, I was advised to create a wireframe using Microsoft PowerPoint. I created slides, incorporating images and text into the slides, and text boxes to be used as buttons, simulating IOs and IDs. I then defined clickable areas linking the contextual information to appropriate slides. This simulated and modeled INDs as an easy way to navigate through the pages (Figure 20, Figure 21).

Figure 20. Illustration of IDs and IOs making up INDs for EPLI.
Designing the first prototype was considered in the context of a larger project that focused on design and development of interactive media systems that could enhance HMI. During the development of EPLI, I utilized HCD educational design methods: this included utilizing a tablet integrated with embedded system schematics, procedures, and other operational documentation that can be retrieved by an interactive user with the system, affording simplicity (Figure 22).
1.1. **A Fully Functional Wireframe Prototype**

A working EPLI prototype using a wireframe was created and used during the modeling and simulation phase for testing the concept (Figure 23, Figure 24).
Figure 23. The author with Manali Desai and the EPLI Wireframe prototype.
This simplicity of the prototype involved designing top-down multiple layers of aircraft systems, systems integration, warnings and alerts, procedures, and flows and checklists. The first level consisted of the user’s desired system knowledge goal (systems, flows, checklists, procedures, flight management, alerts). The second level consisted of the different panel sections on which each system is located:

— The center console
— The forward panel
— The overhead panel
The third level consisted of the individual systems followed by the fourth level, the overall system information and the fifth and final level comprised of the specific contextual information for the selected system.

The goals of this AIM device are to:

— Reduce the complexity of tabbing or scrolling through high numbers of pages
— Reduce the temporal component required by existing systems
— Reduce user cognitive load
— Enhance procedural memory, and system location memory
— Address the needs of the novice, casual, and expert users
— Increase system situational awareness and decision-making
— Provide sense making for the user
— Increase information density
— Enhance natural affordance
— Increase anthropological neuromuscular actions
— Enhance system recognition

Simply stated, the intention was to improve learnability, efficiency, memorability, subjective satisfaction, and reduce errors.

1.2. Testing, Evaluation and Analysis

The device needed to be tested to ensure maturity was of high quality. This required developing scenarios for modeling and simulation to observe the system, the user, and the HSI interfacing behavior (Carrol, 1995). It was necessary to test both novice and expert users to ensure that the system incorporated the entire spectrum of potential users. This was done
through a task analysis with the users and the following basic elements during modeling and simulation (Boy, 2011):

— The user
— The system
— The activity
— Context
— Granularity

1.3. Human-In-The-Loop Simulation (HITLS)

EPLI HITLS testing consisted of using Boeing 737 flight station posters with scenario-based design and expert users (four airline pilots) to observe and measure the learning distance between current training aid devices and EPLI. This required using current paper and digital learning aids and comparing them to EPLI.

During this stage, testing of the tablet occurred to elicit data and analysis to encapsulate the different levels of sophisticated Boeing 737:

— System knowledge
— Flow patterns
— Ease of checklist usage:
  • Normal
  • Abnormal
  • Emergency
— Procedural training
— System alerting
— Limitations

There was a comparison of the difference between EPLI, paper, and digital formats in terms of time required to retrieve specific system information, simulating pilots asking “what-if” questions during study time. The testing consisted of different stages:

1.3.1 Stage 1.

The research subject was presented with the current different types of training devices. Lecture, discussion, and physical manipulation of aids was afforded to the research subject for direct tactile and visual concepts; affording the traditional system relationships. Explanation of how to use the aids was given and the scenarios described; interaction was then initiated, and simulation occurred (Figure 25).
1.3.2 Stage 2.

After the research subject completed stage 1, lecture, discussion, and physical manipulation of the EFB was provided to the research subject for direct tactile and visual concepts; affording EFB system relationships. The RS was then instructed on the EFB system and its use. Simulation then took place.

1.3.3 Stage 3.

After explanation of EPLI use, the research subject was inserted into the simulator and performance using EPLI was measured and recorded. Feedback of system function was also requested, and all suggestions and/or recommendations were considered in the iterative prototyping, HCD methods, and modifications made appropriately to the next prototype. Also, operational comparisons of traditional methods and EPLI were made to measure improvements or degradation to verify system performance.

Figure 25. A Research subject (Airline Captain) interacting with a paper-based manual.
Of course, during the simulation, certain elements not previously considered expressed themselves. During this iterating evaluation of the system, I used formative evaluations to address those needs to improve system design. Additionally, to improve the overall quality of the interface, a summation evaluation was made by asking the experts their opinion about potential improvements, with the goal of creating a system that addressed all of the needs previously mentioned, and an overall mature system that could provide acceptability.

The initial prototype provided a means to test and estimate the possible reduction of time spent finding information using this device. This testing proved the concept. Four highly experienced airline captains were asked to find the information related to two different lights, using the paper version, the EFB (digital) version, and the EPLI prototype. The results show an average 65.5% diminution of the time needed to retrieve system information, when compared to the paper and digital versions (Table 3).

Table 3. Results of EPLI prototype proving concept.
2. The Second Prototype

The preliminary phase of testing proved the concept and found the average reduction of time for four airline pilots to be 65.5%. However, the sample was not large enough to give significant results to a population. Several groups, with different aeronautical experience, would be necessary for complete results. But the first prototype did show the validity of the concept as highly experienced pilots are the most experienced using traditional learning material, given that they are used to working with them. It must be noted that the first prototype was very limited and had to be improved for further testing.

The testing of EPLI with professional airline pilots proved there is increased efficiency with the link-based navigation system. However, the complexity of adding new documents and maintaining updates makes it extremely difficult to create other types of accelerators. Additionally, the wireframe makes it difficult to maintain and modify EPLI. This is because when adding just one new slide, it would involve an excessive amount of time to modify every slide individually as the new slide would change the linking of all the icons. This would be a tedious and expensive process as the links would have to be updated carefully to make sure they navigated to the appropriate contextually correct slide. Updating the content of the system would be expensive. Therefore, using a wireframe is not feasible, sustainable or maintainable.

2.1. The requirements for a new prototype

The second prototype would need to meet the above-mentioned requirements and several others to further prove the feasibility, sustainability, and maintainability of EPLI, if I wanted to make available the improved navigation and tools desired. First, my research into possible software applications demonstrated that a functional prototype would need to feature
hypertext links that directly integrated the narratives, schematics, checklists, and other associated documents. This was to ease the navigation between the systems. The improved prototype also had to include several amended functions that were conceived during the initial testing of the first prototype:

- A search engine
- Interactive menus
- The possibility returning to the previous page
- An advanced feature for the user to write notes and create flash cards

Another significant feature for the iteration of the second prototype was the requirement for ease of maintainability and modification of continual updating and upscaling (revisions). This feature is needed because improvements will have to be applied after testing, because the content of the manuals is regularly updated by the manufacturers, the airlines, and the regulatory entities (the FAA, EASA, ICAO, etc.). This continually generates revisions which deal with safety issues.

2.2. Choice of Hardware

There are many options in today’s market place when choosing an interface. However, before a decision can be made, one must consider:

- The domain environment
- The users
- The applications
- Many other variables

Therefore, one must explore those needs before selecting the appropriate system.


2.2.1 Defining the needs

Defining the exact context for the use of the EPLI prototype was not a simple task. By its innovative nature, the concept of EPLI generated many ideas, providing a large number of practice scenarios for the device. Initially, the project was intended only for the design of a new way to display the content of training manuals for learning purposes. In addition to considering the HCD philosophies, needs of the device encouraged a certain liberty in EPLI’s conception. It was also discovered that the reduction of time required to find information could be an enhancement for inflight information gathering; i.e., when pilots need to quickly find procedures that apply in off-nominal (abnormal and emergency) situations. This finding implied that EPLI could also be available for use in the flight station, as an onboard context-sensitive information retrieval application. It was decided that this could be future work for the project. For my current work, the focus would be on the learning objective. With that said, there was another idea considered that could profoundly modify the aspect of the project development.

2.2.2 Augmented Reality

During the process of defining the exact shape of the project, there was one issue raised: using a tablet-based device did not provide users with the ability to enthuse muscle memory (muscle proprioception) of kinesthetic awareness for switch, lever, button or device location. Indeed, one of the most efficient ways to learn checklists actions is to practice associated flows by physically repeating the desired activities in the flight station. This is to provide muscle memory of the locations of checklist items and create a physical location awareness for the trainee. This can be done in a real simulator, but the availability of these
machines is limited, and pilots need to spend a great amount of time practicing these flows to prepare for the simulator training.

The idea was to combine simple printed mock-up posters of the flight station (See figure 41 on page 136) with Augmented Reality (AR) glasses. AR glasses would be used to display the needed information to the user as an overlay to the posters, and the surface of the poster would have been used to interact with the visuality of glasses. I.e., the user could have moved their hand to the exact location of the perceived switch, knob, lever, or light over the panel with the visual overlay of the AR glasses, establishing muscle memory. For example, the flows could have been displayed on the glasses, overlaying the mock-up of the cockpit, and students would have to touch the current item to display the next one, thus practicing the flow in the right order.

Other features of the project could also have been enhanced; example, the systems section. The student would only have to touch one button to switch to the systems mode, and then touch an item on the mock-up to display the narrative of this item and the links to potential checklists or procedures related to it.

However, this whole idea was based on a technology which is relatively new and, as of this time, still immature. The first issue was that of programming software for AR glasses. Such programming requires a deeper understanding and a higher knowledge-level of programming expertise. Additionally, because it is a new technology, the documentation available online is not developed enough to find detailed information. This data would have afforded the software engineers with the ability to learn what was needed to create an AR device to enhance EPLI for my concept. Unfortunately, I did not have this education and there was not enough time available during my Ph.D. studies to learn the required lengthy
material. The interaction with the glasses is currently too approximate, and the necessary precision to interact with one particular item in the middle of another was lacking. This was due to the close proximity of items in the flight station. It was possible to make approximations, but precision was not afforded with the current technology, because the current technology lacks the ability to achieve the fine motor skills of the human hand. A study of feasibility was conducted by Varun Korgaonkar and Natasha Rao (two SCHDIA students who worked with me on the EPLI project). They indicated these deficiencies. The results are listed in (Table 4).


Current advanced AR glasses considered that are commercially available:

<table>
<thead>
<tr>
<th>Device</th>
<th>Camera</th>
<th>Upload Content</th>
<th>Video Streaming</th>
<th>Hand Gesture</th>
<th>3D Models</th>
<th>3D Models Manipulation</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atheer Air</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, Limited, App based*</td>
<td>Yes, app based</td>
<td>Movement, Zoom</td>
<td>$3950</td>
</tr>
<tr>
<td>MS Hololens</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, Limited, App based*</td>
<td>Yes, app based</td>
<td>Movement, Zoom, Selection**</td>
<td>$3000</td>
</tr>
<tr>
<td>Epson Moverio BT 3000</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes, Limited, App based*</td>
<td>Yes, app based</td>
<td>Movement, Zoom</td>
<td>$779 ($2000 adv. version)</td>
</tr>
<tr>
<td>Meta 2</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes, Limited, App based*</td>
<td>Yes, app based</td>
<td>Movement, Zoom</td>
<td>$949</td>
</tr>
<tr>
<td>Vuzix M300</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* It may be possible to add customized hand gestures but will have to be developed on separate app and will be time consuming and flow may not be smooth.
** Selection of individual components of 3D models/images is possible via a fixed cursor (virtual movement based on physical head movement), but will not be hand gesture based as required, and will also require additional programming for customized images/3D models. Consequently, as a result of this feasibility study, the best solution employing current technologies remains the interactive touchscreen tablet-based device.

2.3. **EPLI Design**

2.3.1 The Navigation

For participative design purposes, I created an improved CMap, which provided tangibility to a software team of what the project would look like. This CMap, displayed in appendix C, shows the global structure as it was intended to be. The different systems and alerts IOs on the main page took the user to an image of the flight station where the user could choose one of three flight station panels on the display (Figure 26). The user could then select a system on this panel and finally select one item on the system’s subpanel. When the user selected the systems mode, it displayed the narrative related to this item. If he or she selects the alerts mode, then the device displays the meaning of the associated light or indicator, the possible interactive consequences on the systems, and a link to the checklist related to this particular failure. The checklist IOs navigate the user to a page that provides a choice between normal, abnormal, and emergency checklists. That contextual link then displays the list of the associated checklists for that system via visual icons of the alert light; this provides visual recognition and stimulates natural and intuitive affordance for the user to quickly select the correct checklist, reducing time to find the information. Every checklist page also incorporates a link to the associated flow.
Eventually, I felt that the alerts and systems mode were redundant, and the content of both modes could be merged into one unique mode. The content displayed when an item is selected would then include all the information that was previously divided, and a link to the associated checklist when the item is an alert. The idea of displaying a full page whenever an item is selected was to provide the correct amount of granularity for the user to quickly and accurately identify the appropriate information. Because the amount of content was large, complexity was increased and needed to be reduced. Therefore, I replaced the associated added documents that would have been needed with a system of pop ups that were linked to the visual icons of the system panels. These panels consisted of the associated system switches, knobs, indicators, and warning lights.
2.3.2 Page Structure

The items displayed in the application are separated into two groups:

— 'Fixed' items that must always be available to the user

— The moving parts that will be successively displayed according to the user’s needs

The fixed items are placed either in a drop-down menu on the left side of the screen (it's the case of the search function and the future tabs and note-taking functions), or in the icon bar at the bottom of the screen. There is a rollback function, a home button, and a button that will later save the current page in a new tab. The mobile elements, which are the different pages opened by the user, are displayed in the main page (Figure 27).

Figure 27. EPLI’s main page.
2.3.3 Color Coding

The colors used in EPLI were the result of extensive considerations. First, a dark background has been chosen because the application could evolve to be used in the flight station (Figure 28). This is a safety consideration, as white backgrounds can diminish a user’s vision and, subsequently, reduce their visual capacities, which can have nefarious results in a flight station. This occurs because the sympathetic and parasympathetic nervous systems automatically adjust the iris of the eye (Figure 29). The color of the text consequently had to be chosen carefully, to optimize the contrast, and thus improve the readability and reduce eye fatigue (Wright and Scott, 2006).

![EPLI Color Coding Table](image)

Note: The text in figure 28 does not provide appropriate fidelity of what is seen in the EPLI application. The images in EPLI are of much higher fidelity and the high-chroma colors are obviously the best choice.
Using a black background prevents parasympathetic pupil dilation during night operations. This is needed to prevent night blindness and associated visual illusions.

![EPLI Color Coding](image)

**Figure 29. EPLI color coding for airline operations.**

Additionally, colors have existing meaning in aviation. Because EPLI needs to provide natural affordance for users, it was necessary to be in line with these understood codes. Accordingly, the following four main color codes were designated for EPLI:

- **GREEN:** Everything related to normal situations
- **AMBER:** Everything related to abnormal situations
- **RED:** Everything related to emergency situations
- **CYAN:** Everything related to advisory information
Finally, the FAA recommends that the number of colors used for an aviation display not exceed more than six. This is to maintain clarity and avoid confusion for the user. Further, it provides the correct amount of granularity. This limitation was also considered when designing EPLI. I have been in the airline industry since 1983 and qualified in 12 transport category aircraft. The black background and colors used in EPLI match the PFDs, MFDs, alerts, and lighting in all of the aircraft I have ever flown during that time. However, we also sampled the colors by asking individuals which shades they could discern more easily. The colors used were considered the best contrast with the exception of Cyan. That color is being changed. Finally, the RSs were asked about visualization via the NASA TLX questionnaire. Visuaity was rated high for EPLI.

2.4. Technical Solutions
As mentioned in HCD philosophies, participatory design is a dominant factor. I do not have any formal training in software engineering. For that, I had to reach out to specialists and work in a participatory fashion to see EPLI become functional. I did make the wireframe for the first prototype, doing so required a relatively simple method to learn and put together. However, to meet the demands of a fully functional prototype capable of the goals desired, a software person or team was required. I was assigned an intern from the French Air Force Academy; Second Lieutenant Antoine Rambrue (Figure 30).
2.4.1 Software Language

Lt. Rambrue and I worked closely together, and he listened intently as I explained the goals of a working prototype for EPLI. Based on my vision, he set out to accomplish the task of developing the appropriate software languages. The first step towards the new prototype was to choose a language that best suited EPLI. Because the prototype could be the basis for the final version of the application, Lt. Rambrue had to allow the coding to afford the wanted features and applications. However, it was also important that the software meet the
needs for EPLI’s feasibility, maintainability, and sustainability for a professional application.

Java was first considered as it is the most commonly used programming language for applications, and one of the few languages that was a part of Lt. Rambrue’s background. Java’s transportability was also in its favor because it was desirable for EPLI to be usable on many different devices, i.e., a tablet, lap top, cell phone, etc. Still, Java is an object-oriented language, which did not exactly meet our needs. According to Lt. Rambrue, creating an interface that is pleasant to interact with, using Java, is long and tedious; and requires relatively advanced knowledge of the language and its subtleties. Languages like C or Python had similar drawbacks.

His knowledge in these languages was even less. The solution that we felt to be the best came late, because it was not initially dedicated to the creation of an application. It is the combination of HyperText Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript (Figure 31).

![Figure 31. Software creating 2nd Prototype of EPLI (Kiss, 2017).](image-url)
It should be noted that this combination of languages was initially designed for the creation and operation of a website. With the recent evolution of these languages, especially JavaScript and its jQuery library, their main application has been for the formation of web applications.

The principle is fairly simple:

— HTML: is used to create the structure of the page/pages by incorporating the various elements and their content

— CSS: allows a change to the formatting of the page/pages and the different elements

— JavaScript: is used to create a dynamic page by creating scripts that are triggered by certain events.

Once Lt. Rambrue learned about HTML, CSS, and JavaScript, he utilized the combination of these three languages to create a fully customized interface with much less code than it would take with Java alone, or any other object-oriented language.

The combination of these languages was also very portable, since the only requirement for the user is to have an up-to-date web browser on his/her device to open and use the application. It can be shared locally for a limited distribution and offline use, or be uploaded online like any website, making it available anywhere and at any time, for broad distribution.

However, for me, there was an issue with this type of application; security, as it made EPLI vulnerable to hacking. However, I was willing to try Lt. Rambrue’s method to prove the concept. He would build the part of EPLI that people could not see, and I would build the part of EPLI that people could see.
2.4.2 Design of the Pages

A master page containing all pages was created to hold a 'content' container in which pages could be loaded (Figure 32). This way, the browser is always on the same html page, but displays other pages in the said container. This is made possible by replacing the usual links with customized ones, which call a function specifically designed to load the page in this particular container.

![Design Concept](image)

**Figure 32. The design concept showing the different levels of EPLI (Kiss, 2018).**

While Lt. Rambrue was working on the software, I was working on the content, i.e., the text, images, and structure of the interface. This required developing the content, presentation and interaction using Stephane’s model.
2.4.3 Content

As stated earlier, a CFA was performed to discover all of the systems that would be required to program into EPLI for a fully operational prototype. Fortunately, I would not have to build EPLI based on a fully functional flight station to prove the concept. The two most popular aircraft in use today are the Boeing 737 with 13,298 ordered since 1965 and the Airbus A320 with 12,463 ordered since 1989 (Assis, 2016). Fortunately, I have experience operating both aircraft. I am type rated on the 737 and possess more than 3,500 flight hours in that aircraft. Additionally, I have access to the most current 737 manuals at American Airlines, where I am employed. To make the content for EPLI, and to prove the concept, I needed the following systems and their respective system panels:

— Air Systems including:
  • Air conditioning
  • Pneumatics/bleed
  • Pressurization

— Electrical
  • Top panel
  • Middle panel
  • Bottom panel

— Fuel

There were a total of 7 panels that needed to be working for the prototype.

Additionally, in fashioning the content, I had to create the following:

— Associated narrative text

— Schematics
— Limitations
— Alerts
— Checklists:
  • Normal
  • Abnormal
  • Emergency

2.4.4 Presentation
For Presentation, I utilized an interactive touchscreen tablet (Microsoft Surface Pro 3) with contextual links via recognizable visual icons (IOs) of virtual system schematics, systems controls and indications, and other operational documentation; i.e., checklists, flows, and limitations (IDs) (Figure 33, next page). This affords the user with the ability to evaluate and choose specific information. The system is envisioned to afford operators with intuitive resilience and robustness via the recognition of easily identifiable symbols. Therefore, agents are afforded with intuitive actions and they can navigate the system through useful visual ques and select the appropriate information desired.
The goal was to reduce system complexity and enhance the simplicity and familiarity of the systems, systems operations, task operations, and checklist usage. The intent of using familiar icon symbology is to provide transparency with the main goal to obtain the highest affordances that allow operators to easily navigate the device platform for quick recognition of information retrieval. This makes the use of EPLI tangible to the operator. Figure 34 shows the main page for EPLI. For more images of EPLI interaction, please see appendix F.
2.4.5 Interaction

The interaction is fundamental. The user simply selects the specific area of interest and touches it (Figure 35).
2.5. The Third Prototype

Unfortunately, Lt. Rambrue did not complete the software for EPLI. He came to the college of Human Centered Design (what it was called before integration into the COE) for his Maters internship, a requirement of the French Airforce Academy. He was able to complete his paper and had to return to France to start his flight training. My hope was that he could finish the project after returning to France. Of course, his flight training took precedence and he no longer had the time available to complete the software. I was in search of a new
software person or team. Under the leadership of Dr. Thomas Eskridge, I was able to procure a software team of FIT students:

— Ian Dillon, acquiring a BS/MS in software engineering
— Melissa Manley, acquiring a BS/MS in software engineering
— Christian Maurno, acquiring a BS in software engineering
— Gaetano Saltalamacchia, acquiring a BS in software engineering

Each of these brilliant students were assigned with developing the different tools to accommodate the requirements of EPLI. The project was contracted as their required senior project for graduation. The team used the work that Lt. Rambrue had begun and made the necessary adjustments. We employed Google Docs, GitHub, Email and face to face meetings to work together as a team. The team contract can be found in appendix D.

These very talented individuals worked tirelessly to develop a functioning EPLI prototype. My task was to complete all of the images, text, checklists, limitations and other content needed to create the visual presentations for EPLI. Some of the EPLI images can be found in appendix F.

Additionally, I worked with the team to insert the contextual linking of the IOs and IDs needed to afford the users with the INDs, providing simplification of the navigation process. I.e., we developed a working system based on users selecting information rather than searching for information. This had to be developed by a pilot to afford the mental model needed to address specific “what-if” questions pilots use to acquire deep knowledge of aircraft systems and their interactions.

According to the team, the EPLI software was created utilizing the following (Dillion, et. al., 2018):
— JavaFX: An application builder that uses FXML

— Extensible Markup Language (XML) based user interface: To create the graphical user interface (GUI)

— Java programming language: A back-end language to interact with the GUI

— NetBeans: The JavaFX framework was used in the NetBeans integrated development environment (IDE). The NetBeans IDE contains all EPLI files, as well as the workspace in which the code can be edited, and the application can be built and run

— JavaFX Scene Builder 2.0: To enhance EPLI visualization, JavaFX Scene Builder 2.0 software was used in combination with NetBeans to design each visible page in the EPLI program

An image of the NetBeans IDE is shown in Figure 36.

![An image of the NetBeans IDE](Dillion, et. al., 2018)
Important to note that I designed the pages while the software team used my documents to overlay the software and build the pages. Scene Builder gives the software engineer the ability to drag and drop buttons, images, shapes, and various other structures to aid in design. The designs made EPLI’s Scene Builder application translate directly to FXML code, which is ultimately what a JavaFX program runs to display the page when built. An example of the Scene Builder in use with the EPLI Home Screen/Main Menu page, along with the FXML code it translates to, is shown in Figure 37 and Figure 38.

Figure 37. An example of the Scene Builder with EPLI (Dillion, et. al, 2018).
Figure 38. EPLI Home Screen/Main Menu page, along with the FXML code it translates to (Dillion, et. al., 2018).

Gitlab software was used to maintain the code base of EPLI (Dillion, et al, 2018). Gitlab is a version control software that allows for private code repositories. This software allowed each team member to work on the same version of the code, so that when one member of the team updates a file, all other members have access to the updates.

The Controls FX library was also utilized in the EPLI software. This is an open-source software library that contains additional functionality for JavaFX. Specifically, the PopOver feature of the library was used to implement the pop-ups seen throughout the EPLI application.

Important to point out that the information defining the software used was provided to me by the team. Working with the team has motivated my curiosity in learning software and I may enroll in classes allowing me to learn this complex domain. For now, I am happily
reliant on the team and trust their expertise implicitly. Sections 2.4.1 through 2.4.5 are offered to the reader from the information provided to me by the software team (Dillion, et al., 2018).

2.5.1 Software Design
The team utilized the Model-View-Controller (MVC) software design pattern to design the EPLI software. According to the team, in the EPLI design pattern, the *model* is the central component of the design as it controls the inclusive actions of the application (GeeksforGeeks, 2018). It works independently of the user interface. The *view* consists of the user interface design. The user interface design was created using FXML and Cascading Style Sheets (CSS) (GeeksforGeeks, 2018). This allowed the *controller* to respond to user input and interact with the view (GeeksforGeeks, 2018). In EPLI, the controller files were in Java, and they were typically used to handle user events that occurred during runtime. For example, if the user clicked the “limitations” button on the home screen, the FXML would send this “button clicked” event to the specified controller file method (Dillion, et al, 2018).

The process within the controller file could then hold the essential code for transitioning the screen to the Limitations document. This relationship between the FXML file and Java controller files is seen throughout the program, with all user events being handled by developer-specified controller methods (Dillion, et al, 2018).

Their software design aims to maximize cohesion, affording the data structures with the ability to synergize well with each other. This also aids in optimization. Additionally, the design minimizes coupling, and when there is a program error, minimal classes are affected.

To implement the design of the different sections of the aircraft for EPLI systems, alerts, narratives, etc., there was a need to send the software team various PDFs and word
documents including the visual design of each page seen in the EPLI application. There was also a need to outline all the textual information for each aircraft system, visually seen throughout the many sections of EPLI, including: limitations, narratives, checklists, and pop-ups in the application. We also sat down and methodically connected the necessary links for the narratives, schematics, systems descriptors, and other sections of EPLI. This process was very tedious and time consuming.

2.5.2 Menu Bar

The menu bar that appears on the bottom of the EPLI application contains buttons to go back, forward, or to the home screen (Figure 39, next page).
2.5.3 Pop-Ups

To implement the pop-ups seen throughout the systems descriptors, schematics, and narratives sections of EPLI, the PopOver class from the open-source ControlsFX library was used (Dillion, et al, 2018). This software library contains functions that include showing, hiding, and dragging the pop-ups, that are then called by the EPLI code. For each pop-up screen, an FXML file was created that included the design of the pop-up. Then, when a button is clicked, that is supposed to show a pop-up, a function in the EPLI code
corresponding to the screen the button was clicked on is called by the code. This function then calls a generic “showPopOver” function that was implemented in a generic PopUpsHelper class.

**2.5.4 Panning and Zooming**

There was a requirement to afford the user with the ability to pan and zoom images. The team had to be creative because JavaFX’s built in zooming and pannable panes were not adequate for their implementation. Therefore, the team created their own classes to gain optimal performance. The custom zoom function takes into account scrolling or the use of two fingers to calculate the dimensional shift in the image’s size. The x and y coordinates are used to manipulate the view of the image, making it larger or smaller, by taking into account the height and width of the image and doing calculations through the use of scale factors and delta transformations (Dillion, et al, 2018). Thus, the custom zoom function registers height and width variables accordingly to properly keep the orientation and scale of the picture intact. This allows the user to properly zoom and then pan across the entire image. The escape key, as well as the refresh button, restores the image to its original scale and resets the zoom properties.

**2.5.5 Program Optimization**

According to the team, EPLI software optimization was a massive task due to the hardware constraints of the Microsoft Surface Pro’s RAM limitation of 4GB (Dillion, et. al., 2018). JavaFx has a lot of what is known as bloatware. Originally, the team implemented a pre-loader so that the transition from screen to screen was smooth and without any delay. However, this required all the images to be loaded at the beginning which caused the Surface Pro tablet to crash. The unneeded bloatware was a major crashing issue because of the
massive amounts of images. The team’s first step to resolve the issue was to implement a “load as you go” format. When you clicked a button, at that point in time, it would load. This assisted in allowing the program to be run on the given machine. However, there was downside to this; the increase in time it takes to transition from screen to screen. However, this proved not to be a problem during the testing of EPLI.

The best feature of the new prototype was the web-based design was no longer required. The team was able to build a software model that could be uploaded to a computer, tablet, or phone. This enhanced the security of the system.

While working with the team, we developed other ideas for the application of EPLI:

— The ability for EPLI to communicate with the aircraft computers to enhance abnormal and emergency operations

— The ability to transfer EPLI from a tablet-based artifact to augmented reality (the team felt they could engineer this capability)

— The ability for a user to access the internet and interact with another pilot while interacting with EPLI’s augmented reality version

— The application of EPLI for single pilot operations or autonomous flight

— EPLI to be incorporated into flight crew operations

These potential applications will be further discussed in Chapter 7: Conclusions and Future Work. The team completed the EPLI software in July 2018. This prototype was used to test 38 pilots during August and September of the same year (See appendix G). The results of that HITLS testing are listed in Chapter 6: Exploratory Human-In-The-Loop Simulation.
2.6. **Exploratory Human-in-the-Loop Simulation**

During the HITLS testing, several new potential enhancements were discovered via the observations made, and by recommendations of the research subjects. These enhancements and recommendations generated an iteration EPLI for a fourth prototype, now in development by the team. This is briefly discussed in section 2.8. However, it will be discussed further in Chapter 7: Conclusion and Future Work.

2.7. **Comparing EPLI to Paper and EFB Methods**

It is paramount that the reader have an understanding of how EPLI is presented to the user in comparison to the traditional methods. This is important because even in the commencement of navigating the different methods, EPLI is much simpler to use as the initial interaction is much less complicated than the other two methods tested; Paper and EFB manuals. The best way for me to accomplish making EPLI’s ease of use tangible to the reader, is to illustrate the three different beginning formats of the different methods and how the user initially interacts with them.

2.7.1 **The Paper Manuals**

There are three paper manuals needed to encompass all of the necessary information that must be available to the user (Figure 40):

- Volume 1. Operations
- Volume 2. Systems
- Volume 3. The Quick Reference Handbook (QRH)

These manuals are large and cumbersome, weighing 17 pounds when combined. To find different types of information, depending on the specific information a student desires, all three manuals must be involved. Therefore, the user must physically pick up one manual and
search for the desired information. If the information is not found in the first selected manual, the user must now transition to one of the other two manuals. Understanding that each of the manuals have specifically organized, one would think that selecting the correct manual would be straightforward. However, it is not always so easy to determine which manual will apply and, often, the user must interact with all three manuals to retrieve the correct information for the specific “what if” question he/she has asked. This requires time, physical energy, and cognition.

Figure 40. Traditional paper 737 Manuals.
2.7.2 The EFB Manuals

There are three EFB manuals needed to encompass all of the necessary information that must be available to the user (Figure 41). The information in the EFB manuals, VOL. 1, VOL. 2, and VOL. 3, is the same as the paper manuals. The only difference is the information is in PDF format with some limited (3 level max) contextually linked information. While there is no weight to the manuals, one must still maneuver between the three different manuals when searching for information. Here, to navigate between the manuals, the user must select one of the tabs that represent the specific manual. Once the manual is selected, the individual must then search through the indexes to find the desired information. Again, one would think it would be relatively easy to pick the correct manual that applies to the information the individual is seeking. However, just as with the paper manuals, the information is not always that easy to find in the location one would believe it to be. The pilot must, often, navigate between the different manuals to find the desired information.
2.7.3 The EPLI Manuals

With EPLI, all three manuals are inserted into the interface (Figure 42). This allows the user to select information between the three different manuals very quickly and efficiently. Interacting between the manuals is accomplished with the selection of two icons: First is the home button, second is the desired tab. One no longer needs to consider which manual they are in as all three manuals are divided into 10 different tabs. This simplifies the indexing and makes the path way to information visually familiar to the user. Indeed, testing the third prototype with 38 pilots proved a decrease in information retrieval by 63%. This will be presented in Chapter 6.
Figure 42. EPLI 737 Manuals.
2.8. The Fourth Prototype

During the testing of the third EPLI prototype, there were several ideas presented by the research subjects. These ideas were made into a list of upgrades for a fourth prototype. That iteration is occurring at this time and will be completed after the defense date. It is part of the software team’s senior class project and will be presented in December. There will not be time to test it. However, EPLI will be more mature as a result. This iterative prototype will be discussed further in Chapter 7 under future work.
Chapter 6
Exploratory Human-In-The-Loop Simulation

1. Methods

This chapter summarizes the formative evaluation that was carried out with the third EPLI prototype. The evaluation utilized a simplified scenario-based HITLS. The overall evaluation was designed to formulate rather than to statistically validate (Shadish et al., 2002). Additionally, the evaluation was developed as an investigative perspective as opposed to a demonstrated one (Wallace & Ross, 2006). Therefore, I describe the second exploratory human-in-the-loop simulation I designed and conducted. 38 pilots participated in the research forming three groups:

— Group 1: All 38 Pilots
— Group 2: 19 Airline Pilots
— Group 3: 19 General Aviation Pilots

The 38 pilots made up the three different groups (Figure 43). Group 1 contained all 38 pilots. Group 2 was made up of 18 airline pilots and 1 airline mechanic (I wanted to garner information from a mechanic as I consider their input as valuable as a pilot when searching for information). Group 3 consisted of 19 general aviation pilots. To help the reader identify the data for the three different groups, I have designated the following colors to the section titles covering the groups:

— Group 1 section titles are colored teal
— Group 2 section titles are colored purple
— Group 3 section titles are colored red
There were several reasons for generating data for the three different groups:

— The need to prove the validity of the EPLI concept in relation to the aviation domain

— The need to verify the cogency of the EPLI concept with the airline realm

— The need to see if GA pilots can benefit from the usefulness of EPLI
— Wanted to grasp if EPLI was more or less intuitive to GA pilots vs. airline pilots; this would verify or disprove an advantage for new hire airline pilots
— Wanted to compare younger less experienced individuals to older more experienced individuals

The first prototype was tested with 4 professional airline pilots. This small sample was used to demonstrate the concept. However, there was not enough subjects to support a full-scale research study and a second study was required to address the above considerations. The following criteria had to be tested:

— Time to retrieve system information, i.e., was there an advantage in time savings comparing EPLI to the other methods (Quantitative Measurement)
— Usability (Qualitative Measurement)
— Situation Awareness (Qualitative Measurement)
— Workload (Qualitative Measurement)

The overall results are positive:

— Pilot feedback was very positive and taken into account in the design iteration of the fourth prototype

— **Group 1:** EPLI had a 63% reduction in system information retrieval time
— **Group 2:** EPLI had a 59% reduction in system information retrieval time
— **Group 3:** EPLI had a 67% reduction in system information retrieval time

— Usability Scale (usability) Results (larger numbers equal enhanced usability):
  - Paper: 37.83
  - EFB: 37.24
  - EPLI: 92.37
— NASA TLX (Work Load) Results (Smaller numbers indicate less workload):

- Paper: 70.83
- EFB: 63.65
- EPLI: 17.87

— CC SART (Cognitive Compatibility) Results (Larger numbers indicate enhanced cognitive compatibility):

— Paper: 51.75
— EFB: 44.44
— EPLI: 92.4

Note: For the qualitative work, only the data from group 1 (All 38 pilots) will be presented. There is sufficient quantitative data demonstrating the effectiveness of EPLI over the other two methods. The qualitative data is not needed for all three groups. This data will be presented in future work.

Note: There was a fourth qualitative method applied, the Self-Assessment Manikin (SAM). However, there is a large amount of overall data to present. The quantitative and three qualitative methods present enough significant data to verify the superiority of EPLI over paper and EFB manuals. The dissertation is quite long and rich with information. Therefore, in the interest of simplifying the information presented to the reader, the SAM results will be published in future work.

Again, the purpose of this second human-in-the-loop simulation of the third prototype was to discover how pilots interact with EPLI when compared to the current paper and electronic methods; I evaluated the time difference to retrieve system information for quantitative data;
the usability, workload, and situational awareness methods were used to collect the qualitative data. This information is discussed further in the following section.

2. Results and Discussion

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

2.1. Traditional Quantitative Data Supporting HCD

In addition to using HCD philosophies to create, develop, and enhance EPLI, I decided to conduct a traditional statistical research project. The intent was to explore the relationship between pilots finding system information and using EPLI. I conducted a research project, inclusive of the modeling and simulation techniques used to iterate EPLI and compare current knowledge transference methods with EPLI. For this study, I was concerned with how much time pilots need to retrieve certain information using current paper manual methods and electronic flight bag (EFB) methods when compared to using the EPLI method. Using human centered design methods, all that was required was testing EPLI with users to observe the human-machine interaction during modeling and simulation to enhance the maturity of EPLI. However, having learned traditional research methods during two statistics classes, one at the University of South Florida and the other at the Florida Institute of Technology, I wanted to utilize that knowledge to support my HCD methods. I performed the following to meet that objective.

38 pilots were used for this study:

— 38 pilots for a sample representing a population of all pilots

Note: Those 38 pilots were also divided into two groups (Figure 43):
— 19 were airline pilots representing a sample of a population of airline pilots
— 19 were general aviation (GA) pilots representing a sample of a population of GA pilots

The purpose of this traditional study was to determine if pilots could use EPLI and save time when compared to current methods, retrieving system information. The targeted pilot population was FAA Part 121 airline pilots, and parts 91, and 141 general aviation pilots.

My primary research question that guided this study was, whether a pilot could conserve the resource of time using the EPLI when compared to current knowledge transference methods. The corresponding research hypothesis was: I believe that as pilots use EPLI, they can save time retrieving aircraft system information when compared to current methods.

The pilots were part of a research study which was conducted from August 16, 2018 through September 26, 2018 at the Florida Institute of Technology’s College of Engineering and Sciences Department of Human Centered Design, and the College of Aeronautics Buhler Aviation and Research Building located at the Melbourne Airport (See appendix G for a copy of the testing schedule). This study was accomplished concurrently with the HCD modeling and simulation research and provided the data set from which to draw. This population was not restricted and included a wide range of pilot research subjects from the United States, including the following states:

- Arizona
- California
- Colorado
- Florida
- Georgia
- Maine
- Minnesota
- North Carolina
- Oklahoma
- Pennsylvania
- Texas
- Washington
- New Mexico
- Tennessee
In addition to the U.S. pilots participating, there was a group of international pilots as well, including the following countries:

- Aruba
- Barbados
- Canada
- China
- Dominican Republic
- France
- Germany
- Haiti
- Holland
- Jamaica
- United Kingdom

The part 121 airline pilots were either currently working for, integrated into, or retired from the following airlines and manufactures:

- Airbus
- Air Cal
- American
- America West
- Atlantic Southeast
- Boeing
- Braniff
- Casino Express
- Com Air
- Continental Express
- Elite
- Express One
- ExpressJet
- Federal Express
- KLM
- MESA
- Midway
- Ozark
- Original PSA
- Piedmont
- Reno Air
- SkyWest
- Southwest
- TWA
- Trans Meridian
- United
- US Airways

Note: Many of the pilots represented more than one airline.

Note: One mechanic representing Southwest was tested. I wanted to test more mechanics as their skills, expertise, and opinions are highly valued and they can also benefit from a system like EPLI. Unfortunately, I was not able to recruit more than one mechanic.

Several of the pilots also represented the following military forces:
For the quantitative portion of this study, I examined the effect that EPLI had on finding aircraft system information and compared the time differences it took pilots and one mechanic to find specific information using EPLI, paper manuals and EFB manuals. Because the variables were recorded during real-time HITLS testing, there was a cause and effect relationship in the study.

It would been ideal to have a prediction value for my research which would require a regression analysis. Unfortunately, a sample of 38 individuals did not allow me to appropriately reach a statistical significance when developing an adequate $r^2$ value that was reliable as a prediction value. It only yielded a value of approximately 12%.

For this study, the independent variable ($X$) was the type of knowledge transference method and the dependent variable ($Y$) was the time required to find information using the different knowledge transference methods. My parameter of interest was whether pilots save time retrieving aircraft system information using EPLI when compared to paper-based aircraft manuals and EFB aircraft manuals. I hypothesized that pilots would save time retrieving
aircraft system information using EPLI when compared to the other two methods. Therefore, the relationship should be negative; when $X$ is used then $Y$ should decrease.

Preliminary analyses verified the final sample of $n = 38$ to have an age range of 21 to 79, with flight hours ranging from 317 to 22,500 (Note: one mechanic was tested, he had 0 flight hours).

Because the research required testing people, there was a need to submit an application to the Florida Institute of Technology Institutional Review Board (IRB) for approval of the IRB’s exemption criteria. The application was approved (See appendix E), and permission granted to conduct the study with the following exception; no names or personal information was to be recorded and/or published. The data was confined to the following:

— Age
— Total flight time
— Education level
— FAA certificates awarded
— Type ratings
— Associated airline employment

**2.2. Data Analysis**

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

I used the JMP statistical software to measure the descriptive statistics. I then preformed a JMP distribution analysis to determine the means and standard deviations for age, total flight time, the times it took for each knowledge transference method during three quizzes and the
time it took for each knowledge transference method during three exams (See appendix H and I). There were three quizzes with 8 questions each: each question covered a specific area to find specific systems questions (See appendix H). The quizzes were organized and listed as Quiz A, Quiz B, and Quiz C (See appendix H). Each time a research subject was tested, the quizzes were randomly moved. I.e., RS number 1 had Quiz A applied to the paper-based manual, Quiz B was applied to the EFB method and EPLI used Quiz C; the second RS had Quiz A applied to the EFB manual, Quiz B applied to EPLI, and the paper-based method utilized Quiz C; the third RS had Quiz A applied to EPLI, Quiz B was applied to the paper-based method and Quiz C was used for the EFB method; this random selection was performed throughout the testing, from RS 1 though RS 38. This random selection of the quizzes (and exams), was performed to apply all quizzes to all methods so there was no chance of bias based on easy or difficult questions applied to just one of the three methods. The random selection was used to ensure a fair and balanced testing of all three methods. Additionally, there were also three exams consisting of 10 questions each (See appendix H). These exams were also listed as A, B, and C and were randomly applied to the different methods using the same format as the quiz rotation. It is important to note that each method required some training and practice for the RSs. This was achieved by using the 737 cockpit posters and explaining to the RSs where to find specific information related to specific questions in each of the three methods (Figure 44).
Each RS subject was given approximately one hour of instruction in the different methods (total time for all three methods). Each RS was asked to announce when they were comfortable with the testing before testing was initiated. This experimentation was intended to simulate and model a pilot learning aircraft system information for the first time. Once training and practice were complete, and the RS was comfortable with continuing, the quizzes were given to the RS and the time it took to retrieve the answer to each specific question was recorded. There were several reasons for this initial quiz taking:
1. For the investigator to ensure the RS was able to locate the specific information, without assistance, in the correct area, simulating the RS subject asking “what-if” questions needed to address potential problem scenarios. This is how pilots learn to resolve abnormal and/or emergency anomalies.

2. For the RS to gain confidence in finding system information.

3. To compare the time it took finding system information during the initial quiz taking with the time it took to find system information during the exam portion of the testing.

This was to determine if there was a reduction in the time saved using EPLI when compared to the other two methods between quiz taking and exam taking. If so, this would indicate that RSs were becoming familiar with information location in the traditional methods and, therefore, requiring less time to find the information due to familiarity. This would also suggest, if there was an efficiency reduction, that EPLI is more intuitive for the beginner. This proved to be true.

Testing was performed by verbally asking the RS the questions in sequential order. A timer was used to measure the time it took the RS to find the answer. Time began after the question was asked and stopped once the RS found the information in the given knowledge transference method, i.e., the paper-based, EFB, or EPLI method.

After the quizzes were completed, a break was afforded to the RS and investigator.

The 10 question exams were given after the break. The questions were selected from oral exams I have given to pilots during type rating check rides as an airline ground school, simulator, and initial operating experience (IOE) instructor for multiple airlines and third-party contract training institutions. Each research subject was asked if they felt the questions
were fair and all agreed they were. Again, the three exams were titled as Oral Exam A, Oral Exam B, and Oral Exam C (See appendix H). They were randomly alternated with each RS just as the quizzes were, to prevent bias towards any one of the three different knowledge transference methods.

When creating Excel spreadsheets, I included columns for the timed results and enhancements of: PAPER, EFB, EPLI, EPLI/PAPER, EPLI/EFB, EPLI/AVG of the PAPER & EFB, and PAPER/EFB. There are seven columns for the Quiz portion (Figure 45) and seven columns for the Exam portion (Figure 46). The entire Excel spread sheet can be seen in appendix I.

Note: MINs equals minuets.

![Figure 45. Excel columns for EPLI quiz results.](image)

![Figure 46. Excel columns for EPLI exam results.](image)
Additionally there are columns for age, total flight time hours, and education (Figure 47).

![Figure 47. Columns for Age, Flight Time, and Education.](image)

For this analysis, I used the Quantitative Results for All Pilots. The results for the other two analyses are presented after this one.

### 2.2.1 All Pilots Age

The distribution for the overall pilot age indicates that if the total years of age were divided by \( n = 38 \), then each pilot would be 48.68 years old at the time of testing; as the mean \( M \) is the sum of age divided by \( n = 38 \) (\( M = \Sigma X/n \)). The standard deviation is 19.26 indicating the average distance each person’s age is from the mean. Standard deviation is an indicator of dispersion or variance. The age range is 21–79, or 58 years. (Figure 48).
2.2.2 All Pilots Total Flight Time

The distribution for the overall pilot total flight time indicates that if the total time were divided by \( n = 38 \), then each pilot would possess 7,714 total flight hours (Figure 49) at the time of the testing; as the mean \( M \) is the sum of total flight time divided by \( n = 38 \) (\( M = \frac{\Sigma X}{n} \)). The standard deviation is 7,416 indicating the average distance each person’s flight time is from the mean. Standard deviation is an indicator of dispersion or variance. The flight
time range is 0 – 22,500, or 22,500 (Note: one mechanic was tested and that individual, while an expert at navigating aircraft manuals, had no flight experience.

![Graph showing flight time hours distribution with summary statistics]

**Figure 49.** All pilots average total flight hours at the time of testing.

### 2.2.3 All Pilots Education

This group of RSs was very well educated with 33 people possessing a four-year degree or higher, including the following number of degrees (Figure 50):

- High School: 3 Individuals
- Associates Degree: 2 Individuals
— Bachelor’s Degree: 18 Individuals
— Master’s Degree: 12 Individuals
— Doctoral Degree: 3 Individuals

In this study, I was investigating the relationship between time saved using EPLI compared to current system knowledge transference methods. However, I decided to also compare pilot total flight hours with EPLI enhancement to see if there was a correlation. While my research method could be correlational, a correlational analysis can only summarize the extent of the relationship between the variables. It cannot yield a variable for prediction. While regression
analysis could yield a prediction equation, \( \hat{y} = Bx + A \), the \( r^2 \) value was only 0.12, meaning that I had only 12 percent of the information needed to make a prediction. This was because a sample of 38 people did not have enough power to make a prediction for a population. Therefore, I will not make a prediction toward the population, just present the facts of what was found in the study. The reader will have to decide if the analysis shows an advantage in time using EPLI when compared to the traditional methods. Based on the overall results of the quantitative and qualitative results, I believe this occurred.

I used the JMP statistical software to perform the analysis. I used the data collected during the research study conducted from August 16, 2018 through September 26, 2018 (See appendix G for testing schedule) and entered the data into JMP statistical software. It should be noted that there were three JMP spreadsheets created from the data collected:

1. Quantitative Results for all Pilots
2. Quantitative Results for Airline Pilots
3. Quantitative Results for GA Pilots.

### 2.2.4 Correlation Between Age and Average Enhancement Using EPLI

Using JMP, I selected the analyze and Fit Y by X. The AGE column was selected to X and EPLI vs. AVG EXAM (The time EPLI saved to find system information compared to the average of the paper and EFB methods) was selected to Y and the analysis was then run. I then selected a Fit Line to compare and determine if there was a correlation of time savings vs. age relationship (Figure 51).
There is a negative relationship between the dependent variable $Y$ (EPLI Enhancement) and the independent variable $X$ (Age), i.e., $Y$ reduces as $X$ increases. This relation indicates that while all RS subjects had a significant savings in time using EPLI when compared to paper-based and EFB manuals, that advantage decreased by approximate 8.5% from the youngest age of 21 to the oldest age of 79, or from an advantage of 67.5% to 59% (Figure 51). This could be attributed to the degradation of cognitive function associated with age, i.e., as one ages, there cognitive abilities decrease. Additionally, the younger RS subjects appeared to be faster with EPLI as they found the device very intuitive.

Figure 51. Bivariate Fit of EPLI vs. AVG EXAM Time Savings compared to Age.
### 2.2.5 All Pilots Correlational Relationship Between Flight Hours and the Average Enhancement Using EPLI

Using JMP, I selected the analyze and Fit Y by X. The Time by Flight Hours column was selected to X and EPLI vs. AVG EXAM (The time EPLI saved to find system information compared to the average of the paper and EFB methods) was selected to Y and the analysis was then run. I then selected a Fit Line to compare and determine if there was a correlation of time savings vs. Flight Hours relationship (Figure 52).

![Figure 52. Bivariate Fit of EPLI vs. AVG EXAM Time Savings compared to flight time.](image_url)

There is a negative relationship between the dependent variable Y (EPLI Enhancement) and the independent variable X (Flight Hours), i.e., Y reduces as X increases. This relation also indicates that all RS subjects had a significant savings in time using EPLI when compared to paper-based and EFB manuals. However, that advantage decreased by approximate 10% from the least flight hours of 0 (The Southwest Mechanic) to the most flight hours of 22,500,
or from an advantage of 67.5% to 57.5%. This can be attributed to the degradation of cognitive function associated with age, i.e., as one ages, there cognitive abilities decrease. This is because as people age, they also acquire more flight time. Additionally, the mechanic presents an outlier variant as he had zero flight hours; this slightly skews the age/flight hours correlation. A Bivariate Fit was performed to determine a correlation between age and flight hours (Figure 53). Age was the independent variable (X) and flight time in hours was the dependent variable (Y). There is positive correlation between age and flight time, i.e., as X increases, Y increases.

Figure 53. Bivariate Fit of Flight Time Hours compared to Age.
2.2.6 All Pilots Time Performance Comparison of Paper, EFB, and EPLI Methods

Using the data in Figure 54, I calculated the data in Table 5. This was accomplished by adding the paper and EFB means and dividing by 2 for an average between paper and EFB. The EPLI time mean was then divided by the paper and EFB average to obtain the results.

![Figure 54. All Pilots Time Performance Comparisons in minutes (MINs).](image-url)
Again, the results are listed in table 5. They show that EPLI has a significant reduction in the time it takes a user to retrieve information when compared to the other two methods. On average, the pilots required 20.23 minutes to retrieve the simulated “what-if” information when using the paper format. On average, the pilots required 21.65 minutes to retrieve the simulated “what-if” information when using the EFB method. On average, the pilots required only 7.74 minutes to retrieve the same information using EPLI. These significant results are listed in table 5. On average, EPLI is 63% faster when compared to the average of the paper and EFB methods. Therefore, EPLI is significantly superior to paper and EFB methods when RSs are retrieving system information. It should be noted that the paper method is 5% faster than the EFB method, on average. Therefore, EFB is inferior to the paper method when RSs are retrieving system information.

Table 5. EPLI All Pilots HITLS System Information Retrieval Testing Results.

<table>
<thead>
<tr>
<th>EPLI/Average Enhancement</th>
<th>EPLI/Paper Enhancement</th>
<th>EPLI/EFB Enhancement</th>
<th>Paper/EFB Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPLI: 63% Faster</td>
<td>EPLI: 60% Faster</td>
<td>EPLI: 63% Faster</td>
<td>Paper: 5% Faster</td>
</tr>
</tbody>
</table>

### 2.2.7 Paper Manuals vs. EFB Manuals

Jean-Philippe Ramu tells us that Airbus used a user centered approach, based on task analysis to design electronic operational documentation to be used in operations and training (Ramu, 2002). He goes on to say that the EFB advantages have the potential to reduce the search and retrieval time of information for pilots. This research study suggests otherwise. In fact, paper
appears to be faster at searching and retrieval time by just a small percentage (Figure 55). I am not aware of any other studies conducted to test the information retrieval time between paper and electronic documents. The following information is presented as a byproduct of the EPLI vs. paper and EFB formats research project. On average Paper is 7% faster.

![Figure 55. Paper Manual vs. EFB Manual Time Performance Comparisons in minutes (MINs).](image)

### 2.2.8 Airline Pilots Age

The distribution for the airline pilot age indicates that if the total years of age were devided by $n = 19$, then each pilot would be 61.84 years old at the time of testing (Figure 56); as the mean $M$ is the sum of age devided by $n = 19$ ($M = \Sigma X/n$). The standard deviation is 11.05 indicating the average distance each person’s age is from the mean. Standard deviation is an indicator of dispersion or variance. The age range is 34–79, or 45 years.
Figure 56. Airline pilots average age at the time of testing.

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

2.2.9 Airline Pilots Total Flight Time

The distribution for the overall pilot total flight time indicates that if the total time were devided by \( n = 19 \), then each pilot would possess 13,629 total flight hours at the time of the testing (Figure 57); as the mean \( M \) is the sum of total flight time devided by \( n = 19 \) \( (M = \Sigma X/n) \). The standard deviation is 6,074 indicating the average distance each person’s flight time is from the mean. Standard deviation is an indicator of dispersion or variance. The flight
The time range is 0 – 22,500, or 22,500. It should be noted that one mechanic was tested and that individual, while an expert at navigating aircraft manuals, had no flight experience. He is considered an outlier, affecting the mean which would be higher without the mechanic. However the mechanic had valuable information and he was therefore included.

Figure 57. Airline pilots average total flight hours at the time of testing.
2.2.10  Airline Pilots Education

This group of pilots was highly educated with more than 50% of the group possessing a graduate degree (Figure 58).

![Figure 58. Airline pilots’ education.](image)

2.2.11  Airline Pilots Correlational Relationship Between Flight Hours and the Average Enhancement Using EPLI

In this study, I was investigating the relationship between time saved using EPLI compared to current system knowledge transference methods. However, I decided to also compare pilot total flight hours with the EPLI enhancement to see if there was a correlation.
I used the JMP statistical software to perform the analysis. I used the data collected during the research study conducted from August 16, 2018 through September 26, 2018 (See appendix G) and entered the data into JMP statistical software. It should be noted that there were three JMP spreadsheets created from the data collected.

Figure 59. Bivariate Fit of EPLI vs. AVG EXAM Time Savings compared to Flight Time Hours.

There is a positive relationship between the dependent variable Y (EPLI Enhancement) and the independent variable X (Age), i.e., Y increases as X increases. This relation indicates that while all RS subjects had a significant savings in time using EPLI when compared to paper-based and EFB manuals, that advantage increased by approximate 7.5% from the lowest flight time in hours of 0 to the highest of 22,500, or from an advantage of 55% to
62.5% (Figure 59). This suggests that EPLI had a greater advantage with the pilots possessing more flight time. I believe this occurred because there were 7 pilots (37% of the total sample of airline pilots) tested who were beyond the mandatory retirement age of 65 years. They are not current. I believe it is because EPLI is intuitive as those with the greatest enhancement, in this group, are the individuals who have not trained in some time. Those pilots with less enhancement are current with the traditional knowledge transference methods. However, 55% enhancement is still significant. It should be noted that all RSs verbalized that EPLI was much more intuitive than the traditional methods and they significantly preferred EPLI over the traditional methods. This information will be presented in the qualitative section of this dissertation. Additionally, when comparing the information articulated in Group 1 and comparing that to group 2, there is an anomaly. In group 1, there is a negative relationship. In group 2, there is a positive relationship. This is because group 1 consists of 19 younger pilots and group 2 is devoid of those 19 younger pilots. Therefore, the younger population affects the results between the two different groups. This is important as it indicates two variables:

- Group 1 has a negative relationship as EPLI is more intuitive for the less experienced pilots, offsetting the results
- Group 2 has a positive relationship as EPLI is more intuitive for the retired group of pilots, therefore, they have a greater advantage using EPLI

This information indicates that, while all pilots have a significant advantage using EPLI, those with less experience, or those who have been “out-of-the-loop” have the greatest
advantage. Therefore, EPLI is more advantageous to novice pilots than expert pilots. In other words, EPLI is more intuitive for the novice user. This was one of the goals of the design.

2.2.12 Airline Pilots Correlational Relationship Between Age and the Average Enhancement Using EPLI

Using JMP, I selected the analyze and Fit Y by X. The AGE column was selected to X and EPLI vs. AVG EXAM (The time EPLI saved to find system information compared to the average of the paper and EFB methods) was selected to Y and the analysis was then run. I then selected a Fit Line to compare and determine if there was a correlation of time savings vs. age relationship (Figure 60).

![Figure 60. Bivariate Fit of EPLI vs. AVG EXAM Time Savings compared to Age.](image)
There is a positive relationship between the dependent variable Y (EPLI Enhancement) and the independent variable X (Age), i.e., Y increases as X increases. This relation indicates that while all RS subjects had a significant savings in time using EPLI when compared to paper-based and EFB manuals, that advantage increased by approximately 5% from the youngest age of 34 to the oldest age of 79, or from an advantage of 56% to 61% (Figure 60). Again, this result suggests that EPLI had a greater advantage with the older pilots. Why? There were 7 pilots (37%) tested who were beyond the mandatory retirement age of 65 years. They are not current. I believe it is because EPLI is intuitive as those with the greatest enhancement, in this group, are the individuals who have not trained in some time. Those pilots with less enhancement are current with the traditional knowledge transference methods. Therefore, EPLI is more intuitive for the pilots who have been out-of-the-loop for some in regard to training.

2.2.13 Airline Pilots Time Performance Comparison of Paper, EFB, and EPLI Methods

The results are listed in figure 61. They show that EPLI has a significant reduction in the time it takes a user to retrieve information when compared to the other two methods. On average, the airline pilots required 21.51 minutes to retrieve the simulated “what-if” information when using the paper format. On average, the pilots required 22.25 minutes to retrieve the simulated “what-if” information when using the EFB method. On average, the pilots required only 8.75 minutes to retrieve the same information using EPLI.
Figure 61. Airline Pilots Time Performance Comparisons in minutes (MINs).
These significant results are listed in table 6. On average, EPLI is 59% faster when compared to the average of the paper and EFB methods. Therefore, EPLI is significantly superior to paper and EFB methods when RSs are retrieving system information. It should be noted that the paper method is 3% faster than the EFB method, on average. Therefore, EFB is inferior to the paper method when RSs are retrieving system information.

Table 6. EPLI Airline Pilot HITLS System Information Retrieval Testing Results.

<table>
<thead>
<tr>
<th>EPLI/ Average Enhancement</th>
<th>EPLI/Paper Enhancement</th>
<th>EPLI/EFB Enhancement</th>
<th>Paper/EFB Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPLI: 59% Faster</td>
<td>EPLI: 58% Faster</td>
<td>EPLI: 59% Faster</td>
<td>Paper: 3% Faster</td>
</tr>
</tbody>
</table>

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

2.2.14 GA Pilots Age

The distribution for the GA pilot age indicates that if the total years of age were divided by \( n = 19 \), then each pilot would be 35.52 years old at the time of testing; as the mean \( M \) is the sum of age divided by \( n = 19 \) (\( M = \Sigma X/n \)). The standard deviation is 16.57 indicating the average distance each person’s age is from the mean. Standard deviation is an indicator of dispersion or variance. The age range is 21–68, or 47 years. (Figure 62).
2.2.15 GA Pilots Total Flight Time

The distribution for the GA pilot total flight time indicates that if the total time were divided by $n = 19$, then each pilot would possess 1,799 total flight hours at the time of the testing; as the mean $M$ is the sum of total flight time divided by $n = 19$ ($M = \Sigma X/n$). The standard deviation is 1,508 indicating the average distance each person’s flight time is from the mean. Standard deviation is an indicator of dispersion or variance. The flight time range is 317 – 4,500, or 4,183 (Figure 63).
In this study, I investigated the relationship between time saved using EPLI compared to current system knowledge transference methods. However, I decided to also compare GA pilot total flight hours and GA pilot age with EPLI enhancement to see if there was a correlation.

I used the JMP statistical software to perform the two analyses, the data was collected during the research study conducted from August 16, 2018 through September 26, 2018 and entered the data into JMP statistical software.
2.2.16 GA Pilots Correlational Relationship Between Age and the Average Enhancement Using EPLI

Using JMP, I selected the analyze and Fit Y by X. The AGE column was selected to X and EPLI vs. AVG EXAM (The time EPLI saved to find system information compared to the average of the paper and EFB methods) was selected to Y and the analysis was then run. I then selected a Fit Line to compare and determine if there was a correlation of time savings vs. age relationship (Figure 64).

![Bivariate Fit of EPLI vs. AVG EXAM By AGE](image)

Figure 64. Bivariate Fit of EPLI vs. AVG EXAM Time Savings compared to Age.

There is a slight negative relationship between the dependent variable Y (EPLI Enhancement) and the independent variable X (Age), i.e., Y reduces as X increases. This relation indicates that while all RS subjects had a significant savings in time using EPLI
that advantage decreased by approximate 1.5% from the youngest age of 21 to the oldest age of 68, or from an advantage of 67.5% to 66% (Figure 64). This can be attributed to the degradation of cognitive function associated with age, i.e., as one ages, their cognitive abilities decrease. Additionally, the younger RS subjects appeared to be faster with EPLI as they found the device very intuitive. However, it should be noted that the 66% advantage is still statistically significant.

### 2.2.17 GA Pilots Correlational Relationship Between Flight Hours and the Average Enhancement Using EPLI

Using JMP, I selected the analyze and Fit Y by X. The Time by Flight Hours column was selected to X and EPLI vs. AVG EXAM (The time EPLI saved to find system information compared to the average of the paper and EFB methods) was selected to Y and the analysis was then run. I then selected a Fit Line to compare and determine if there was a correlation of time savings vs. Flight Hours relationship (Figure 65).
There is a negative relationship between the dependent variable \( Y \) (EPLI Enhancement) and the independent variable \( X \) (Flight Hours), i.e., \( Y \) reduces as \( X \) increases. This relation also indicates that all RS subjects had a significant savings in time using EPLI when compared to paper-based and EFB manuals. However, that advantage decreased by approximate 5% from the least flight hours of 317 to the most flight hours of 4,500, or from an advantage of 68% to 63% (Figure 65). This can be attributed to low time experience. Those with the greater advantage have less experience navigating manuals. This indicates that EPLI is more intuitive to the beginner and that EPLI address both the experienced pilot and the novice pilot. This was one of the main goals behind the design of EPLI. However, it should be noted that the 63% enhancement is still statistically significant, and the more experienced
pilots also enjoy a greater advantage using EPLI over the traditional knowledge transference methods. A Bivariate Fit was performed to determine a correlation between age and flight hours (Figure 66). Age was the independent variable (X) and flight time in hours was the dependent variable (Y). There is positive correlation between age and flight time, i.e., as X increases, Y increases.

Figure 66. Bivariate Fit of GA Flight Time Hours compared to Age.
2.2.18 GA Pilots Time Performance Comparison of Paper, EFB, and EPLI Methods

The results are listed in figure 67. They show that EPLI has a significant reduction in the time it takes a user to retrieve information when compared to the other two methods.

On average, the GA pilots required 18.96 minutes to retrieve the simulated “what-if” information when using the paper format. On average, the GA pilots required 21.05 minutes to retrieve the simulated “what-if” information when using the EFB method. On average, the pilots required only 6.73 minutes to retrieve the same information using EPLI.
Figure 67. GA Pilots Time Performance Comparisons in minuets (MINs).
These significant results are listed in table 7. On average, EPLI is 67% faster when compared to the average of the paper and EFB methods. Therefore, EPLI is significantly superior to paper and EFB methods when the GA RSs are retrieving system information. It should be noted that the paper method is 8% faster than the EFB method, on average. Therefore, EFB is inferior to the paper method when RSs are retrieving system information.

Table 7. EPLI GA Pilots HITLS System Information Retrieval Testing Results.

<table>
<thead>
<tr>
<th>EPLI/Average Enhancement</th>
<th>EPLI/Paper Enhancement</th>
<th>EPLI/EFB Enhancement</th>
<th>Paper/EFB Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPLI: 67% Faster</td>
<td>EPLI: 62% Faster</td>
<td>EPLI: 67% Faster</td>
<td>Paper: 8% Faster</td>
</tr>
</tbody>
</table>

Additionally, it should be noted that the GA pilots took less time, on average, to retrieve system information than the airline pilots did (Table 8).

Table 8. Retrieval time comparison for Airline and GA pilots.

<table>
<thead>
<tr>
<th></th>
<th>Paper</th>
<th>EFB</th>
<th>EPLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airline Pilots</td>
<td>21.51 MINs</td>
<td>22.25 MINs</td>
<td>8.75 MINs</td>
</tr>
<tr>
<td>GA Pilots</td>
<td>18.96 MINs</td>
<td>21.05 MINs</td>
<td>6.73 MINs</td>
</tr>
<tr>
<td>Percentage Difference</td>
<td>12%</td>
<td>5%</td>
<td>23%</td>
</tr>
</tbody>
</table>
On average, the GA pilots were 11% faster using EPLI when compared to the Airline Pilots using the paper format. On average, the GA pilots were just 5% faster using the EFB method when compared to the Airline Pilots. Finally, when comparing the GA pilots to the Airline Pilots using EPLI, the GA Pilots, on average, are significantly faster; 23% faster! At the beginning of the research, I felt it was important to break the 38 pilots into the two separate groups, so I could compare and determine if there was a difference between the Airline Group and the GA Group. The comparison identified the following differences:

— Overall, the GA Pilots are faster in all methods
— The GA Pilots are somewhat faster than the Airline Pilots using the paper manuals
— The EFB comparison indicates there is not much of a difference between the two groups
— The GA Pilots are significantly faster than the Airline Pilots using EPLI

What does this data mean? Group 2 had a significant number of retirees who have been away from the training for some time. This group may have been affected by a lowering of cognitive efficiency due to age (cognition slows as one ages) and lack of currency (cognition slows as one becomes less familiar with information retrieval due to lack of practice). The EFB format appears to be less efficient than paper and EPLI as it simply is an inferior method to the other two. For me, this information implies that EFBs are simply less intuitive and more complicated to use than the other two formats. Group 3 consists of a younger generation that have grown up in a culture of social media, internet browsers, cell phones, and other computer/software operating devices. They are more familiar with human-interactive electronic devices. Therefore, EPLI is significantly more intuitive for them to use.
In any case, the quantitative data indicates that EPLI is significantly superior to current methods and, indeed, today’s technology has evolved enough that we should be able improve the system information retrieval times employing new methods. 

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

2.2.19 Paper Manuals vs. EFB Manuals Re-examined

As stated earlier, Jean-Philippe Ramu told us that Airbus used a user centered approach, based on a task analysis to design electronic operational documentation to be used in operations and training (Ramu, 2002). He claims that the EFB advantages have the potential to reduce the search and retrieval time of information for pilots. This research study suggests otherwise. In fact, paper appears to be faster at searching and retrieval time by just a small percentage. I am not aware of any other studies conducted to test the information retrieval time between paper and electronic documents. The following information is presented as a byproduct of the EPLI vs. paper and EFB formats research project.
Figure 68. **All Pilots**: On average, Paper is 7% faster.

Figure 69. **Airline Pilots**: On average Paper is 3% faster at information retrieval.
Figure 70. **GA Pilots**: On average, Paper is 10% faster at information retrieval, Kiss, 2018.

Table 9. Percentage difference comparing paper to EFB for all groups.

<table>
<thead>
<tr>
<th></th>
<th>All Pilots</th>
<th>Airline Pilots</th>
<th>GA Pilots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>20.23 MINs</td>
<td>21.51 MINs</td>
<td>18.96 MINs</td>
</tr>
<tr>
<td>EFB</td>
<td>21.65 MINs</td>
<td>22.25 MINs</td>
<td>21.1 MINs</td>
</tr>
<tr>
<td>Paper is Faster:</td>
<td>7%</td>
<td>3%</td>
<td>10%</td>
</tr>
</tbody>
</table>
This data also indicates that paper is superior to the EFB method when retrieving system information. Therefore, again, the EFB format is less desirable for learning system information.

Utilizing traditional quantitative research, statistically, EPLI has proven to be superior to the current two methods offered to users when retrieving system information. Also, the research clearly shows that the EFB format is sub-standard when compared to paper and EPLI manuals. However, quantitative methods lack a very important component; the user’s evaluation (Casner and Gore, 2010). How does the user rate the three different methods utilized in this research? To answer that question, we must turn to qualitative research.

3. **Traditional Qualitative Data Supporting HCD**

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

Quantitative data was incorporated into this research project because quantitative analysis does not provide enough information for a determination of acceptable performance levels by the user (Casner and Gore, 2010). Clearly, the quantitative data for EPLI shows a significant enhancement in lowering the time it takes for a user to retrieve system information. According to Casner and Gore, speed and accuracy are two of the simplest ways to measure performance (Casner & Gore, 2010). When measuring time, all the experimenter needs to do is observe the operator’s performance and record the time it takes for the research subject to accomplish the task given. If the performance is acceptable when comparing different methods, then it should be assumed that workload is acceptable. However there are
some disadvantages to this approach. Measuring speed does not consider the operator’s account of the workload or measure the user’s assessment of the system. Casner and Gore explain that the operator’s feeling of high workload or low workload is negated when measuring performance alone. Therefore, in addition to measuring the speed of a given task, it is beneficial in measuring the user’s evaluation of a system. Qualitative measurement is more sensitive to the state of the operator and their valuation of system performance. Therefore, I wanted to provide data that not only measured the time it took the users to retrieve system information, but also provide the user’s evaluation of EPLI. This required utilizing several qualitative measuring methods.

The different qualitative assessment methods I used are listed in table 10 and the associated forms are available in Appendix H. In addition to acquiring a qualitative measure for the performance of the third EPLI prototype, this data was used for combining design enhancements in the fourth prototype of EPLI.

Table 10. Qualitative assessment methods used for the research.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>System Usability Scale</td>
<td>Evaluation/Exploration</td>
</tr>
<tr>
<td>Cognitive Compatibility</td>
<td>CC-SART</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Workload</td>
<td>NASA-TLX (modified)</td>
<td>Evaluation/Exploration</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>Self-Assessment Manikin</td>
<td>Evaluation</td>
</tr>
</tbody>
</table>
3.1. Usability

Usability was discussed in Chapter 4. However, it is briefly reviewed here before discussing the System Usability Scale or SUS. According to Nielsen, Usability is dependent on two areas (Nielsen, 1993):

— Its Social Acceptability: Does the system satisfy every need and requirement of every user

— Its Practical Acceptability: Does the system meet the following practicality issues:
  
  • Costs
  • Support
  • Reliability
  • Compatibility with existing systems

If the system is socially and practically acceptable, the question then becomes is the system useful (Nielsen, 1993). Usefulness can be broken down into two other categories:

— Utility: Can the functionality of the system accomplish what was intended

— Usability: How well the users can practice that functionality, including:
  
  • Learnability: System should be easy to use; allows the user to start working rapidly
  • Efficiency: System should be efficient, affording the user with high productivity
  • Memorability: System should be easy to remember, affording a novice user the ability to return and use the system, after some time away, with little need to re-learn how to use the system
  • Errors: System should have a low error rate, so the user makes few errors and can recover quickly and easily when an error is made
• Satisfaction: The system should be pleasant to use providing a sense of user satisfaction

Usability is characteristically measured by testing a number of qualified domain users with the system. Therefore, in addition to the quantitative testing, I also provided the RSs with the System Usability Scale (SUS) rating questioner. The SUS provides an easy-to-understand score from 0 (negative) to 100 (positive) (Bangor, Kortum, & Miller, 2008-09; Sauro, 2011; Brooke, 2013; Lebson, 2014; and Brooke, 2018). The SUS is a reliable industry standard usability test with references in more than 600 publications (Sauro, 2011). Additionally, Bangor, Kortum, and Miller have added an adjective rating scale to the original scale to provide the familiar concept of letter grades as a reference point that is easily understood by the many different individuals involved in design teams (Bangor, Lebson, and Brooke, 2018). The following provide visual information of SUS score information related to acceptability, letter grades, and adjective ratings:

— 90-100: Acceptable, A, Excellent: Exceptional Usability
— 80-89: Acceptable, B, Good/Excellent: Good Usability
— 70-79: Acceptable, C, Good: Acceptable Usability
— 60-69: High Marginal, D, OK, Cause for Concern
— 50-59: Low Marginal, F, OK, Cause for Concern
— 40-49: Not acceptable, F, Poor, Not Usable

Figure 71 shows the SUS scale with the other scales for comparison.
Figure 71. A comparison of the adjective ratings, acceptability scores, and school grading scales in relation to the average SUS score (Bangor, Kortum, and Miller, 2018).

The usability questioner used to rate Paper, EFB, and EPLI is in Appendix H. The data showing the results of the testing are found in Appendix J. The Usability Scale results for the three different methods are listed below:
Figure 72. Paper SUS Average: 37.83.

Figure 73. EFB SUS Average: 37.24.
When comparing the resultant scores, clearly, EPLI is superior in usability. The usability score for Paper Manuals was just 37.83. According to the SUS Score, paper rates less than poor, an F, and not acceptable by the RSs of this study. The EFB manuals were rated just slightly worse than paper with a SUS Score of 37.24. EPLI scored 92.37. Therefore, the RSs SUS Score rating for EPLI was rated as Excellent, Acceptable, and Exceptional. Consequently, it appears that the Usability of EPLI is rated very high and should be considered an acceptable interface that should provide all of the needs for the associated users, including: Learnability, Efficiency, Memorability, Errors, and Satisfaction. This qualitative measure has taken into account the users’ performance measure and is positive towards EPLI as a system information retrieval method. Therefore, the SUS qualitative measure supports the quantitative data supplied in the research.
3.2. **NASA TLX (Task Load Index)**

In addition to the SUS rating, I also wanted to measure the users’ assessment of workload to garner a satisfactory user performance measure of EPLI’s workload. Therefore, in addition to the quantitative testing and the SUS Scale rating, I also provided the RSs with the NASA TLX questionnaire. Workload means different things to different people (Casner and Gore, 2010). What may be considered low workload to a highly skilled individual may be considered high workload to a novice. The NASA TLX is a multi-dimensional subjective workload assessment method (Gawron, 2000). According to Gawron, Workload is defined as the “cost incurred by human operators to achieve a specific level of performance” (Gawron, 2000). Subjectively, workload is defined as a conglomeration of different weighted subjective responses such as:

- Emotional
- Cognitive
- Physical

The subjective responses are driven by the research subjects’ perceptions of task demand. Over time and through the results of different experiments, six dimensions of subjective experience of workload were developed (Gawron, 2000):

- Mental demand
- Physical demand
- Temporal demand
- Performance
- Effort
— Frustration level

Table 11 lists the rating scale definitions (Gawron, 2000).

Table 11. NASA TLX Rating-Scale Descriptions.

<table>
<thead>
<tr>
<th>Title</th>
<th>Endpoints</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>Low, High</td>
<td>How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?</td>
</tr>
<tr>
<td>Visual Demand</td>
<td>Low/High</td>
<td>How much visual activity was required to process the visual scene (Clustering effects, visual cues, relative size, etc.).</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>Low, High</td>
<td>How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful, or laborious?</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>Low, High</td>
<td>How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?</td>
</tr>
<tr>
<td>Performance</td>
<td>Good, Poor</td>
<td>How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?</td>
</tr>
<tr>
<td>Effort</td>
<td>Low, High</td>
<td>How hard did you have to work (mentally or physically) to accomplish your level of performance?</td>
</tr>
<tr>
<td>Frustration Level</td>
<td>Low, High</td>
<td>How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?</td>
</tr>
</tbody>
</table>

A study conducted by Hart and Staveland found that the NASA TLX is a good indicator of overall workload (Hart and Staveland, 1987). Additionally, they determined that each of the NASA TLX dimensional magnitudes provided valuable diagnostic information about task loading sources (Hart and Staveland, 1987). They reported that the NASA TLX scale is useful in operational environments similar to the testing milieu of EPLI, i.e., establishing working scenarios in a simulated environment to test the information retrieval times. Essentially, the RS answers the questions on a rating sheet (Figure 75).
I used Microsoft’s Excel spread sheet to tally the scores of the sheets (See Appendix J for a copy of the Excel spreadsheet results).

Figure 76 shows the last three RSs NASA TLX scoring for EPLI and the final average number for all 38 scores.

![Figure 76. Excel Results of the NASA TLX for EPLI.](image)
Figures 77, 78, and 79 show the NASA TLX results for paper, EFB, and EPLI, respectively.

Figure 77. Paper NASA TLX Average: 70.83.

Figure 78. EFB NASA TLX Average: 63.65.
The workload scores were calculated by multiplying each rating by the weight given to the factor by the subject (Nasa Ames, no date). The sum of each weighted rating for each task was then divided by 15 (The sum of the weights). The individual scores were then totaled and divided by 38 (n=38) for the average score. The lower the score, the lower the overall workload.

The NASA TLX results for all three information retrieval methods are listed below and shown in figures 77, 78, and 79. The number represented for EPLI, 17.80, shows that EPLI is far superior to the traditional paper and EFB methods in terms of workload. I.e., EPLI, according to how the RSs answered the NASA TLX questioner, requires much less work to retrieve system information when compared to the Paper and EFB methods.
Therefore, EPLI requires very low workload in terms of cognition, physical, time, effort, and frustration on the part of the users. Additionally, one variable was added to the NASA TLX questionnaire: Visual Workload. This was to measure, obviously, the visual workload involved (Stephane, 2013).

### 3.3. CC SART: Cognitive Compatibility Situation Awareness Rating Technique rating scales

Establishing system requirements is a vital activity in the life cycle of any artifact. Designers often approach this need via progressive prototyping and acceptance testing; this was done with the research for EPLI. However, Taylor suggests that it is difficult for a designer to sustain focus on the needs of the human user when a system possess high levels of complexity in system functioning (Taylor, 1996). This is because there is a gulf in the knowledge gap between the designer and the user. Additionally, as automation is afforded more authority, the nature of the users’ tasks change. Therefore, the associated cognitive functions and processes can be more difficult to define than physical tasks and, as a result, they can change more rapidly during changes of the operational environment (Taylor, 1996).

Consequently, a designer should consider cognitive quality when developing a new system. One method for discovering specific user requirements when developing a new system employing advanced technology, is measuring cognitive compatibility (CC) (Taylor, 1996).
Cognitive compatibility refers to “ease of perceiving, thinking and doing, in line with past experience, training, and expectations” (Taylor, et. al., 1995). In pursuit of finding a way to measure CC, Taylor et. al, developed CC-SART as an experimental measures approach using the following working model (Taylor, et. al., 1995):

\[ CC = AoK + EoR - LoP \]

Where:
AoK = Activation of Knowledge
EoR = Ease of Reasoning
LoP = Level of Processing

Cognitive Compatibility Results

![Graph showing paper cognitive compatibility scores](image)

**Figure 80.** Paper CC Average: 51.75.
Figure 81. EFB CC Average: 44.44.

Figure 82. EPLI CC Average: 92.4.
A CC rating is indicated with a score between 0 – 100. The larger the number, the better the CC. The CC-SART results for EPLI were exceptional indicating that the cognitive compatibility of EPLI, on average, is significantly superior to the paper and EFB manual information retrieval formats, as they were rated by the RSs of this research project. Additionally, it should be noted that the CC for paper manuals, once again, was rated superior to the EFB manual.

3.4. SAM: Self-assessment Manikin

Another area of interest was whether EPLI was more enjoyable to work with when compared to the paper and EFB methods. However, it is difficult to assess the measuring of how people feel when interacting with a device (Bradley and Lang, 1994; Morris, 1995; and Geethanjali, et. al., 2017). The Self-Assessment Manikin (SAM) has been used to measure emotional responses. SAM is a 9-point rating scale and was used in this research to directly measure the research subjects’ enjoyment of interacting with EPLI and the paper and EFB methods. Sam directly assesses three dimensions, pleasure, arousal and dominance, of a person’s response to an act, object, or event (Bradley and Lang, 1994). SAM uses a non-verbal, graphic description of different points along these three dimensions (Figure 83).
To measure enjoyment using SAM, I simply added the scores for pleasure (1-9), Arousal (1-9) and dominance (1-9) and divided the total by 3. The following is an example:

Pleasure (6) + Arousal (4) + Dominance (7) = $17/3 = 5.67$. Sam was applied to all 38 pilots. The scores for paper, EFB and EPLI were than totaled and divided by 38 ($n=38$) for an average enjoyment score each method. The results are listed below and shown in figures 84, 85, and 86.

---

1. **Pleasure**: Select the image best representing your level of pleasure working with EPLI.

   ![Pleasure Manikin](image)

2. **Arousal**: Select the image best representing your level of excitement working with EPLI.

   ![Arousal Manikin](image)

3. **Dominance (Control)**: Select the image best representing your feeling of control using EPLI.

   ![Dominance Manikin](image)

---

**Figure 83. Self-Assessment Manikin.**
SAM Scores:

Paper: 3.78
EFB: 4.15
EPLI: 8.2

Figure 84. Paper SAM average enjoyment score.
Figure 85. EFB Sam average enjoyment score.

Figure 86. EPLI SAM average enjoyment score.
The rating score can be from 0 – 9. The larger the number, the more enjoyable the system is for the user. Clearly, EPLI is much more enjoyable to work with when compared to the paper and EFB methods.
Chapter 7
Conclusion and Future Work

1. Conclusion

The qualitative and quantitative formative results of this research indicate that current knowledge transference methodologies of aircraft systems and systems integration are tedious, time-consuming, and unenjoyable to work with. Additionally, they promote negative motivation and attitude, demoralizing the user. The research, consisting of 38 airline and GA pilots, indicates the current methods are less than desirable and below the acceptable standards identified in each qualitative questionnaire:

— The SUS results show that paper and EFB methods are below the standards of usability acceptance
— The NASA TLX results are indicative of high workload
— The CC SART results also stipulate that paper and EFB methods are below the associated standards
— The SAM results indicate that paper and EFB methods are less enjoyable to work with
— The quantitative results specify that EPLI dose indeed reduce the time it takes a user to retrieve specific information when compared to the traditional methods

Thus, paper and EFB manuals make it difficult for the student to find the right information in an efficient and comfortable manor. Further, they can make it difficult for new-hire pilots to learn the required material.
Conversely, the formative research indicates that EPLI is superior to both Paper and EFB methods:

— The SUS results rate EPLI very high in usability acceptance: 92.7
— The NASA TLX results rate EPLI with low workload: 17.8
— The CC SART results indicate the EPLI possesses high cognitive compatibility: 92.4
— The SAM results indicate that EPLI is enjoyable for the user: 8.2
— The quantitative results specify that EPLI dose indeed reduce the time it takes a user to retrieve specific information when compared to the traditional methods:
  • Group 1: All pilots required 63% less time to retrieve information
  • Group II: Airline pilots required 59% less time to retrieve information
  • Group III: GA pilots required 67% less time to retrieve information

The first human-in-the-loop simulation studies were successful at proving the concept of EPLI. The feedback generated from the four airline pilots of that study was very positive and fortified my resolve to move beyond the wireframe prototype and develop a full-scale working prototype for further testing as the concept appeared to be a tangible one to test; those results are listed in Chapter 6.

In the second HITLS study, the research subjects clearly preferred using EPLI over the other two methods. Many of the RSs studied stated that they wished EPLI was available for current training. One individual, who was retired, stated, “I wish this EPLI had been available during my career. It would have made learning the different aircraft I flew much more enjoyable and simpler.” Many of the research subjects wanted to know if I would develop, patent, and market EPLI to the airlines; they wanted to invest in EPLI if I was intending to do so. One
airline pilot offered to introduce me and EPLI to the company he worked for and believed the company would want to develop it for their operations. One company, not mentioned here, having heard about EPLI form a research subject who is one of their employees, has offered to invest in EPLI and share the profits. Therefore, it is my goal to move forward in the development of EPLI and look at future applications.

2. Future Work

There are many possible future projects that can be applied to EPLI. I restricted the research to the training application. The main reasons for this were economical and simplicity.

2.1 Prototype Number Four

Chapter 5 described the different prototypes developed during the evolutionary development of EPLI. The first prototype, a Microsoft wireframe, was used to successfully prove the working concept of EPLI. The second prototype was basically a developmental model for potential software and never tested. The third prototype was developed using the information gathered from the second prototype and enhancing that knowledge. That prototype was successfully used in this research for the full-scale testing of 38 pilots. It proved that EPLI is a viable device that is feasible, sustainable, and maintainable. Additionally, the results proving the EPLI advantages, compared to the current technologies, have exceed my original expectations. With that said, there were several other potential advances considered through the observation of the testing subjects interacting with the device, and recommendations made by the research subjects. Those advances are being incorporated into a fourth prototype as of this writing. They will make EPLI more
efficient and comfortable, and faster at information retrieval than the current prototype. Unfortunately, there is not enough time to test and evaluate that prototype for this report. That prototype will not be complete until after December 1st, 2018. Therefore, future work could encompass a research project testing the fourth EPLI prototype.

2.2 Flight Station Use
Many of the airline pilots involved in the research felt, very strongly, that EPLI should be utilized in the flight station for normal, abnormal, and emergency operations. I agree with those pilots. However, developing research for that application, would have been very expensive and complex. It would have required renting simulators, hiring flight crews and developing scenarios for HITLS during normal, abnormal, and emergency operations. This was beyond my resources.

Additionally, it should be noted that the airlines are currently looking for a way to replace the paper version of volume 3, the quick reference handbook (QRH). The QRH holds all of the checklists. The information is retrieved much faster with the paper format than with the EFB. During an emergency, the flight crew need to have the ability to retrieve the information as soon as possible. EPLI could be a potential replacement for the QRH. In fact, research subjects were able to retrieve the EPLI QRH checklists in mere seconds, on average, when compared to the other two methods which took tens of seconds. Therefore, there are two potential research projects in this regard. One for training, the other for replacing the QRH.
2.3 **EPLI as an Onboard Context-Sensitive Information System**

Moreover, in the future, EPLI could be tested as an Onboard Context-Sensitive Information System (OCSIS) which could also be used to display useful information for operators when they need the right information at the right time. Context-Sensitivity information, via appropriate operational information, can be used to solve current issues in real time (Tan, 2016). Therefore, another potential future work for EPLI can be in this area.

2.4 **Linking EPLI to the Aircraft Warning Systems**

Additionally, one of the projects the software team and I discussed was linking EPLI directly to the warning systems of the aircraft. If EPLI was linked to the warning systems, the checklists could be activated and ready to use before the pilots could physically pick up and handle EPLI. In other words, the monitoring pilot could grab EPLI and immediately run the necessary checklists instead of attempting to retrieve the checklists, saving valuable seconds. Thus, another research project could test that application.

2.5 **Augmented Reality**

I used a tactile tablet for this research. However, the application I most desired was using EPLI in the capacity of augmented reality so the users could wear glasses and use the associated aircraft flight station panel posters to learn systems and, at the same time, develop the muscle proprioception (muscle memory) for switch, lever, and button location. This is a very important aspect of training. In fact, one of the learning methods that many pilots use is to find a vacant aircraft in maintenance, on the ramp, or at a gate, and sit in the flight station and close their eyes to run appropriate checklists and ensure their hand is moving to the correct location of the desired switches. This is to instill natural and automatic actions to
enhance resilience and robustness against unstable situations. If EPLI was enhanced with augmented reality, there would be no need for pilots to look for vacant aircraft. Consequently, another research project could be the application of augmented reality.

2.6 Training with Virtual Reality on the Internet

Another interesting area is using virtual reality for training. Often, when assigned to a new aircraft, a pilot will consult with other pilots currently type rated in that aircraft. This could enhance their knowledge so that when they start ground school, they could have an advantage in learning the new aircraft. If EPLI could be enhanced with virtual reality, then, theoretically, the new pilot could call a pilot, or several pilots, who are type rated on the new aircraft and seek their expertise. Hypothetically, the new pilot (pilot #1) could recruit the experienced pilot (pilot #2) and utilize EPLI to train on the internet. Pilot #1 and pilot #2 could both insert themselves into the VR environment and train together. Using VR goggles, the internet, and EPLI, the two pilots could actually sit in the flight station and pilot #2 could train pilot #1, transferring his/her expertise of the aircraft to that pilot. This application could open a new business opportunity for retired pilots who wish to supplement their retirement income. Qualified individuals could offer their expertise to train others, never leaving the comfort of their homes. Hence, another research project could involve proving this concept.

2.7 Domains Beyond Aviation

In addition to aviation, there are many other domains that could benefit from a device like EPLI. The following list are a few of those domains:

— Commercial Spacecraft
— Submarines
— Naval Vessels
— Nuclear Power Plants
— Automobiles
— Medicine
— Textbooks
— Virtually any domain that requires using a manual

2.8 Undisclosed Applications
There are other applications that apply. However, for proprietary reasons, I wish not to disclose them at this time and save them for my own future work as I consider the possibility of advancing to post-doctoral work.

2.9 Prediction Values
Lastly, the overall sample size was small by traditional statistical methods. As a result, there is not enough information to make a prediction towards a population. The r² value was just 17 percent. However, for HCD methods and rapid prototyping, 6 to 9 experts are typically used for experimentation. Therefore, it would be beneficial to test a large sample of airline and GA pilots to make a prediction.

3. In Closing
When I started this project, my intent was to find a better way to make aircraft system knowledge transference methods more efficient, comfortable, and, ultimately, safer for the industry. I did not realize the full implications of what EPLI might possibly achieve. The
feedback and results of the research were beyond my expectations. The response of the research subjects has been very positive and provided additional motivation, on my part, to continue working on EPLI. This includes the development of the fourth prototype currently under construction. I have pursued the idea of applying for a patent and will work to bring EPLI to the market. Hopefully, EPLI will change the way people learn about the complex machines they interact with. It is possible that EPLI could change the way people learn about complex systems, or at least how they retrieve that information. In other words, they will become information selectors, rather than information sorters. As one research subject put it, “EPLI could become the state-of-the-art method for finding system information and could potentially revolutionize how the world learns.” If that were to come to fruition, then this research would be significant, and it is my hope that I will have made a valuable contribution to society in that regard. I cannot think of a greater reward for this work.
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## Appendix A

### Cognitive Function Allocation of Aircraft Systems

#### AIR SYSTEMS

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Air/Environmental C</td>
<td>Maintain life support</td>
<td>Support situational awareness, decision making, actions and response</td>
<td>Livel裕 (Human) Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System.</td>
<td></td>
</tr>
<tr>
<td>AIR CONDITIONING SYSTEM DISPLAY</td>
<td>Provide System illustration, indications, and control</td>
<td>Maintain cabin conditions</td>
<td>Livel裕 (Human) Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
<td></td>
</tr>
<tr>
<td>Flight Deck</td>
<td>Maintain cabin and flight station conditions</td>
<td>AUTO: PACK automatically controlled OR PACK off (LIGHT) associated PACK not</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
<td></td>
</tr>
<tr>
<td>PACK Switches</td>
<td>Recirculation Fans (RECIRC FANS)</td>
<td>Recycle the air in the cabin for fuel efficiency</td>
<td>ON: Recirculation fans in automatic operation OR Fans do not operate</td>
<td>Livel裕 Hardware, Switches, Software, Checklists, Training, Electrical System.</td>
</tr>
<tr>
<td>FWV Equipment Cooling (EQUIP COOLING FWV Switch)</td>
<td>Reduce Ambient Temperatures from Electronics Heat Dissipation in Electronics</td>
<td>AUTO: FWV equipment cooling fan controlled automatically OFF: FWV equipment cooling fans do not operate</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
<td></td>
</tr>
<tr>
<td>Cabin Temp Control</td>
<td>Maintain Cabin Temperature</td>
<td>Reduce the load on the air conditioning system</td>
<td>AUTO: Cabin temperature maintained</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>Air Conditioning Reset (AIR COMD RESET) Switch</td>
<td>Reset Control for Air Conditioning System</td>
<td>and attempts to restart normal operation</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
<td></td>
</tr>
<tr>
<td>FWV Cargo Temp Switch</td>
<td>Switch: Forward Control Cargo Heat Temperature</td>
<td>Provide air to the cargo area</td>
<td>AUTO: Forward cargo temperature maintained</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>FWV Cargo Temp Switch</td>
<td>Switch: AFT Control Cargo Heat Temperature</td>
<td>Provide air to the cargo area</td>
<td>AUTO: Forward cargo temperature maintained</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>Humidification Switch</td>
<td>Humidify cabin and flight station area</td>
<td>Provide air moisture for passenger and crew comfort</td>
<td>ON: Humidification system operates automatically</td>
<td>Livel裕 Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Penumatics System, Engines, and Outflow Valves</td>
</tr>
</tbody>
</table>
### Anti-Ice & Rain

#### Table of Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2.1 Anti-Ice &amp; Rain System</td>
<td>Notify crew when icing conditions exist</td>
<td>Provide safe operations during icing conditions</td>
<td>Engine anti-ice valves are closed</td>
<td>Liveware (Human), Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, System, Encoders, and Engines</td>
</tr>
<tr>
<td>7</td>
<td>Notify crew when engine anti-ice is operating</td>
<td>Provide safe operations during icing conditions</td>
<td>Engine anti-ice system is on</td>
<td>Liveware, Hardware, Switches, Software, Checklists, Training, Electrical System, System, Encoders, and Engines</td>
</tr>
<tr>
<td>8</td>
<td>Heat the leading edges of the wings</td>
<td>Provide system information to flight crew</td>
<td>Wing anti-ice system is on</td>
<td>Liveware, Hardware, Switches, Software, Checklists, Training, Electrical System, System, Encoders, and Engines</td>
</tr>
</tbody>
</table>

#### Diagram:

- **Engine Anti-Ice Switches (Off, Auto, On)**
- **Wing Anti-Ice Switch (Off, Auto, On)**

#### System Warnings:

- **Cabin Altitude**
  - AUTO: cabin altitude is excessive
  - Automatic pressurization control has failed or both output valve switches are in manual
- **Cabin Temperature**
  - Off: engine anti-ice valves are closed
- **Engine Cooling**
  - AUTO: in flight, the engine anti-ice valves are opened or closed automatically via ice detection system
- **Landing Altitude**
  - Engine anti-ice system is on
- **Outflow Valve Failure**
  - AUTO: in flight, the wing ice protection system is powered on and off automatically by the ice protection system
- **Pack Mode Switch**
  - The pack is inoperative
  - Both packs are inoperative
  - Recirculation fan switch is off
### AUTOFLIGHT

#### Aircraft Flight Station Nominal

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4. AUTOMATIC FLIGHT</strong></td>
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<tr>
<td>Vertical and Lateral</td>
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<tr>
<td>Designate Trajectory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control by Autopilot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Direction</td>
<td></td>
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<tr>
<td>Navigation System</td>
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<td></td>
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<td></td>
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<tr>
<td><strong>MODE CONTROL PANEL (MCP)</strong></td>
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<td></td>
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<tr>
<td>Autopilot (AP)/Flight Director (FD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select/Deselect</td>
<td></td>
<td></td>
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<tr>
<td>Autopilot, and Flight Director</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Engage/Disengage</td>
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<tr>
<td>Autotrottle Authority</td>
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## Electrical and Communication Systems

### Electrical Power

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.5 Electrical Power</strong></td>
<td></td>
<td></td>
<td></td>
<td>Liveware, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
</tbody>
</table>

### Battery Switch and OFF Light (Mechanical)

<table>
<thead>
<tr>
<th>Battery Switch</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BATTERY Switch</strong></td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>The SATCOM datalink has failed</td>
<td>Lights, Software, Electrical System</td>
</tr>
<tr>
<td><strong>Battery OFF Light</strong></td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>The BATTERY switch is OFF</td>
<td>Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
</tbody>
</table>

### Miscellaneous Communication

<table>
<thead>
<tr>
<th>Communication System/Indications/Controls Display (MCD)</th>
<th>Task</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AVIONICS</strong></td>
<td></td>
<td></td>
<td>Liveware, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
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</tr>
<tr>
<td>10</td>
<td>APU Generator (APU GEN) Switches</td>
<td>Closes and opens APU generator field. Lights, Gages, Software, Checklists, Training, Electrical System.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>APU Generator OFF Lights</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. APU generator control breaker is open. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Engine Generator Control Indications (Display)</td>
<td>Provides situational awareness, decision making, actions and feedback. APU generator control breaker is open. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Generator Control (GEN CTRL) Switches</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. APU generator control breaker is open. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Generator Drive Disconnect (DRIVE DISC) Switches</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. Generator drive is functioning. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Generator DRIVE Lights</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. Generator drive is malfunctioning. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>External Power ON Light</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. External power is selected ON. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>System Schematic with appropriate AC, DC, Volts, Frequencies, and Amperage Indications</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. External power is selected ON. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>System Indication Lights</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. Engine generator is operational and supplying power. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>ON: Engine generator</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. Engine generator is operational and supplying power. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>ON: APU generator</td>
<td>Provides system information to flight crew. Support pilot situational awareness, decision making, actions and feedback. APU generator is operational and supplying power. Literature, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves.</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Task</td>
<td>Role</td>
<td>Context</td>
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<tr>
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</tr>
<tr>
<td>ENGINES/APU</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>APU generator is off</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td></td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>APU generator is operational and ready to supply power</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td></td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>External power is plugged in and ready to supply power</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>EICAS Messages</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>APU battery has failed</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>APU BATTERY</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Associated AC bus is not energized</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>ELEC AC BUS L/R</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Associated generator drive fault</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>ELEC GEN DRIVE L/R</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Generator control breaker is open</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>ELEC OFF L/R</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Standby power system has failed</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>ELEC STANDBY SYS</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Main battery is discharging or the hot battery bus is not energized</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>MAIN BATTERY DISCH</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Main battery charge is low</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
<tr>
<td>MAIN BATTERY LOW</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Main battery has failed</td>
<td>Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
</tr>
</tbody>
</table>

**Aircraft Flight Station Nominal**

1. **Function**
2. **Task**
3. **Role**
4. **Context**
5. **Resources**

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6 Engines, Auxiliary Power Unit</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td>Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
<td></td>
</tr>
<tr>
<td>EICAS Display</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mode Indications</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
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<tr>
<td>Primary Engine Indications</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>H1 Indicators</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference/Target H1</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum H1 Line Ica</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystal Anti-Ice Indication</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGT Indications</td>
<td>Provide system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White normal operating range: Amber: maximum continuous limit reached; Red: maximum start or takeoff limit reached</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
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</tr>
<tr>
<td>Red Line</td>
<td></td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td></td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td></td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>10</td>
<td>Secondary Engine Indications</td>
<td>Provide system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>Displays N2 RPM during nominal and off-normal operations</td>
</tr>
<tr>
<td>11</td>
<td>N2 Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>Fuel flow to the engine (in cubic feet per hour x 1000)</td>
</tr>
<tr>
<td>12</td>
<td>Fuel Flow Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White: normal operating range; Amber: caution range reached; Red: operating limit reached</td>
</tr>
<tr>
<td>13</td>
<td>Oil Pressure Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White: normal operating range; Amber: caution range reached; Red: operating limit reached</td>
</tr>
<tr>
<td>14</td>
<td>Oil Temperature Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White: normal operating range; Amber: caution range reached; Red: operating limit reached</td>
</tr>
<tr>
<td>15</td>
<td>Oil Quantity Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White: normal quantity; Amber: low quantity</td>
</tr>
<tr>
<td>16</td>
<td>Engine Vibration Indications</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>White: normal operating range; Black: high vib.</td>
</tr>
<tr>
<td>17</td>
<td>Engine Controls</td>
<td>Provide Manual Engine Control</td>
<td>Controls engine forward thrust</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>Provide Manual Engine Control</td>
<td>Controls engine reverse thrust</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>21</td>
<td>Reverse Thrust Lever</td>
<td>Provide Manual Engine Control</td>
<td>Lower plot workload and enhance safety</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>22</td>
<td>Engine Control Panel</td>
<td>Provide Manual Engine Control</td>
<td>Lower plot workload and enhance safety</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>23</td>
<td>Fuel Control Switches</td>
<td>Provide Manual Engine Control</td>
<td>Lower plot workload and enhance safety</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>24</td>
<td>START Selector</td>
<td>Provide Manual Engine Control</td>
<td>Lower plot workload and enhance safety</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>25</td>
<td>Autostart</td>
<td>Provide Automatic Engine Control</td>
<td>Lower plot workload and enhance safety</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines</td>
</tr>
<tr>
<td>26</td>
<td>Engine Ignition</td>
<td>Provide ignition source for fuel combustion during engine start, icing conditions, rain, and hail</td>
<td>Keep engine running during off-normal operations</td>
<td>Off ignition is an OFF: ignition is off</td>
</tr>
<tr>
<td>27</td>
<td>Auto-Restart</td>
<td>Provide ignition for auto restart during off-normal operations</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines, Pneumatics</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Thrust Reverser</td>
<td>Controls engine reverse thrust</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines, Pneumatics</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>APU Control Display</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines, Pneumatics</td>
</tr>
<tr>
<td>30</td>
<td>APU Controls</td>
<td>Provides system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines, Pneumatics</td>
</tr>
<tr>
<td>31</td>
<td>APU FAULT Light</td>
<td>Provides system information to flight crew, see context</td>
<td>Support plot situational awareness, decision making, actions and feedback</td>
<td>Hardware, Switches, Lights, Gages, Sensors, Checklists, Training, Electrical System, Engines, Pneumatics</td>
</tr>
<tr>
<td>Page 231</td>
<td>APU FAULT Light</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>APU fault and/or fire is detected (Auto shutdown)</td>
</tr>
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</tr>
<tr>
<td>32</td>
<td>APU Indications</td>
<td>Provide system information to flight crew</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>RPM: APU rotation speed (% RPM) EGT: APU exhaust gas temperature (°C) OIL PRESS – APU oil pressure (PSI) OIL TEMP – APU oil temperature (°C) OIL QTY – APU oil quantity (quarts)</td>
<td>Provide system information to flight crew</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>GREEN: Normal YELLOW: Caution RED: Limits OFF:</td>
</tr>
<tr>
<td>34</td>
<td>Provide method to manually start and stop APU</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
<td>ON:</td>
</tr>
<tr>
<td>35</td>
<td>APU Start Selector (OFF, ON, START)</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
<td>Illuminated (amber):</td>
</tr>
<tr>
<td>36</td>
<td>APU FAULT Light</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
<td>APU fault and/or fire detected</td>
</tr>
<tr>
<td>37</td>
<td>APU Shut Down</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
<td>Any of the following faults cause the APU to shutdown immediately:</td>
</tr>
<tr>
<td>38</td>
<td>APU Automatic Start</td>
<td>Provide automatic mitigation against off-nominal operations</td>
<td>Lower plot workload and enhance safety</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>EXCAS MESSAGES</td>
<td>Provide system information to flight crew</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>ENG LIMIT EXCEED</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>Engine limit exceedance occurs</td>
</tr>
<tr>
<td>41</td>
<td>ENG REV AIR/GND</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>Air-ground thrust reverser logic has failed</td>
</tr>
<tr>
<td>42</td>
<td>ENG REV COMMANDED</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>Reverse thrust lever is not in the down position in flight</td>
</tr>
<tr>
<td>43</td>
<td>ENG REVERSER</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td>Reverser operation is limited</td>
</tr>
<tr>
<td>44</td>
<td>ENG REV LIMITED</td>
<td>Provide system information to flight crew; see content</td>
<td>Support situational awareness, decision making, actions and feedback</td>
<td></td>
</tr>
</tbody>
</table>
FIRE DETECTION/PROTECTION

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
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</thead>
<tbody>
<tr>
<td>Fire Protection</td>
<td>Fire Bottle Discharge</td>
<td>Light and tone relays pilot of extinguisher discharge or low pressure</td>
<td>The extinguisher bottle is discharged or has low pressure</td>
<td></td>
</tr>
<tr>
<td>Engine Fire Protection</td>
<td>Engine Fire Panel</td>
<td>Make crew aware of extinguisher discharge or low pressure</td>
<td></td>
<td>Hardware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatics, Systems, and Outflow Valves</td>
</tr>
<tr>
<td>Fire Bottle Discharge</td>
<td>Engine Fire Switches</td>
<td>Rotate to position 1 or 2 to discharge extinguisher into targeted engine</td>
<td>Preps for fire, depressurizes hydraulic pump</td>
<td>Fire, High Pressure, Engine, Control, Switch, Low Pressure, Engine, Fire, Low Pressure, Engine, Fire</td>
</tr>
<tr>
<td>Engine Fire Panel</td>
<td>Engine Fire Switches</td>
<td>Make crew aware of engine fire</td>
<td>Enhance crew awareness of off-nominal scenarios</td>
<td>An associated engine fire is detected</td>
</tr>
<tr>
<td>Engine Fire Switches</td>
<td>Fuel Control Switch/Fire Warning</td>
<td>Make crew aware of engine fire</td>
<td>Enhance crew awareness of off-nominal scenarios</td>
<td></td>
</tr>
<tr>
<td>Page</td>
<td>Description</td>
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<tr>
<td>233</td>
<td>11 APU Fire Protection</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Makes crew aware of fire extinguisher discharge light and tone notification pilots of fire extinguisher discharge or low pressure</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>In normal position, mechanically locked; unlocks automatically for fire warning. Out —</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>• arms the APU fire extinguisher bottle</td>
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<tr>
<td></td>
<td>• closes the APU air intake door</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• trips the APU generator field and generator breaker</td>
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<tr>
<td></td>
<td>• shuts down the APU (if automatic shutdown does not occur)</td>
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<tr>
<td></td>
<td>Rotate — either</td>
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<tr>
<td></td>
<td>Liiware, Hardware, Switches, Lights, Gages, Software, Checklists, Training, Electrical System, Pneumatics System, Engines, and Outflow Valves</td>
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<tr>
<td>233</td>
<td>12 APU Fire Panel</td>
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<tr>
<td>233</td>
<td>13 APU Bottle Discharge Light</td>
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<tr>
<td></td>
<td>Rotates either direction to discharge the APU fire extinguisher</td>
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<td>233</td>
<td>14 APU Fire Switch</td>
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<tr>
<td></td>
<td>APU fire extinguisher is automatically shut down</td>
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<td>233</td>
<td>15 APU Fire Warning Light</td>
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<tr>
<td></td>
<td>The extinguisher bottle is discharged or has low pressure</td>
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<td>16 Cargo Fire Protection</td>
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<td>233</td>
<td>17 Cargo Fire Panel</td>
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<tr>
<td>233</td>
<td>18 CARGO FIRE ARM Switches</td>
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<tr>
<td></td>
<td>Activate switch to arm cargo fire extinguishers for associated cargo fire suppression area is</td>
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<td>19 CARGO FIRE ARM Switches</td>
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<tr>
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<td>Activate switch to disarm cargo fire extinguishers in armed area is</td>
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<td>233</td>
<td>20 CARGO FIRE Discharge Switch</td>
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<tr>
<td></td>
<td>Extinguishes cargo fire</td>
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<td>233</td>
<td>21 CARGO FIRE Discharge Switch</td>
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<tr>
<td></td>
<td>Makes crew aware that cargo fire extinguisher has been discharged</td>
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<tr>
<td>233</td>
<td>22 FIRE/OVERHEAT TEST Switch</td>
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<tr>
<td></td>
<td>APU ground fire protection panel</td>
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<td>233</td>
<td>23 APU Fire Light</td>
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<tr>
<td></td>
<td>Makes crew aware of APU fire</td>
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<td>24 APU Bottle Discharge Switch</td>
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<tr>
<td></td>
<td>Activates switch to discharge APU fire extinguisher into APU equipment</td>
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<td>25 APU FIRE SHUTDOWN Switch (RED)</td>
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<tr>
<td></td>
<td>Activates switch to shut down APU and arm extinguishing system</td>
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<td>233</td>
<td>26 APU FIRE SHUTDOWN Switch (RED)</td>
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<td></td>
<td>Alert crew of APU fire bottlearming</td>
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<td>APU Fire Warning Light</td>
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<td>Cargo Fire Protection</td>
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<tr>
<td>Cargo Fire Panel</td>
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<td>CARGO FIRE ARM Switches</td>
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<td>CARGO FIRE Discharge Switch</td>
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<td>FIRE/OVERHEAT TEST Switch</td>
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<td>APU Fire Light</td>
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<td>APU Bottle Discharge Switch</td>
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<td>APU FIRE SHUTDOWN Switch (RED)</td>
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<td>APU FIRE SHUTDOWN Switch (RED)</td>
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<td>Fire and Overheat Detection</td>
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<td>DET FIRE WHEEL WELL</td>
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<td>SMOKE LAVATORY</td>
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<td>SMOKE EQUIP CLG</td>
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# Flight Controls

<table>
<thead>
<tr>
<th>Function</th>
<th>Task</th>
<th>Role</th>
<th>Context</th>
<th>Resources</th>
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<tbody>
<tr>
<td>8. Flight Controls</td>
<td>Adjust lever to adjust</td>
<td>Flap positioning</td>
<td>Positions the slots and flaps</td>
<td>Liveware, Hardware, Switches,</td>
</tr>
<tr>
<td>Flap Lever</td>
<td>Alternate flaps Arm (ALTN FLAPS ARM)</td>
<td>Switch</td>
<td>Activates the flap control mode</td>
<td>Liveware, Hardware, Switches,</td>
</tr>
<tr>
<td>Flap Gates</td>
<td>Alternate flap control mode</td>
<td>Provides alternate flap control mode</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Alternate Flaps Arm (ALTN FLAPS ARM) Switch</td>
<td>Alternate flap control mode</td>
<td>Provides alternate flap control selection</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Alternate Flaps Selector</td>
<td>Alternate flap control selection</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Flap Limit Switch</td>
<td>Reference for flap display</td>
<td>Displays extended speed limits</td>
<td>Liveware, Hardware, Switches,</td>
<td></td>
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<tr>
<td>Flap Position Indicator</td>
<td>Visually indicate flap</td>
<td>Displays combined flap and slat position</td>
<td>Liveware, Hardware, Switches,</td>
<td></td>
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<tr>
<td>Primary Flight Computers</td>
<td>DISC: disconnects the primary flight computers (PFCs) from the flight control system</td>
<td></td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>PRIMARY FLIGHT COMPUTERS Disconnect Switch</td>
<td>AUTO: the flight control system operates in the normal mode</td>
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<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>PRIMARY FLIGHT COMPUTERS Disconnect Switch</td>
<td>The primary flight computers are disconnected in the low mode</td>
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<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Pitch and Stabilizer (STAB)</td>
<td>Control wheel and column</td>
<td>Control aircraft attitude</td>
<td>Provide crew with control of trim</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Control Wheel and Column</td>
<td>Provide crew with control of trim</td>
<td></td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Pitch Trim Switches</td>
<td>Switch to change the stabilizer trim</td>
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<td>Liveware, Hardware, Switches,</td>
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<td>STAB Trim</td>
<td>Make crew aware of stabilizer position</td>
<td>Displays actual stabilizer position</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Rudder/Brake Pedals</td>
<td>Push (both switches) on the ground</td>
<td>Pushes electrical power from</td>
<td>Liveware, Hardware, Switches,</td>
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<td>RUDDER TRIM Indicator</td>
<td>Displays rudder trim position</td>
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<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Rudder/Brake Pedals</td>
<td>Direct rudder</td>
<td>Moves rudder to the desired direction</td>
<td>Liveware, Hardware, Switches,</td>
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<tr>
<td>Speed Brakes/Spoilers (LIFT)</td>
<td>On the ground</td>
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<td>Liveware, Hardware, Switches,</td>
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### Flight Instruments

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<th>Task</th>
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<th>Resources</th>
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<tr>
<td>Flight Instruments, Displays</td>
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<tr>
<td>FUNCTION</td>
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<tr>
<td>Flight Mode Indicators</td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Software</td>
</tr>
<tr>
<td>AFS Roll Modes: LMA, HDO, HEC, HOG, WITS, VLS</td>
<td>Display current</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>AFS Pitch</td>
<td>Display current</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
</tr>
<tr>
<td>Autopilot, Director Information System</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Status</td>
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<tr>
<td>Attitude Indicators</td>
<td>Display ADI, altitude</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Vertical Speed Indicator</td>
<td>Display ADI</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Selected Speed</td>
<td>Display selected</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Speed Trend Vector</td>
<td>Display speed trend</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Current Airspeed</td>
<td>Display current</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
</tr>
<tr>
<td>Current Mach</td>
<td>Display current</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Maximum Speed</td>
<td>Displays max speed</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Maximum Mach Speed</td>
<td>Displays max speed</td>
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<td>Selected Speed Bug</td>
<td>Points to selected</td>
<td>Support pilot situational awareness</td>
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<td>Stall Reference Speeds</td>
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<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>VNAV Speed Band</td>
<td>Indicates range of VNAV speed</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Approach Speeds</td>
<td>Display reference to VNAV</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<tr>
<td>Minimum Approach Speed</td>
<td>Display reference to VNAV</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Minimum Speed</td>
<td>Displays min speed</td>
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<td>Landing Flap and VREF Speed</td>
<td>Display flap position</td>
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<td>Bank Pointer</td>
<td>Indicates bank angle</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Roll Reference</td>
<td>Indicates roll amount</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Yaw Reference</td>
<td>Indicates yaw angle</td>
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<td>Heading Reference</td>
<td>Indicates heading</td>
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<td>Lights, Gages, Software</td>
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<tr>
<td>Roll Reference</td>
<td>Indicates roll amount</td>
<td>Support pilot situational awareness</td>
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<td>Pitch Limit Indicator</td>
<td>Takes pitch limit</td>
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<td>Horizon Line and Pitch Scale</td>
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<td>Support pilot situational awareness</td>
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<td>Flight Path Vector (FPV)</td>
<td>Display flight path</td>
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<td>Airport Information System</td>
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<td>Radio Altitude</td>
<td>Maintain a set</td>
<td>Support pilot situational awareness</td>
<td>Lights, Gages, Software</td>
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<td>Localizer Pointer and Scale</td>
<td>Indicates localizer</td>
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<td>Marine Beacon Indication</td>
<td>Indicates beacon</td>
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<td>Selected Altitude Bag</td>
<td>Display alt set</td>
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<td>Airport Information System</td>
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<td>Plan Mode</td>
<td>Provide system</td>
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<td>Lights, Gages, Software</td>
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<tr>
<td>Chart Mode</td>
<td>Provide map node</td>
<td>Map inside controller</td>
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<td>Aircraft Information System, Pneumatics, Systems, Engines, and Outflow Values</td>
<td>Provides system information to flight crew</td>
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<td>Lights, Gages, Software</td>
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<tr>
<td>Airport Information System, Pneumatics, Systems, Engines, and Outflow Values</td>
<td>Provides system information to flight crew</td>
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<td>Redundant control system control</td>
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<td>Redundant control system control</td>
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<td>CFS CTRL/DUAL/RS Key</td>
<td>Enables CFS</td>
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<td>Backup EFIS Control</td>
<td>Provide an alternate control functions of the EFIS control panel and/or the EFIS Control Panel</td>
<td>Redundant control system control</td>
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<td>Support pilot situational awareness</td>
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### FUEL

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<th><strong>Role</strong></th>
<th><strong>Context</strong></th>
<th><strong>Resources</strong></th>
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<tr>
<td>Fuel Pump Switches</td>
<td>Turn fuel pump on/off</td>
<td>Allow for direct control of fuel flow</td>
<td>Nominal, operational, emergency operation</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
</tr>
<tr>
<td>Forward and All Fuel Pump Pressure Lights (AMBER)</td>
<td>Indicate pump pressure for forward &amp; aft fuel pumps</td>
<td>Fuel pressure is low</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
<td></td>
</tr>
<tr>
<td>Center Fuel Pump Pressure Lights (AMBER)</td>
<td>Indicate pump pressure for center fuel pump</td>
<td>Fuel pressure is low</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
<td></td>
</tr>
<tr>
<td>CROSSFIRE Switch</td>
<td>Selects crossfire valve</td>
<td>Selects crossfire valve</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
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<tr>
<td>CROSSFIRE VALVE Light (AMBER)</td>
<td>Value and valve setting not aligned</td>
<td>Crossfire valve is not in selected position</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
<td></td>
</tr>
<tr>
<td>FUEL QTY (AMBER)</td>
<td>Fuel quantity may not be accurate</td>
<td></td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
<td></td>
</tr>
<tr>
<td>FUEL BALANCE</td>
<td>Automatic weight imbalance of fuel</td>
<td>Displayed if the main tank fuel exceeds more than 265 pounds</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
<td></td>
</tr>
<tr>
<td>Fuel Schematic Display</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fuel Quantity</td>
<td>Provide system information to flight crew</td>
<td>Fuel Used</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
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<tr>
<td>Fuel Temperature</td>
<td>Provide system information to flight crew</td>
<td>Amber: Temperature approaches MAX or MIN limit</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
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</tr>
<tr>
<td>Fuel Pump Switches Left, Right, Center, Rear</td>
<td>Provide system information to flight crew</td>
<td>Nominal, operational, emergency operation</td>
<td>Lumeware, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Fuel System</td>
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## HYDRAULICS/LANDING GEAR

<table>
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<td><strong>Display (BTO)</strong></td>
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<tr>
<td><strong>Hydraulic Panel</strong></td>
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<tr>
<td><strong>RAM AIR TURBINE Switch</strong></td>
<td>Provide control over automatic</td>
<td>Provide backup electrical and hydraulic power</td>
<td>Off-nominal or emergency power loss</td>
<td>Liveares, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatic Systems, Engines, and Outboard Valves</td>
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<tr>
<td><strong>Ram Air Turbine Pressure</strong></td>
<td>Provide system information to</td>
<td>Support plot situational</td>
<td></td>
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<tr>
<td><strong>Ram Air Turbine Unlocked</strong></td>
<td>Provide system information to</td>
<td>Support plot situational</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ram Air Turbine</strong></td>
<td>Generate electricity and hydraulic pressure</td>
<td>Provide backup electrical and hydraulic power</td>
<td>ON - engine-driven hydraulic pump pressurizes associated left or right hydraulic system; OFF - engine-driven hydraulic pump is off and depressurized; FAULT (amber) - low primary pump pressure; excessive primary pump fluid temperature; or pump selected OFF</td>
<td>Liveares, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatic Systems, Engines, and Outboard Valves</td>
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<tr>
<td><strong>Left/Right Engine (L/R ENG) PRIMARY Pump Switches (Engine Driver)</strong></td>
<td>Power system components</td>
<td>Power system components</td>
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<td><strong>Left Hydraulic System</strong></td>
<td>Generate hydraulic power</td>
<td>Provide 3,000 psi for operation of hydraulic components</td>
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<tr>
<td><strong>Right Hydraulic System</strong></td>
<td>Generate hydraulic power</td>
<td>Provide 3,000 psi for operation of hydraulic components</td>
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<tr>
<td><strong>Center Hydraulic System</strong></td>
<td>Generate backup hydraulic power</td>
<td>Provide 3,000 psi for operation of hydraulic components during off nominal operations</td>
<td>Center demand pump operates under following conditions; system low pressure; no leaks or seal failure; pump or gear is in operation; or pump selected OFF</td>
<td>Liveares, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatic Systems, Engines, and Outboard Valves</td>
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<tr>
<td><strong>Center Hydraulic System Electric Pump Switches</strong></td>
<td>Generate backup hydraulic power</td>
<td>Provide 3,000 psi for operation of hydraulic components during off nominal operations</td>
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<tr>
<td><strong>Left and Right Hydraulic System Electrical Pump Switches</strong></td>
<td>Energize and de-energize left and right electrical hydraulic pumps</td>
<td>Provide 3,000 psi for operation of hydraulic components during off nominal operations</td>
<td>AUTO - Pumps alternate, primary pump operates continuously and demand pump operates during high system demand; A/C pump selected OFF</td>
<td>Liveares, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatic Systems, Engines, and Outboard Valves</td>
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<tr>
<td><strong>Hydraulic System</strong></td>
<td>Support plot situational awareness, decision making, actions, and feedback</td>
<td>Support plot situational awareness, decision making, actions, and feedback</td>
<td>LO (amber) - Hydraulic reservoir quantity is low; RF (white) - Hydraulic reservoir quantity is low,</td>
<td>Liveares, Hardware, Switches, Lights, Gauges, Software, Checklists, Training, Electrical System, Pneumatic Systems, Engines, and Outboard Valves</td>
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<tr>
<td><strong>Quantity (QTY) Light</strong></td>
<td>Provide system information to flight crew</td>
<td>Support plot situational awareness, decision making, actions, and feedback</td>
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<td>15</td>
<td>Pressure (PRESS)</td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>LIVE/SAFE: associated flight control surface is electrically unlocked.</td>
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<td>31</td>
<td>FLIGHT CONTROL Lockout</td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Flaps to a position after the aircraft has landed.</td>
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<td>Nose Wheel Steering</td>
<td>Turns the nose wheels</td>
<td>Provide aircraft steering on ground and in flight</td>
<td>Nominal ground operation</td>
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<td>56</td>
<td>VPbrakes</td>
<td>Provide system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>An anti-skid fault or system failure is detected.</td>
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<td>60</td>
<td>AUTOBRAKE light (Amber)</td>
<td>Display system information to flight crew</td>
<td>Support pilot situational awareness, decision making, actions and feedback</td>
<td>Displayed if any of the following occur:</td>
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### Table: LANDING GEAR PNL

| 38 | AUTOBRAKE Selector | Select appropriate autobrake setting | Command sensitivity | OFF: deactivates and resets the autobrake system. |
| 41 | Autobrake Switch | Deploy alternate landing gear | Reduce brake pressure | 1, 3, 5, 7, 9: MAX AUTO: selects desired deceleration rate. |
| 42 | Spoiler Position Indicator | Provide system information to flight crew | Support pilot situational awareness | Crosscheck (white) the selected landing gear is extended and locked. |
| 43 | Nose Wheel Steering | Turns the nose wheels | Provide aircraft steering on ground and in flight | Nominal ground operation |
| 50 | Parking Brake Levers | Secure aircraft when at rest | Provide aircraft deceleration to a full stop | Nominal, off nominal, emergency braking. |
| 51 | Brake Temperature Indication | Displayed on the GEAR synoptic display | Support pilot situational awareness, decision making, actions and feedback | Braking/servoing. |
| 52 | Anti-skid Protection | Prevent brake failure, suction of air, increase safety | Support pilot situational awareness, decision making, actions and feedback | Off: nominal or emergency stopping or slowing. |
| 55 | Autobrakes | Provide system information to flight crew | Support pilot situational awareness, decision making, actions and feedback | Electrohydraulic. |
### WARNING SYSTEMS

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<td>14. Warning Systems</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>EICAS Event Record Switch</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<td>Display Select Panel (DSP)</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<td>PFD Alerts</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Master WARNING/CAUTION Reset</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Audio Cancel Control Panel</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
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<td>Traffic Alert and Collision Avoidance System</td>
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<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Ground Proximity Warning System (GPWS)</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Predictive Windshear (PWS) Display</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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### LIGHTS

<table>
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<tr>
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<th>Role</th>
<th>Context</th>
<th>Resources</th>
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<tr>
<td>15.1 Lights</td>
<td>Provide system in emergency</td>
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<td>Awareness, decision making, actions and feedback</td>
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<tr>
<td>Exterior Lighting</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
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<tr>
<td>Landing Lights</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Runway Turnoff Lights</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<tr>
<td>Taxi Lights</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<td>Strobe Lights</td>
<td>Provide system in emergency</td>
<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
<td>Lights, Gages, Switches, Hardware, Switches, Electronics</td>
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<td>Beacon Lights</td>
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<td>Awareness, decision making, actions and feedback</td>
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<td>Navigation Lights</td>
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<td>Logi Lights</td>
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<td>Awareness, decision making, actions and feedback</td>
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<td>Dome Lights</td>
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<td>Support pilot situational</td>
<td>Awareness, decision making, actions and feedback</td>
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<td>Awareness, decision making, actions and feedback</td>
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### SEATBELTS and RESTRAINTS

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<td>Second Observer Seat</td>
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### EMERGENCY EQUIPMENT

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<td>21-24 Doors</td>
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<td>Flashlights</td>
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<td>Used to break or</td>
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<td></td>
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<tr>
<td>Smoke Goggles</td>
<td>Covers eyes to</td>
</tr>
<tr>
<td>Personal Breathing Apparatus (PBE)</td>
<td>Covers face to</td>
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Appendix B
EPLI Function Allocation List

Intentionally Left Blank
8. CHECKLISTS
   d. Normal
      • Safety & Power On
      • Originating/ Receiving
      • Before Engine Start
      • After Engine Start
      • Before Takeoff
      • After Take Off
      • Preliminary Landing
      • Landing
      • After Landing
      • Parking & Securing
   e. Abnormal
      • Air Conditioning
        • Pack
        • Pack Trip Off
        • Zone Temp
        • Equipment Cooling
      • Electrical
        • Bat Discharge
        • Drive
        • Elec
        • Loss of Both Engine Driven Generators
        • Source Off
        • Standby Power Off
        • TR Unit
        • Transfer Bus Off
      • Fuel
        • Low Pressure
        • Filter Bypass
      • Pneumatics
        • Bleed Trip Off
        • Dual Bleed
        • Duct Overheat
      • Pressurization
        • Alternate
        • Auto Fail
        • Manual
        • Off Schedule Descent
   f. Emergency
      • Engine Failure Flameout
      • Engine Overheat
      • Engine Fire Severe Damage Separation
      • Single Engine Preliminary Landing
      • Single Engine Landing
      • Aborted Starts
      • Start Valve Open
      • Loss of Thrust on Both Engines
      • Airspeed unreliable
      • Inflight Start
      • Smoke or Fumes Removal
      • Electrical Smoke or Fire
      • APU Fire
      • Excessive Cabin Altitude
      • Passenger Evacuation
      • Runaway Stabilizer
      • Uncommanded Yaw or Roll/ Jammed Rudder

9. LIMITATIONS
   m. Operational
   n. Weights
   o. Speeds
   p. Air Systems
   q. Autopilot/ Flight Director
   r. Electrical
   s. Hydraulics
   t. Engines/ APU
   u. Flight Controls
   v. Flight Management/ Navigation
   w. Fuel
   x. Landing Gear

10. PANELS
    d. Overhead
      • Air Conditioning
      • Electrical
      • Fuel
      • Pneumatics
      • Pressurization
    e. Forward
    f. Center

11. POP UPS
    f. Fuel
    g. Air Conditioning
    h. Pneumatics
    i. Pressurization
    j. Electrical

12. SCHEMATICS
    g. Fuel
    h. Air Conditioning
    i. Electrical
    j. Pneumatics
    k. Pneumatics T
    l. Pressurization

13. SYSTEMS NARRATIVE
    f. Air Conditioning
    g. Electrical
    h. Fuel
    i. Pressurization
    j. Pneumatics

14. FLOWS
    k. Safety & Power On
    l. Originating/ Receiving
    m. Before Engine Start
    n. After Engine Start
    o. Before Takeoff
    p. After Take Off
    q. Preliminary Landing
    r. Landing
    s. After Landing
    t. Parking & Securing
Appendix C
EPLI CMap
Appendix D
Software Team Contract

Enhanced Pilot Learning Interface System

**Members:**
Gaetano Saltalamacchia: gsaltalamacc2014@my.fit.edu
Melissa Manley: mmanley2014@my.fit.edu
Ian Dillon: idillon2015@my.fit.edu
Christian Maurno: cmaurno2015@my.fit.edu

**Sponsor:**
Dr. Thomas Eskridge: teskridge@fit.edu

**Client:**
Captain De Vere Kiss, Pilot for American Airlines/Ph.D. Candidate FIT: deverekiss@gmail.com

**General Meetings:** Tuesdays/Thursdays, 2-3:30 P.M.

**Task Progress for Milestone 1**

<table>
<thead>
<tr>
<th>Task</th>
<th>Completion</th>
<th>Gaetano</th>
<th>Melissa</th>
<th>Ian</th>
<th>Christian</th>
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<tr>
<td>Compare and select technical tools</td>
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<td>25%</td>
<td>25%</td>
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<tr>
<td>Provide small traversal demo to evaluate topic relations</td>
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<td>25%</td>
<td>25%</td>
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</table>
Discussion for Accomplished Tasks and Member Contributions of Milestone 1

Each team member was assigned with comparing and contrasting certain technical tools with which to create our application. The members met after each had considered their options, and had come to a consensus that JavaFX, something the group researched as a whole, was a much more beneficial option than any considered previously.

The traversal demo was a group effort that helped each group member to understand how the others work both on their own and with others, allowing everyone to work together more efficiently and move more quickly throughout the rest of the semester.

After a few new ideas being circulated amongst the group members, an agreement was made to collaborate using Google Docs and GitHub to work together and send/receive information and code.

The requirement document was worked on in parts, with the majority being completed with the other group members in person. For missing information discovered later in its completion, each member added their designated information as it was discovered.
The design document was distributed more heavily amongst Melissa and Christian, though Gaetano and Ian worked on portions as well. The document was looked over by everyone equally to ensure its validity and correctness.

The test plan was completed mainly by Ian and Christian. Gaetano and Melissa helped with formatting and organization. The group met together in order to certify the validity of the document and checked for spelling and grammatical errors.

**Milestone 2 Plan**

Task Matrix

<table>
<thead>
<tr>
<th>Task</th>
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<tr>
<td>Implement, test, and demo the “systems” portion of the EPLIS design for electrics, fuel, and pneumatics systems.</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
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<tr>
<td>Implement, test, and demo the “checklists” portion of the EPLIS design for electrics, fuel, and pneumatics systems.</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
<td>Complete 25%</td>
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</table>
Discussion

- **Task 1:** Implement, test, and demo the “systems” portion of the EPLI design for electrics, fuel, and pneumatics systems.
  - In this task, the Systems information for electrics, fuel, and pneumatics systems will be added to the EPLI application. A “Systems” button will be placed on the home page, which will lead the user to options between Overhead Systems, Instrument Panel Systems, and Center Console Systems. Each of these choices leads the user to an image corresponding to that section of the plane. Sections of these images can then be clicked on to bring up information about the corresponding part of the plane. In milestone 2, this functionality will be added.

- **Task 2:** Implement, test, and demo the “alerts” portion of the EPLI design for electrics, fuel, and pneumatics systems.
  - In this task, the Alerts information for electrics, fuel, and pneumatics systems will be added to the EPLI application. An “Alerts” button will be placed on the home page, which will lead the user to an image of the plane. Different sections of this image can be clicked to see the specific alerts for each section of the plane. In milestone 2, this functionality will be added.

**Sponsor feedback on each task for the current Milestone**

<table>
<thead>
<tr>
<th>Compare and select technical tools:</th>
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<td>Compare and select collaboration tools for software development,</td>
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documents/presentations, communication, task calendar:

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<th>Create Requirement Document:</th>
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<th>Create Test Plan:</th>
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Sponsor Signature: _______________________________ Date: __________

**Sponsor Evaluation**

Sponsor: detach and return this page to Dr. Shoaff

Score (0-10) for each member: circle a score (or circle two adjacent scores for .25 or write down a real number between 0 and 10)

<table>
<thead>
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<th>Gaetano Saltalamacchia</th>
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<td>Ian Dillon</td>
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Sponsor Signature: _______________________________ Date: __________
Appendix E
IRB Exempt Review Form

Notice of Exempt Review Status
Certificate of Clearance for Human Participants Research

Principal Investigator: De Vere Michael Kiss
Date: July 17, 2018
IRB Number: 18-112
Study Title: Enhanced pilot learning interface

Your research protocol was reviewed and approved by the IRB Chairperson. Per federal regulations, 45 CFR 46.101, your study has been determined to be minimal risk for human subjects and exempt from 45 CFR46 federal regulations. The Exempt determination is valid indefinitely. Substantive changes to the approved exempt research must be requested and approved prior to their initiation. Investigators may request proposed changes by submitting a Revision Request form found on the IRB website.

Acceptance of this study is based on your agreement to abide by the policies and procedures of Florida Institute of Technology’s Human Research Protection Program (http://web2.fiu.edu/crm/hrp) and does not replace any other approvals that may be required.

All data, which may include signed consent form documents, must be retained in a secure location for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Access to data is limited to authorized individuals listed as key study personnel.

The category for which exempt status has been determined for this protocol is as follows:

2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior so long as confidentiality is maintained.
   a. Information is recorded in such a manner that the subject cannot be identified, directly or through identifiers linked to the participant and/or
   b. Subject’s responses, if know outside the research would not reasonably place the subject at risk of criminal or civil liability or be damaging to the subject’s financial standing, employability, or reputation.
Appendix F
EPLI Interactive Examples

Intentionally Left Blank
ALERTS
Wing-body Overheat Light
CHECKLISTS/FLOWS
Normal Before Takeoff Checklist/Flow
CHECKLISTS/FLOWS
Abnormal SOURCE OFF Checklist
CHECKLISTS/FLOWS
Emergency Engine Fire/Severe Damage/Separation
Checklist
CHECKLIST SWITCHING
Before Takeoff to APU FIRE

APU Fire Warning

NORMAL OPS

SAFETY and POWER ON
ORIGINATE/RECEIVE
BEFORE START
AFTER ENGINE START
BEFORE TAKEOFF
AFTER TAKEOFF

AFTER LANDING
PRELIMINARY LANDING
LANDING
PARKING & SECURING
CLEAR
FLASHCARDS
Memory Items: Rapid Decompression

EMERGENCY CHECKLISTS FLASHCARDS

Question

Answer

1. Degaus sieve on 100%
2. Over communications establish
3. Pressure mode select to manual
4. Outflow valve close
LIMITATIONS
MAX N1 RPM
## PERFORMANCE

- 250 KIAS CRUISE - GEAR DOWN - ALL ENGINES - AC AUTO
- ALTITUDE CAPABILITY - GEAR DOWN - 250 KIAS CRUISE
- ALTITUDE CAPABILITY - Landing Range & Climb & Mach
- CLIMB & CRUISE
- DETERMINING TRUE OUTSIDE TEMPERATURE
- DISENT, LANDING, & TAKES
- DISENT / ENGINE INOPERATIVE
- DISENT / ONE ENGINE INOPERATIVE
- ENGINE OUT NET DISENT DATA
- ENGINE OUT / NET DISENT DATA
- IN ROUTE CLIMB CHARTS
- FLIGHT PLANNING FACTORS

### PERFORMANCE CHARTS

- 50% CHARTS

### LIMITATIONS

- NORMAL OPER. PROCED.
- SYSTEMS DESCRIPTORS
- SYSTEMS SCHEMATIC

### FLIGHT GUIDANCE

- CHECKLISTS & FLOWS

### ALERTS

- FLASHCARDS
NORM OPER PROCEDS

PROcedures

- After Landing
- After Takeoff
- Aircraft Tire Hydroplaning
- Before Start
- Before Takeoff
- Braking Action
- Checklist Amplification
- Climb
- Cold Weather Operations
- Cruise
- Descent
- Engine Starting
- Final Landing
SYSTEM DESCRIPTORS
Galley Power Switch
GALLEY POWER SWITCH:
ON: Electrical power is provided to the galleys. Galley power is available only when both transfer buses on.
OFF: No electrical power is supplied to the galley.
Note: Galley power is automatically disconnected if APU gen output is > 167 amps when the AC is on the ground.
SYSTEMS EXPANDED
MIX MANIFOLD & Duct Overheat Abnormal Checklist

AIR CONDITIONING & PRESSURIZATION

GENERAL
Cabin ventilation and flight station temperature are controlled via aircraft air conditioning system. Air conditioned ground source feeds air conditioning system via right manifold. Engine or APU bleed air or an air conditioning ground source blower is a separate, parallel source of conditioning air.

The left pack feeds flight station. The right pack and engine left pack air from ventilation system is mixed in the right manifold and feeds passenger cabin.

Two Recorders Air Conditioning Control and Recorders System which maintains proper ventilation and air economy via bleed air use. The recirculation system recycles and filters air from the aircraft cabin and returns to the aircraft engines where in a manner with fresh conditioned air supplied by packs.

Two packs use separate temperature sensors and two packs temperature sensors. Pack temperature control is adjustable.

The Control Cabin (right station) Temperature Selector controls outlet temperature of the left pack via the air mixer.

The Passenger Cabin Temperature Selector and Cabin Temperature Sensor control the right pack outlet temperature via the air mixer.

Because engine left air pack is mixed with air from right pack within manifold, changing pack outlet temperature of left pack (via Control Cabin Temperature Selector) will also change outlet temperature of right pack, thus maintaining consistent passenger cabin temperature.

BASIC AIR SUPPLY
The basic supply control flow of bleed air to the air conditioning packs.

Single pack operation can maintain pressurization and adequate temperature throughout aircraft.

Two-pack operation from a single engine bleed air source is not recommended (excessive bleed requirements).
SYSTEMS SCHEMATICS
Pressurization & Associated OFF SKED DESCENT Checklist
Appendix G
EPLI Testing Schedule

GREEN: Testing Completed
AMBER: Testing to be completed
RED: No show
PURPLE: Weekends, I will test on weekends

AUGUST:
1. RS PREP/DISS
2. RS PREP/DISS
3. RS PREP/DISS
4. OFF
5. OFF
6. RS PREP/DISS
7. RS PREP/DISS
8. RS PREP/DISS
9. RS PREP/DISS
10. RS PREP/DISS/OGP
11. Open
12. Open
13. RS PREP/DISS
14. RS PREP/DISS
15. RS PREP/DISS
16. Fred B (10:00), Pete D (14:00)
17. RS PREP/DISS
18. Open
19. Elizabeth W (13:00)
20. DISS/RS SCHED
21. Greg F (15:00)
22. Jim W (09:30)
23. Open
24. Michael M (20:00)
25. Open
26. Open
27. John W (10:00)
28. Michael Ki (18:00)
29. Pat M (10:30)
30. Shem M (15:30)

SEPTEMBER:
1. Open
2. Open
3. Tom J (10:00)
4. Pete S (15:00)
5. Software Team (12:30), Lucas (15:30)
6. Lawrence B (14:00)
7. Mike Kl (14:00)
8. Ray H. (11:00)
9. Nicole N. (11:00) (5000) Shane I (16:00)
10. Open
11. David C (15:00) (3,000)
12. Owain G (9:00), Christa R (16:00)
13. Karl B (9:00) (317), Open
14. Sam H (10:00), Margaret A (16:00) (580)
15. Kevin W (14:00)
16. Greg H (9:00) Paul P (14:00)
17. Ken Do (16:00)
18. Dillion J (09:00), Kenny Di (18:00)
19. Nick J. (9:00),
20. Steve C (7:00), Hayden F (14:00),
21. Anfernee E (08:00), Roland (16:00)
22. Open
23. Open
24. Tim A (10:00), David W (14:00)
25. Ed W (9:00), Erik H (14:00)
26. Ray M (13:00)
27. TESTING COMPLETE
Appendix H

Assessment methods forms

RS Number:

_______________________

ORAL CONSENT FORM: Statement of Research Purposes
Title of Project: Enhanced Pilot Learning Interface

Principal Investigator: De Vere Michael Kiss, College of Engineering and Sciences, HCD
Florida Institute of Technology 150 University Avenue, Melbourne, FL 32901

Explanation of Research Project: I am conducting a research project as a Ph.D. Candidate for the Department of Human Centered Design, College of Engineering and Sciences, Florida Institute of Technology in Melbourne, FL. The name of the research project is “Enhanced Pilot Learning Interface.” The purpose of the study is to compare a user (a pilot in this case) navigating an enhanced device (The Enhanced Pilot Learning Interface (EPLI) and navigating current information finding methods, i.e., paper aircraft manuals and digital aircraft manuals. The research question is: How does EPLI compare to current aircraft system information methodologies in relation for a user acquiring specific information in a specific period of time?

You have been chosen as a potential research subject because your expertise will help define the overall applicability of this enhanced artifact to the airline/aviation training industry. You will receive no monetary benefit from being part of this study. However, because EPLI integrates a mental model of an experienced airline pilot, novice research subjects will benefit from interacting with a new tool that can enhance their learning. If you are a professional airline pilot research subject, you will be exposed to a new and enhanced tool which may help you more easily learn aircraft systems and enhance your knowledge base. Moreover, you will contribute in the development of a new artifact which may improve professional and novice pilot training. Finally, if EPLI proves to be successful, it could garner a new and more efficient way for users to learn important information about Life Critical Systems. This could lower risk, improve safety, reduce costs, enhance efficiencies, and make learning more enjoyable. Testing will require about 3 hours of your time.
EPLI testing will involve the following stages

Stage A1: You will be presented with the different types of current knowledge transference methods, i.e., paper and digital. Lecture, discussion, and physical manipulation of the learning aids and how to navigate within them.

Stage A2: Specific system search scenarios will be described to you, and the simulation will begin. The time required for you to accomplish the scenarios will be measured and recorded. The difficulty or ease of performing the scenarios will also be observed.

Stage B1: After stages A1 and A2 are complete, you will receive instruction on how to navigate the EPLI device.

Stage B2: Once the EPLI demonstration is completed, again, you will be given specific system search scenarios and the EPLI simulation will begin. The time required to accomplish the EPLI scenarios will also be measured and recorded. The difficulty or ease of performing the scenarios with EPLI will also be observed.

Additionally, to improve the overall quality of the interface, a summation evaluation will be presented to you. This will be accomplished by asking you about potential improvements that could enhance the device.

I will be observing and recording the time it takes you to accomplish the specific tasks.

Your name will remain confidential. Your name, age, sex, race, and other personal information is not needed for the study. As a result, no personal information will be recorded. Therefore, confidentiality and privacy will not be endangered. Because it is important for the study, we will need to record certain qualifications: i.e., certificates you hold, ratings, flight Hours, aircraft flown, and other relative qualifications engendering your experience levels. Certificate numbers will not be needed. This means that while we may publish and share your qualifications and experience information, your name and identity will be not be published. You can stop being a part of the study at any time. Your participation in this study is voluntary. There is no compensation made for your participation in the study. If you wish not to be a part of this study, please inform us so.

Do you have any questions about the project?

If you want to talk to anyone about this research project, I am leaving you the contact information of the principal investigator for this study. [ACTION: A flyer stating the researcher’s name, affiliation, address, telephone and fax numbers, and email address will be provided at this time.]

Do you agree to be in this study?
Please circle: YES or NO

If NO, could you please give a brief description why:

_______________________________________________________________

If YES, thank you for your agreement in participating in this study.

__________________________                          ________________________
Participant’s Name                                                Participant’s Signature

__________________________                          ________________________
Investigator                                                        Signature of Investigator

__________________________
Date and Time
HITLS SCENARIOS Single Question Form A

RS Number: _______________________

DATE: _______________________

1. ALERTS
   a. Electrical: What does the amber SOURCE OFF light indicate?

2. CHECK LISTS
   b. Normal: Find the normal DESCENT checklist.
   c. Abnormal: Find the associated abnormal checklist for the amber fuel FILTER BYPASS light.

3. LIMITATIONS
   a. FUEL: What is the maximum fuel temperature?

4. SYSTEMS DESCRIPTORS (POP UPS)
   b. Electrical: What does the amber electrical TR UNIT light indicate when it is illuminated?

5. SYSTEMS EXPANDED
   c. Find the location of the ENGINE START VALVE description in the AIR SYSTEMS section.

6. SYSTEMS SCHEMATICS
   d. Find the AIR CONDITIONING schematic.
HITLS SCENARIOS Single Question Form B

RS Number: ______________________
DATE: ______________________

1. ALERTS
   a. Pneumatics: What does the amber WING-BODY OVERHEAT light indicate?

2. CHECK LISTS
   a. Normal: Find the normal BEFORE START CHECKLIST
   b. Abnormal: Find the associated abnormal checklist for the electrical SOURCE OFF light.
   c. Emergency: Find the associated emergency checklist for an engine overheat condition.

3. LIMITATIONS:
   a. What is the MAX TAKEOFF WEIGHT?

4. SYSTEMS DESCRIPTORS (POP UPS)
   a. Fuel: What does the blue crossfeed VALVE CLOSED light indicate when it is illuminated bright?

5. SYSTEMS EXPANDED
   a. Find how many AC sources of AC power exist in the Electrical System section.

6. SYSTEMS SCHEMATICS
   a. Find the BLEED AIR SYSTEM schematic.
HITLS SCENARIOS Single Question Form C

RS Number: ____________________

DATE: _________________________

1. ALERTS
   a. Fuel: What does the Blue SPAR VALVE CLOSE light indicate?

2. CHECK LISTS
   a. Abnormal: Find the associated abnormal checklist for the amber pneumatic WING-BODY overheat light
   b. Emergency: Find the associated emergency checklist for an ENG FIRE/SEVERE DAMAGE/SEPERATION condition.
   c. Normal: Find the normal LANDING checklist.

3. LIMITATIONS
   a. Electrical: What is the minimum IDG oil pressure?

4. SYSTEMS DESCRIPTORS (POP UPS)
   a. Air Systems: What does the ISOLATION VALVE switch do when selected to AUTO?

5. SYSTEMS EXPANDED
   a. Find the COOLING CYCLE description in the Air Conditioning section.

6. SYSTEMS SCHEMATICS
   a. Find the ELECTRICAL SYSTEM schematic.
EPLI 737 EXAMINATION A

RS Number: _____________________
DATE: __________________________

1. What is the maximum taxi weight of the 737? ____________________________

2. What are the memory items for the SMOKE or FUMES REMOVAL checklist?
   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________

3. What is the maximum gear extension Speed? ____________________________

4. What is the Maximum Cabin Differential Pressure (SYS Relief)? ______________

5. What is the maximum speed with flaps selected to 15? ______________________

6. What is the maximum demonstrated crosswind? ____________________________

7. What is the maximum operating altitude? ____________________________

8. Under normal conditions, what powers the AC Standby Bus? ________________

9. What is the fuel capacity of the center tank? ____________________________

10. The left pack of the air conditioning systems feeds? ________________________
EPLI 737 EXAMINATION B

RS Number: _____________________
DATE: __________________________

1. What is the maximum takeoff weight of the 737?
   ____________________________________

2. What are the memory items for the DUAL ENGINE FLAMEOUT/ LOSS OF THRUST on BOTH ENGINES checklist?
   ____________________________________
   ____________________________________
   ____________________________________
   ____________________________________
   ____________________________________

3. What is the maximum gear extended speed? _____________________________

4. What is the Maximum Flap Extension Altitude? _____________________________

5. What is the alternate power source for the AC Standby Bus? _________________

6. What is the maximum CATII crosswind? _____________________________

7. What is the maximum takeoff/landing altitude? _____________________________

8. Which cargo area is heated and can carry live animals? _________________

9. What is the maximum speed with flaps selected to 10? _____________________________

10. What does the amber BAT DISCHARGE light indicate when illuminated?
   ____________________________________
EPLI 737 EXAMINATION C

RS Number: _____________________
DATE: __________________________

1. What is the maximum gross landing weight of the 737? ___________________________________

2. What are the memory items for the APU FIRE checklist?
   ______________________________________
   ______________________________________
   ______________________________________

3. What is the maximum gear retraction speed? __________________________

4. What is the maximum takeoff/landing altitude? __________________________

5. What is the maximum speed with flaps selected to 30? ______________________

6. What does the amber OFF SCHED DESCENT (PRESS) light indicate?
   ______________________________________

7. How may transformer rectifiers (TRs) exist in the electrical system? ____________

8. What is the fuel capacity of the No. 1 (left) main tank? ______________________

9. What conditions will cause the AUTO FAIL (PRESS) light to illuminate?
   ______________________________________
   ______________________________________
   ______________________________________

10. What is the maximum takeoff and landing tail wind? _________________________
**System Usability Scale**

**EPLI USABILITY SCALE**

<table>
<thead>
<tr>
<th>RS Number:</th>
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<tbody>
<tr>
<td>1. I think I would like to use this system frequently.</td>
<td>![Rating Scale]</td>
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<tr>
<td>2. I found the system unnecessarily complex.</td>
<td>![Rating Scale]</td>
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<tr>
<td>3. I thought the system was easy to use.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>4. I think I would need the support of a technical person to be able to use the system.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>5. I found the various functions in the system were well integrated.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>6. I thought there was too much inconsistency in this system.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>7. I would imagine that most people would learn to use this system very quickly.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>8. I found this system very cumbersome to use.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>9. I felt very confident using this system.</td>
<td>![Rating Scale]</td>
</tr>
<tr>
<td>10. I needed to learn a lot of things before I could get going with this system.</td>
<td>![Rating Scale]</td>
</tr>
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Comments:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
# NASA-TLX

## EPLI NASA-TLX

**RS Number:**

**Date:**

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<thead>
<tr>
<th>Title</th>
<th>Endpoints</th>
<th>Definitions</th>
</tr>
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<tr>
<td>MENTAL DEMAND</td>
<td>LOW/HIGH</td>
<td>How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? I.e., was the task easy or demanding, simple or complex, exacting or forgiving?</td>
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<tr>
<td>VISUAL DEMAND</td>
<td>LOW/HIGH</td>
<td>How much visual activity was required to process the visual scene (Clustering effects, visual cues, relative size, etc.)</td>
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<tr>
<td>PHYSICAL DEMAND</td>
<td>LOW/HIGH</td>
<td>How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, sack or strenuous, restful or laborious?</td>
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<tr>
<td>TEMPORAL DEMAND</td>
<td>LOW/HIGH</td>
<td>How much time pressure did you feel due to rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?</td>
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<tr>
<td>EFFORT</td>
<td>LOW/HIGH</td>
<td>How hard did you have to work (mentally and physically) to accomplish your level of performance?</td>
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<tr>
<td>PERFORMANCE</td>
<td>POOR/GOOD</td>
<td>How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?</td>
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<tr>
<td>FRUSTRATION LEVEL</td>
<td>LOW/HIGH</td>
<td>How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?</td>
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</tbody>
</table>
CC SART

- Natural
- Automatic
- Intuitive
- Associated

- Confusing
- Contradictory

- Strange
- Unusual

High
Low
Level of processing
Ease of reasoning
Activation of knowledge

FAST
SLOW
FAST
SLOW

Analytic
Considered
Conceptual
Abstract
Straightforward
Understandable

Recognizable
Familiar
Research Subject Questionnaire

RS Number: _____________________
DATE: __________________________

1. Age: _________________________

2. Certificates (Circle all that apply):
   a. Private
   b. Commercial
   c. Instrument
   d. Multi-engine
   e. Instructor (CFI, CFII, or MEI)/ (Airline Instructor)
   f. ATP

3. Type Ratings:

   ____________________________________________
   ____________________________________________

4. Approximate Total Flight Hours: _____________________________

5. Education (Circle all that apply):
   a. High School
   b. AA/AS
   c. BA/BS
   d. MA/MBA/MS
   e. Ed.D./J.D./Ph.D.
Appendix I

Quantitative Assessment methods results

Note: The overall evaluation was designed to formulate rather than to statistically validate; and was developed as an investigative perspective.

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Appendix J
Qualitative Assessment methods results

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