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by

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Problem Statement

In a modern global economy, transportation of passengers and goods over long distances is critical to an individual nation's success. Although rail and shipping can meet this transportation requirement, in a time critical environment aviation provides the most effective and efficient method for movement. The aviation workforce is recognizably crucial to participation in the global economy. According to Fassinger (2008), "A strong workforce … is critical to the continued economic leadership of the United States in an increasingly competitive global marketplace" (p. 253).

A number of researchers have recognized the need for an increase in the number of female pilots in order to facilitate continuation and growth of the aviation industry. According to Turney and Maxtant (2004), "[g]iven the need for a highly technically skilled workforce, the aviation industry seeks to attract and retain the best and brightest talent for its future and growth. And that of necessity means drawing from a diverse talent pool" (p. 5). Fassinger (2008) claimed that, "the strength of the workforce depends on the full utilization of the talents, abilities, and perspective of diverse workers… Research indicates that diversity can be highly effective in workplace tasks requiring innovation and exploration of new opportunities and ideas" (p. 253). Diversity in a workforce can involve member development from traditionally under-represented groups; in the aviation industry, these groups include (but are not limited to) women and minorities. Fassinger (2008) implied that integrating these groups would increase the breadth of ideas for ways to improve work processes and new product development. According to a 2005 United States Department of Education report, Congressional leaders supported investigating how to increase women's employment in civilian aviation jobs, specifically as pilots (as cited in Ison, 2009). A perhaps unanticipated consequence of this increase in access for women was the possibility that cockpits typically designed for male physiology might not accommodate female physiology.

This design project examined female pilots' experiences with how well or poorly cockpit design allowed them to safely accomplish their flying missions. The general aviation (GA) aircraft cockpit is not designed for female pilots, often causing them to find ways to adapt to the cockpit in order to operate the aircraft safely. Two primary focal areas for adaptations address issues with accessibility of controls and "viewability" inside and outside the cockpit. The design team used a Situation Awareness-Oriented Interface Design (SAOD) approach in preparing cockpit design recommendations for general aviation (GA) aircraft that would accommodate female pilots.

The Federal Aviation Administration (FAA, 2014) recently published a report identifying the estimated number of active GA aircraft in the United States along with projections for aircraft numbers through 2034. Table 1 shows a comparison between the historical numbers from 2000 with estimated numbers for 2013 and forecast numbers for 2034. While single-engine and multi-engine piston aircraft are expected to continue a decline in numbers, turbo-prop and turbo-jet fixed-wing aircraft, as well as piston and turbine rotorcraft are expected to increase in numbers. The decline in numbers of piston aircraft presents opportunities to design upgrades that cater to a larger population of pilots. Similarly, the increases in turbine fixed-wing and rotorcraft (piston and turbine models) create opportunities for new design features that can be marketed to a larger population of pilots, and upgrade opportunities for existing models. Turbine fixed-wing and rotorcraft are typically associated with business operations. Combining these aircraft opportunities with a focus on improved cockpit design for female pilots, as well as smaller-statured male pilots, supports a goal to increase the number of female pilots in GA and encourage a more diverse pilot population.

Table 1
Comparison of Actual, Estimated, and Forecast GA Fleet Aircraft

Aircraft Description	2000	2013 Estimated	2034	Projected Growth 2013-2034
Fixed Wing				
Single engine piston	149,422	123,730	113,975	-0.4%
Multi engine piston	21,091	14,235	12,890	-0.5%
Turbo prop	5,762	10,195	14,370	1.6%
Turbo jet	7,001	11,890	22,050	3.0%
Rotorcraft				
Piston	2,680	3,360	4,750	1.7%
Turbine	4,470	7,025	13,145	3.0%
Total GA fleet	217,533	202,865	225,700	0.5%

Note. Adapted from "Active General Aviation and Air Taxi Aircraft", Table 28, Copyright 2014 by the Federal Aviation Administration. Some aircraft categories considered not critical for business aviation are not displayed and some years, both actual and forecast, have also been omitted.

Review of Literature

A distinct lack of literature has investigated gender-related issues in cockpit design, especially studies focusing on pilot situation awareness. Mostly anecdotal studies of gender issues in aviation were published in the 1990s and early 2000s; significantly fewer empirical studies were published (Hynes & Puckett, 2011). In 2012, an entire issue of the *Ergonomics* journal was dedicated to articles focused on frameworks in which ergonomic intervention might be enhanced if gender-based differences in particular work activities were examined. Habib and

Messing (2012) stated that, “an understanding of gender, sex and other sources of diversity can lead to innovative and successful interventions that ensure better health for all workers” (p. 129).

Cockpit Design and Ergonomics

The cockpit is one of the primary workplaces in the aviation industry. Seminal work in anthropometric research by Morant (1955) found that six specific body measurements had the most connection with cockpit design: (1) stature; (2) sitting height; (3) arm length; (4) thigh length; (5) leg length; and (6) seat breadth. Additional work by Stewart (1955) in the same timeframe recommended standardizing cockpits in dimensions for: (1) clearance above the head; (2) degree of vision over the nose; (3) position of the sighting line; and (4) position of the instrument panel. In further studies in the 1970s (Bittner, 1976; National Aeronautics and Space Administration, 1978) and 1980s (Croney, 1981; Schafer & Bates, 1988; Schrimsher & Burke, 1989), researchers validated the conclusions found in the 1950s and investigated specific ranges of physical dimensions for males and females. Roskam (1989) described major factors in cockpit design as: (1) crew members must be in a position where they are able to reach all controls comfortably; (2) crew members must be able to see all essential flight instruments without undue effort; (3) crew members must be able to communicate by voice or touch without undue effort; and (4) crew members must have visibility outside the cockpit that meets minimum standards for safety of flight. Each of these factors is directly related to the aircraft control, direction, communication, information access, and comfort components of this project’s Goal Directed Task Analysis (GDTA) structure.

The GDTA structure provides a methodology for future research in how individual systems or equipment might be modified or re-positioned in the cockpit for better use by female pilots. Rong, Ding, and Valasek (2003) conducted a study to examine general aviation cockpit system design through an application of cognitive engineering models. They used the Aircraft Approach and Landing Assistant as an example of a general aviation system, recommending that designing ‘decision-support tools’ should incorporate how individual pilots use those tools to obtain information, process the information, and make related decisions. The researchers concluded that using models based on how pilots process and reason would provide for more effective cockpit systems than those designed in a more technology-driven approach.

In a study of vehicle interiors and office workstations, Chaffin et al. (2000) found that stature and age had more of an impact on reach motion postures than gender. They suggested that the simulation methods, models, and results of their study would enhance ergonomic design to adjust industrial workspaces and vehicle interiors for a wider range of physiologies. In a later related study, Chaffin (2007) refined the motion posture research, arguing that digital human models should incorporate valid posture and motion prediction models, based on real motion data, and combine with psychophysical and biomechanical models to more accurate prediction of human performance motion.

Gender Differences

Within the body of aviation research, investigators have approached gender differences from a variety of directions. Sweetman (1997) reported on research by the United States Air Force in designing fighter aircraft cockpits and related equipment to fit female pilots. He quoted technical directives stating that an expanding pilot population required description by, "extremes of height and weight, … [and] a range of body types that includes shortest reach with high shoulder and short limbs with short sitting height" (p. 33). He introduced McDonnell Douglas' virtual manikin, a software-generated model that simulated eye positions and body movements. Such a model could be used by designers and engineers to ensure equipment placement would allow any pilot to operate an aircraft successfully and safely. Dylewska (1994) surveyed active, civil, female pilots who held Airline Transport Pilot (ATP) certificates in the U.S., regarding anthropometric cockpit designs as they related to aircrew accommodation. The results indicated that in civil aviation, female pilots did not perceive aircrew accommodation was diminished by use of male-based anthropometric designs.

Côté (2012) examined recent literature on physical and operational differences for males and females, concentrating on elements of neck/shoulder musculoskeletal injuries. The research investigated the physiological differences with respect to work-related disorders by asking questions about how men and women deal with fatigue, pain, and stress. Côté (2012) presented her work as an initial foray into existing studies to change the viewing prism from strict examination of anthropometric and functional body characteristic comparisons to a more comprehensive approach that might consider additional explanatory variables. She made a number of recommendations for further research to expand the body of knowledge so that stakeholders could make better informed decisions about the workplace. Motamedzade and Moghimbeigi (2011) also studied the possible relationship between anthropometric dimensions and musculoskeletal symptoms, recommending certain modifications that would adjust equipment to typical body size and shape for women. These researchers actually studied female carpet weavers, but their findings applied universally to women in the workplace. One significant finding was that, "[p]oor workstation design,…, design inappropriate for the anthropometric dimensions of weavers, was a major risk factor for musculoskeletal symptoms in carpet weaving…this industry should develop equipment adapted to women's size and shapes" (p. 229). They identified issues with non-ergonomic postures based on equipment design that actually negatively affected productivity in addition to being associated with musculoskeletal problems.

Tan, Czerwinski, and Robertson (2006) examined recognized differences between males and females in visualization. They set their study in the 3-D visualization simulator environment, and investigated the differences in performance related to changes in visual displays. The researchers found that using large displays to create wider fields of view resulted in eliminating a previously identified gap between males' and females' performance. Additionally, all participants showed improvements in their performance.

Summary

Limited research in the area of gender-related aviation design concerns exists today. In particular, researchers are compelled to conduct investigations into various aspects of cockpit design for situation awareness enhancement for female pilots. The design team incorporated the literature review information with input from subject matter expert interviews while performing SAOD for female pilot-accommodated cockpit design in GA aircraft. This project will serve as a springboard for further research that will afford aircraft manufacturers opportunities to develop cockpit designs that enhance female pilots' ability to meet their flying mission requirements and ensure improved safety of flight.

Goal Directed Task Analysis (GDTA) of Female Pilots

Targeted Role

The targeted role for this project was female pilots using GA aircraft. These aircraft include single- and multi-engine fixed-wing aircraft, turbo-prop and turbo-jet aircraft, and piston and turbine rotorcraft, among others, which are used in a variety of military, government, and civil aviation capacities. As female pilots are actively engaged in all three applications, and there are increased opportunities to provide aircraft upgrades for existing aircraft and innovative solutions for new designs, the project considered how to best design the GA aircraft cockpit to enhance female pilot situation awareness. The design team used the Situation Awareness-Oriented Design (SAOD) approach (see Endsley & Jones, 2012) to identify cockpit design recommendations for GA aircraft that would accommodate female pilots.

Method

The design team gathered information from four subject matter experts (SMEs) to create a GDTA for the female pilot. All four SMEs were female pilots with varying flying and aircraft experience. The four SMEs interviewed for this project achieved significant positions in their aviation careers, reaching levels of Aircraft Commander in the Coast Guard or Captain with a major US airline. Although successful in their aviation careers, each pilot endured significant physical and emotional challenges along the way. A brief summary of each SME's background is given below along with a list of the interview questions.

Subject Matter Expert 1. SME 1 has flown propeller, helicopter, jet, and passenger aircraft during her career. Her stature is 5 feet 1.5 inches. She was trained to fly for the Coast Guard in Naval Flight School. She flew the Bell Jet Ranger (helicopter trainer) and T34C (single engine propeller driven airplane trainer) during training. Her first official assignment was the C130 cargo aircraft. She continued in the Coast Guard until reaching the position of Aircraft Commander. Later she left the Coast Guard for a commercial pilot job and flew regional jets. Her latest occupation is an acquisition and requirements manager for the Coast Guard.

Subject Matter Expert 2. SME 2 has flown propeller and helicopter aircraft during her career. Her stature is 5 feet 10 inches. She was trained to fly for the Coast Guard in Naval Flight School. She flew the Bell Jet Ranger and the T34C during training. Her main assignment was the HH-60J helicopter. She continued in the Coast Guard until reaching the position of Aircraft Commander.

Subject Matter Expert 3. SME 3 has flown propeller and helicopter aircraft during her career. Her stature is 5 feet 7 inches. She was trained to fly for the Coast Guard in Naval Flight School. She flew the Bell Jet Ranger and T34C during training. Her main assignments included the HH-60 (J and T models) and HH-65 (B and C models) helicopters. She has taken her career from student to co-pilot to Aircraft Commander, and she now is an instructor pilot and flight examiner. She is also the Commanding Officer of a Coast Guard Air Station.

Subject Matter Expert 4. SME 4 has flown numerous models of propeller, jet, and passenger aircraft during her career. Her stature is 5 feet 3 inches. She pursued flight training during college, earning private pilot through certified flight instructor and multi-engine ratings, followed by certified flight instructor – instrument and multi-engine instructor ratings. She has flown many models of Cessna and Beechcraft aircraft, among others, before moving on to passenger operations with regional airlines. Her latest position is as a Captain at Southwest Airlines.

Interview Questionnaire Summary

- Discuss the privacy statement
- Clarify the distinction that this is a design study not a research study
- Request summary of piloting experience
- Request summary of aircraft flown
- Request height information and thoughts on how this factor played into aviation experience.
- Explain what GDTA is and request thoughts on overall goal of cockpit design.
- Request thoughts on overall goal for the different aircraft flown.
- Request thoughts on sub-goals.
- Request thoughts on decisions needed for each goal and subgoal.
- Request thoughts on information required for making these decisions.
- Request thoughts on challenges encountered while obtaining information.

Results

The four SMEs were consulted during the initial GDTA interviews of female pilots related to their flight activities and the design team's interest in optimizing cockpit design for female pilots. Each SME presented information that allowed for evaluation of similarities and differences, as well as different perspectives of flight experience.

All SMEs flew propeller aircraft during their careers. Three of the four also flew helicopters and two of the four flew jet and passenger aircraft. The three pilots who flew helicopters were trained in the Coast Guard, flying the T34C and Bell Jet Ranger, before moving on to other aircraft models. The civilian pilot possessed the most experience with other models of aircraft, including many models of Cessna, Beech (Beechcraft), and Piper aircraft, as well as regional aircraft and variations of the Boeing 737.

The SMEs ranged in height from 5 feet 1.5 inches tall to 5 feet 10 inches tall. The tallest pilot reported that cockpit adjustments felt safe and comfortable. The three shorter pilots (less than 5 feet 7 inches) reported the greatest variety of challenges. These three pilots could usually overcome viewing and accessibility challenges by adjusting seat and rudder pedals to their limits. Although these SMEs were able to fly successfully, having to make accommodations to overcome challenges requires attention from the pilot, reducing her processing capacity for information, which could negatively affect her situation awareness. Additionally, one of the pilots reported that there were occasions during which she was forced to sacrifice views inside or outside of the aircraft, depending on the task at hand.

The shortest pilot provided substantial history, thoughts, and experience with specific models. Although reach and visibility were less than convenient, the greater burden was continued peer scrutiny of her strength, leg and arm reach, etc. Doubt in the commanding officer's ability to manage controls of the aircraft is not ideal for the pilot or team SA. The next shortest pilot highlighted issues with seat adjustments in Cessna aircraft, which were less of a problem when she was flying in the left seat versus instructing from the right seat.

The pilots noted that in some aircraft, the equipment layout and availability of adjustments was generally good, though not perfect. Three of the four pilots reported on these challenges. The fourth pilot – the tallest of the group – reported more difficulties with navigation and communication.

The pilots each provided goal and subgoal comments related to the common phrase, "Aviate, navigate, communicate." One pilot separated roles of pilot-in-command and supporting pilot as responsible for controlling the aircraft and ensuring safety, respectively. Another pilot noted that the act of flying itself was easy; however communication presented the greatest challenges to situation awareness.

Visibility and accessibility challenges were noted to varying extents by all SMEs. SMEs reported making adjustments to seat and rudder positions often to the extremes in order to optimize visibility and accessibility. Equipment was not always in an optimum location and, at times, lack of redundancy in equipment placed further challenges on the pilots.

Summary

Drawing from the GDTA results, the pilot's overall goal was identified as "Execute the mission safely," while fulfilling the four major goals. The GTDA goal hierarchy illustrating the overall goal and major goals is shown in Figure 1. Figures 2 through 5 provides the GDTA structure for each major goal and subgoal.

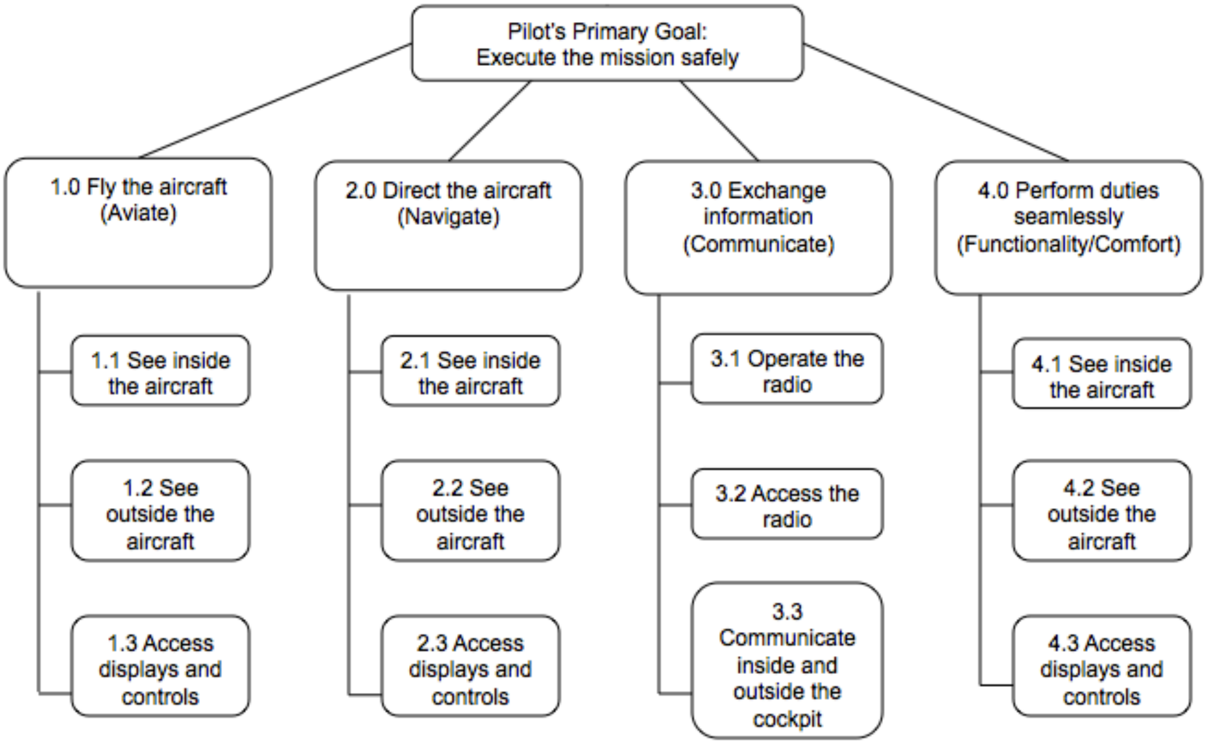

Figure 1. GDTA goal hierarchy for pilot's primary goal *Execute the mission safely*.

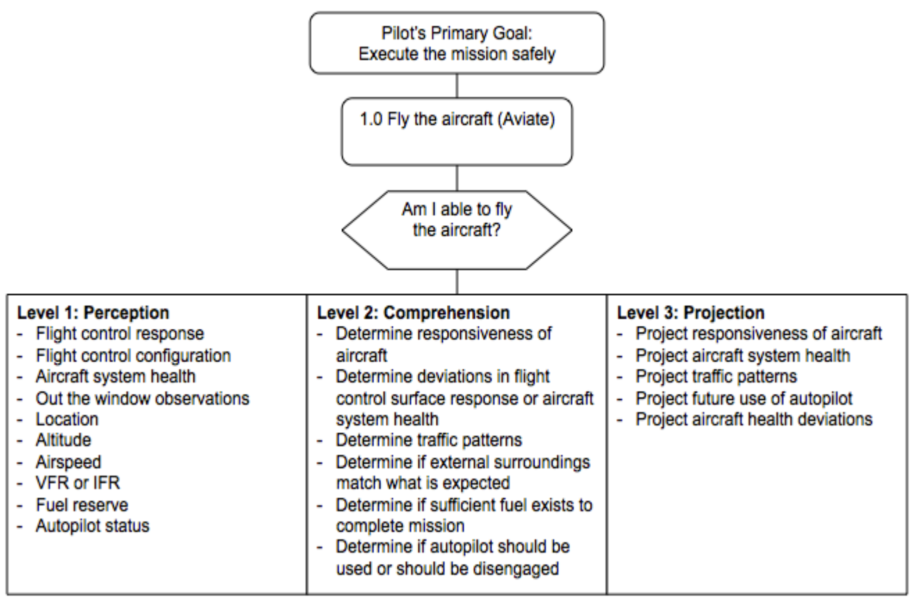

Figure 2. GDTA structure for pilot's major goal 1.0 *Fly the aircraft (Aviate)*.

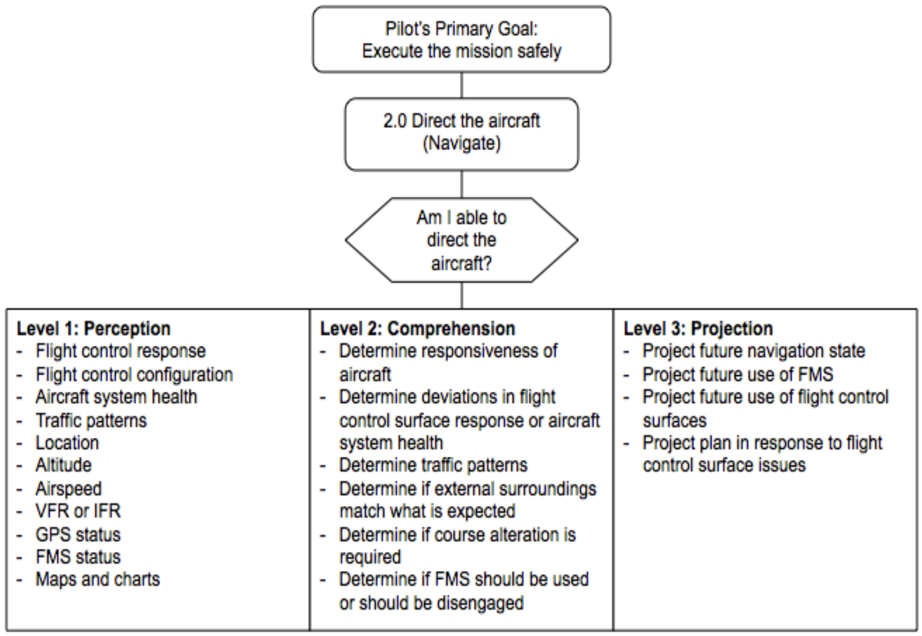

Figure 3. GDTA structure for pilot's major goal 2.0 *Direct the (Navigate)*.

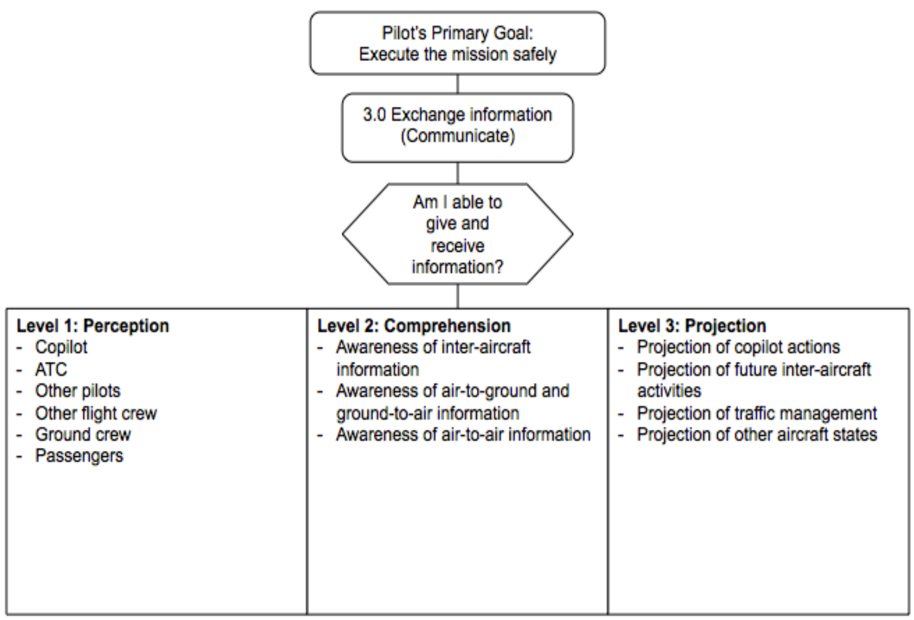

Figure 4. GDTA structure for pilot's major goal 3.0 *Exchange information (Communicate)*.

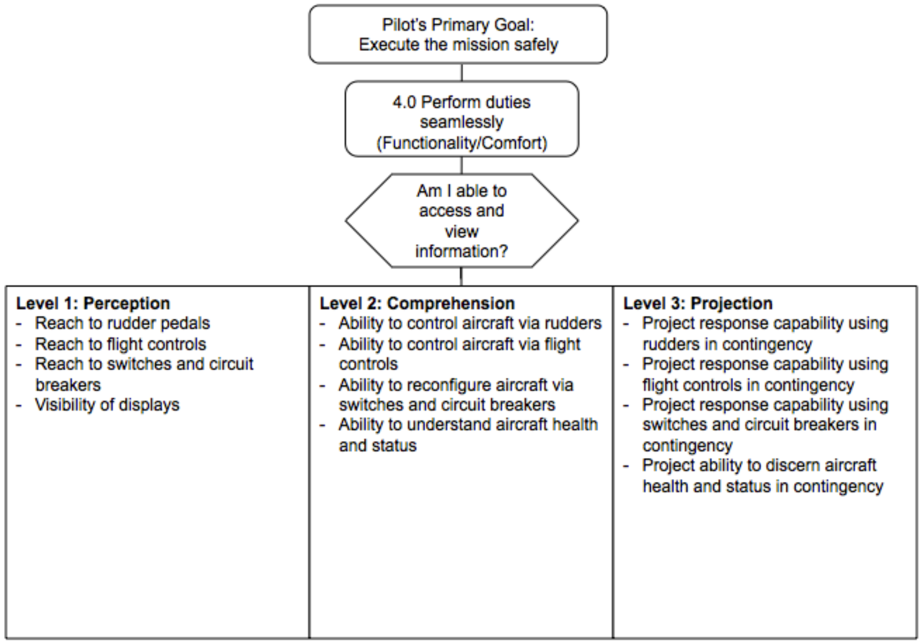

Figure 5. GDTA structure for pilot's major goal *4.0 Perform duties seamlessly (Functionality/ Comfort)*.

GDTA Applied – Design Principles

The overall design goal is to enable the user to "operate the aircraft with the highest level of Situation Awareness (SA) possible." Why is the highest level of SA possible important? Evidence suggests that good SA supports good decision-making. In turn, good decision making leads to good aviating and navigating (Goals 1.0 and 2.0, respectively). Good communication (Goal 3.0) leads to good decision making. Functionality and comfort (Goal 4.0) are not directly related to good decision-making but can influence how pilots are able to execute Goals 1.0 through 3.0. Additionally, good SA promotes safety in piloting aircraft.

Wise et al. (2010) postulated that a high SA level might be the most crucial factor in successful aviation mission completion. Salas and Maurino (2010) stated that SA serves as a primary factor in how humans participate in the safety process. Effective decisions are based on SA; appropriate procedures and automation are used when these decisions are made; recognition of conditions requiring changes to procedures or choosing manual control over automation is based on SA; appropriate team dynamics are based on SA; and the resultant knowledge-based opportunities are also dependent on SA. Enhancing a pilot's SA via user-centered cockpit design therefore contributes to the safety of each flight.

Salas and Maurino (2010) warned that lack of information as well as information overload must be avoided in the aviation system design process. Cockpit controls should be designed to optimize provision of information to pilots without creating an environment that provides so much information that it cannot be interpreted in time for effective use in safe flight. According to Stanton et al. (2001), SA research has been "closely coupled with the increase in the degree of automation in flight control" (p. 189). They referred to an earlier review, by Hartel, Smith, and Prince (1991), of over 200 military aircraft accidents in which impaired situational awareness was identified as the primary causal factor. Wise et al. (2010) described an Endsley (1995) study in which 88 percent of the major air carrier accidents investigated revealed human error was involved and that error was associated with SA problems.

The design team examined the priorities involved in flying aircraft: aviate, navigate, and communicate. While the *aviate, navigate, communicate* mantra is more commonly associated with primary goals in emergency situations, these goals are the foundation of every flight from the first day a student pilot climbs into an aircraft. To *aviate* is to maintain control of the aircraft; it relates to monitoring everything internal and external to the aircraft including flight characteristics such as airspeed and attitude and the weather conditions. In order to navigate, the pilot must maintain control of the aircraft. *Navigate* relates to the understanding of the destination of the aircraft and what route the pilot will take to get the aircraft to that location. It accounts for understanding the effect of weather conditions on path of flight, knowledge of the intended route of flight, navigational procedures, and available options. Advances in automation have made aviate and navigate nearly synonymous in certain situations (Anonymous, 2008). Lastly, *communicate* relates to the information shared with other aircraft, air traffic control, flight service, or other entities that may be involved throughout a flight.

The focus of application of this project GDTA is on aviate (Goal 1.0), as the ability to fly the aircraft ultimately affects whether a pilot can navigate or communicate. Thus, maintaining SA for aviation is key for the overall goal to execute the mission safely. Figure 2 illustrates the GDTA structure for Goal 1.0. Goal 1.0 is comprised of three subgoals: 1.1 See inside aircraft, 1.2 See outside the aircraft, and 1.3 Access displays and controls for design.

The design team researched SAOD Principles, as described in Endsley and Jones (2012) and applied them to Goal 1.0. The four principles deemed most relevant to Goal 1.0, presented in order of perceived importance, are the following:

- *Principle 47* – Provide flexibility to support shared SA across functions.
- *Principle 45* – Build a common picture to support team operations.
- *Principle 16* – Manage rampant featurism through prioritization and flexibility.
- *Principle 21* – Group information based on Level 2 and 3 requirements and goals.

Principle 47: Provide Flexibility to Support Shared SA across Functions

The principle that was most applicable to Goal 1.0 was Principle 47, provide flexibility to support shared SA across functions (Endsley & Jones, p. 215). This principle suggested cockpit design consider that even though information may be presented to each member of an aircrew, the perspective of an individual aircrew member will not always be the same as the perspectives of other crew members. Endsley and Jones (2012) state, "each team member can have different physical vantage points" (p. 215). Crew members who are small in stature may have diminished SA if their perception of information provided by cockpit equipment is reduced due to a lack of flexibility in presentation, availability, or access.

This principle addressed the issue most frequently reported in the SME interviews. Three of the four SMEs interviewed expressed concern about the distance between the rudder pedals and the seat. These three female pilots were small in stature (height at or less than 5 feet 7 inches). Each pilot had to adjust seat and/or rudder pedal positions to the extreme forward position to optimize the information they could acquire inside and outside the aircraft, as well as reach other control input points. In at least one case, a SME accepted less than optimal positions because what was optimal for one task was not optimal for another (i.e., cruise flight versus hoisting operations). When an individual pilot must choose between types of information or facets of SA due to a lack of flexibility in the aircraft design, SA is not equally shared across all aircrew functions.

In design, since each of these SMEs would have different vantage points due to their smaller stature, they needed more flexibility in the adjustments for the seat and rudder pedals with additional consideration for placement of controls on the instrument panel and around the cockpit. Previous research investigating ergonomics, anthropomorphics, and cockpit design can be utilized to identify (a) further research necessary related to the female form, (b) ergonomic situations unique to the cockpit environment, and (c) prioritization of control usage during different phases of flight. By preparing a cockpit design that better accounts for the female form, pilots will be able to focus on completing required tasks rather than making considerations for less-than-optimal cockpit conditions. They can perform tasks as equal members of an aircrew without having to expend flight and crew time making adjustments throughout a flight. It is imperative that this design principle be considered.

Principle 45: Build a Common Picture to Support Team Operations

Principle 45, build a common picture to support team operations (Endsley & Jones, 2012, p. 213), also plays a major role in cockpit design. While most GA aircraft are certified for single pilot operations, the versatility of the aircraft models and their use around the world does enable multi-pilot operations. SME 1 recommended that the design ensure both operating pilots can access the same information. This design feature would allow common SA across team members, and as Endsley and Jones (2012) stated, "to support the information needs of all the parties on the team and to insure that they are all properly coordinated and 'reading from the same page' is the critical task" (p. 213). Equally useful is the common access to the same information in the face of a contingency where one team member is debilitated and actions need to be taken by the remaining crewmember. A common picture across the team and equal access to the relevant information arms each team member with what is required to perform duties outside his/her nominal assignments should the need arise. This requirement would apply to pilots of all genders.

To ensure consideration for a common picture, multiple steps are required prior to the design phase. A list of common and/or probable operational scenarios must be developed to determine when multiple-pilot situations may occur and what information is most critical to be shared. The critical information can be assessed for priority and logical grouping to identify common picture scenarios. As the cockpit design will require elements of a flight management system (FMS) to enter and display flight information, design for this principle ties into design for Principle 47. Elements related to Principle 47 would address location of equipment relative to the pilot(s) whereas display information would be communicated to the avionics manufacturer(s) through system design requirements.

Principle 16: Manage Rampant Featurism through Prioritization and Flexibility

Principle 16, manage rampant featurism through prioritization and flexibility (Endsley & Jones, 2012, p.142), recommends cockpit design consider prominence and organization of items in the design. Principle 16 applied to information provided to the team from the interview of SME 3. SME 3 spoke about often not being able to reach a button or switch or not being able to get close enough to read the label. On the helicopter she flew, many of the buttons, switches, and circuit breakers were similar in size and shape making them hard to distinguish, especially the ones that were difficult to reach, such as a remote circuit breaker under the seat. She recommended that the size and shape of buttons and switches should be different instead of all being very similar or the same. Ensley and Jones (2012) recommended in this principle that buttons associated with less common use should be minimized and put in less prime locations. Since women's hands are smaller and often their reach is shorter, the buttons and switches could be designed to be different shapes and sizes depending on priority so that female pilots could easily identify them.

The concept of changing shapes and sizes of buttons and knobs is not new to aviation. Decker (2000) recounted the historical background of several knobs and controls that have evolved to have standard locations, sizes, and shapes. In one example, the placement of mixture, throttle, and propeller pitch control varied between aircraft serving similar mission profiles or having similar sizes. To address issues with human error, aircraft manufacturers standardized the size, shape, and color of the controls as well as the position of the controls: black throttle on the left, blue propeller pitch in the middle, and red mixture on the right.

Similarly, buttons, switches, and other controls in GA aircraft could be arranged to address priorities, with consideration given to size, shape and color. Anthropomorphic studies could again be used to address a wider range of hand sizes operating the buttons, switches, and controls, as well as arm reach and seat position to establish the most appropriate locations on the instrument panel or around the cockpit.

Principle 21: Group Information based on Level 2 and 3 Requirements and Goals

Principle 21, group information based upon Level 2 and 3 SA requirements and goals (Endsley & Jones, 2012, p. 144), suggested cockpit design group different parts of the system so that these parts can provide Level 2 and 3 SA to the pilot(s). This principle addressed grouping buttons and switches based upon SA priority. Principle 21 tied directly to another recommendation made by SME 3, consideration for location of buttons and switches needs to be carefully planned. Buttons and switches should be positioned so that important (emergency) buttons and switches are not located next to something that is used frequently, such as placing an emergency switch next to the windshield wipers. Consideration of this SA feature is also critical for women's smaller hands and limited reach capability. Implementing this feature allows smaller pilots to easily reach for frequently used items without accidentally activating an emergency button or switch in the process.

The Human Factors (HF) Website (Federal Aviation Administration, n.d.) provided an overview of display design considerations in the Visual Displays module. One design requirement, in particular, tied with Principle 21; it stated that a display must be "detected by the sensory system for which it is designed" (Overview, para. 3). The use of colors such as red, amber, and green is becoming more standardized in general aviation, based on influence from transport aircraft. Similarly, symbology and text characteristics used with buttons, switches, and related annunciations could be reviewed and modified in support of improved situation awareness.

Summary

Cockpit design influences pilot SA. When the design returns focus to the higher level goals of every pilot – aviate, navigate, communicate – the result is a better balance of information provided to the pilot and flight crew, with fewer compromises that affect SA. This design project considered how cockpit design influences female pilot execution of the main goal to safely complete a mission.

From the SME interviews, data suggested that "viewability" and display/control access must be addressed to enhance female pilot SA. The SAOD approach supports development of recommendations for redesign of GA aircraft cockpits to better accommodate female pilots. Through the GDTA process and in-depth analysis of Goal 1.0 (fly the aircraft – aviate), cockpit design should be modified to address Principles 16, 21, 45, and 47, as described in Endsley and Jones (2012). With the application of these principles, the cockpit design would provide adequate organization of features to prevent inadvertent use of the wrong functions, reduce the need to search for information that supports Level 2 and Level 3 SA, deliver more consistent information for all crewmembers to provide a common picture, and present appropriate information for each crew member function.

Conclusion

The design team applied the SAOD process to examine cockpit design as it related to female pilots' experiences with safely accomplishing their flying missions. The team was motivated by a recognized need for diversity among pilots and opportunities present within the aging and new aircraft fleets for improved cockpit design. Adaptations focused on issues with accessibility of controls and viewability inside and outside the cockpit.

A literature review demonstrated minimal presence of research focused on gender-related issues in cockpit design, including studies related to situation awareness. Research that had been completed tended to be dated, with most studies of the female form in the cockpits of military aircraft dating to the late 1990s. Earlier studies focused on female ATP certificated pilots, with the conclusion that no gender-related issues were present in cockpit design. More recent research identified poor workplace design as a factor in musculoskeletal symptoms in women and decreased productivity, though the research was conducted in a non-aviation environment. Additionally, recent research concluded that increasing a pilot's field-of -view in the cockpit eliminated performance differences between males and females, suggesting that more traditional designs are insufficient for both genders.

The GDTA involved SME interviews with four accomplished female pilots who possessed varying flying and aircraft experience. With an emphasis on achieving the highest level of situation awareness possible to facilitate the pilot's ability to execute the mission safely, three major goals - fly the aircraft, direct the aircraft, and exchange information - were identified. Through the interviews, accessibility challenges and visibility were noted with varying degrees of significance, motivating the decision to pursue adaptations related to accessibility of controls and viewability, both inside and outside the cockpit.

Application of GDTA focused on one of the major goals, fly the aircraft (or aviate). Four SAOD Principles were closely associated with the application of GDTA to the major goal, fly the aircraft. Principle 47, provide flexibility to support shared SA across functions, supported the conclusion that previous research investigating ergonomics, anthropomorphics, and cockpit design could be used to improve seat and control input adjustments to improve cockpit design for a greater population of pilots. Principle 45, build a common picture to support team operations, suggested the redesign effort for GA cockpits should also accommodate team flight scenarios. Although GA aircraft are typically certified for single-pilot operations in the United States, their use around the world requires consideration of a team environment. Design emphasis for Principle 45 related to Principle 47 in ensuring seat and control input adjustments function equivalently for all anticipated users of the system. Principle 16, manage rampant featurism through prioritization and flexibility, endorsed redesign efforts that focus on location, size, and shape of buttons and switches, accommodating shape of the hands using the buttons and switches, as well as attention to color, size, shape, and location of the of the buttons and switches relative to priority and use. Finally, Principle 21, group information based on level 2 and 3 requirements and goals, further addressed priority and location of buttons and switches, as well as color, symbology and text characteristics to improve situation awareness.

Implications for Future Research

One of the greatest weaknesses uncovered during the design project involved the lack of prior research related to gender issues and cockpit design, as well as the implications for situation awareness. The research explored during the design project addressed elements of design considerations, however their significance was often limited and most of the research was dated. Future research opportunities may include: gender issues and situation awareness in mission-critical applications, such as medical or search-and-rescue; anthropomorphic considerations for the current population of pilots; the effect of poor cockpit design on retention of female pilots in GA; and the effect of poor cockpit design on career choices for female pilots in GA. Additional research opportunities are available in replicating studies accomplished in previous decades to examine any differences or changes that might provide new insight to gender issues in aviation. The list of future research opportunities is not exhaustive, however, it provides an indication of research paths that could be taken in light of the underrepresentation of gender issues and cockpit design in GA.

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