EVALUATING UAV GROUND CONTROL STATION DESIGN USING AVAILABLE HUMAN FACTORS GUIDELINES AND STANDARDS

T. Amida (a), J. Chung (a), S. Roy (b), E. Simon (b)
(a) Ryerson University, Department of Aerospace Engineering, MIMS Laboratory http://www.ryerson.ca/~j3chung/
(b) Presagis Canada Inc.

A comprehensive set of human factors guidelines and standards regarding unmanned aerial vehicles (UAV) ground control station (GCS) design have been published by numerous standard organizations such as FAA, NASA and military agencies. However, designers of GCS have found it difficult integrating all these standards into their design due to the difficulty in locating the specific document applicable to their work. As a result, most GCS designers only focus on factors such as past design trend and pilot workload evaluation results. In addition to this, unlike conventional aircraft cockpit designers, the GCS designers do not necessarily have to follow a specific set of rules in terms of concept and technology to use; some organizations have even started exploring building their control stations using virtual reality and augmented reality devices such as the Oculus Rift, Microsoft Hololens etc. These flexibilities and freedom are the main reason behind the recent exponential growth of the GCS design. However, they also pose a huge challenge in terms of integrating the human factors standards.

This research work focused on creating a human factors compliant design and evaluation (HFCDE) that can be used to design and evaluate a GCS based on the degree at which the designer followed the applicable human factors guidelines and standards available. The first stage of the research concentrated on designing and evaluating a new GCS built using commercial off the shelf software. In order to create a relationship between the HFCDE and NASA task load result, the research endeavored to achieve a high HFCDE for the GCS. The second stage focused on comparing the GCS built using the HFCDE to existing GCS with similar attributes. Finally, we checked if the HFCDE result affects the pilot workload result.

Introduction

Unmanned Aerial Vehicles (UAVs) are powered, fixed or rotary-wing aircraft without an on-board human pilot. They can be autonomous, semi-autonomous, remotely controlled or have a combination of these capabilities. They can be used for a wide variety of civilian and military applications such as weather monitoring, forest fire detection, traffic control, cargo transport, emergency search and rescue, communication relaying, etc. In addition, UAVs can be equipped with various types of sensors and payloads, making them acceptable for performing specific tasks which are normally considered dangerous for human piloted aircraft [1]. The pilot of a manned aircraft is usually located on-board while controlling the aircraft while the pilot of UAV controls the aircraft remotely using a simple controller or an advanced Ground Control Station (GCS) linked to the aircraft via applicable communication links.

This research paper demonstrates how a UAV GCS can be designed and evaluated using available human factors standards and guidelines.

The research is part of the Presagis Canada Inc. project of creating a GCS for Roy Aircraft & Avionic Simulation Inc. (RAAS) for a tandem UAV. Presagis Canada Inc. is a global provider of software for the development of modeling, simulation, visualization, and embedded display applications. The whole work was performed while the researcher was working as an intern at Presagis Canada Inc. Therefore, the final product belongs to Presagis Canada Inc.

Research Objectives

The Objective of the research is to design and evaluate UAV GCS using available human factors standards and guidelines.

- Take into consideration all the applicable human factors standards and guidelines to ensure optimum human factors integration

- Improve the concept of the existing reconfigurable GCS designed at the Ryerson University's Mixed Immersive motion Simulation (MIMS) laboratory
- Integrate modern technology such as the multi-touch gesture into the GCS design
- Evaluate our methodology

Human Factors and Human-Centered Design

The term-human factors (or ergonomics) can be clearly defined as a scientific multidisciplinary field that deals with understanding the interaction between humans and all other elements present in a system by applying theory, principles, data and methods to design in order to improve system safety, human well-being and overall system performance [2]. Especially in aviation, human well-being has not always been the priority. During the World War I for example, high number of causalities among pilots were recorded and majority of these deaths were not caused by combat but human factors issues in the design of the airplane in general. Issues such as: physiological stresses on the pilots were a major problem, and thorough design of the equipment to ensure mission effectiveness and safety were completely missing [3]. However, during the World War II, despite the unimaginable advancement in technology, greater emphasis was put in studying human capabilities and limitations. Numerous guidelines for the design of displays, controls, environmental systems, equipment, and communication systems were developed, which brought about the start of human factors as part of design requirements of any system.

After the war era, Human factors became increasingly popular in military and commercial aviation. This happened after the industry realized that most accidents happen due to human negligence and error rather than mechanical failure [4]. It was recorded that majority of all manned aircraft accidents causes can be traced back to human factors issues. Similarly, same issues were also being encountered in the realm of unmanned aircrafts. About 67% of UAV accidents can also be directly or indirectly related to human factors issues [5]. Moreover, about 24% of these accidents can be attributed to specific human factors issues in the GCS and interface design [6].

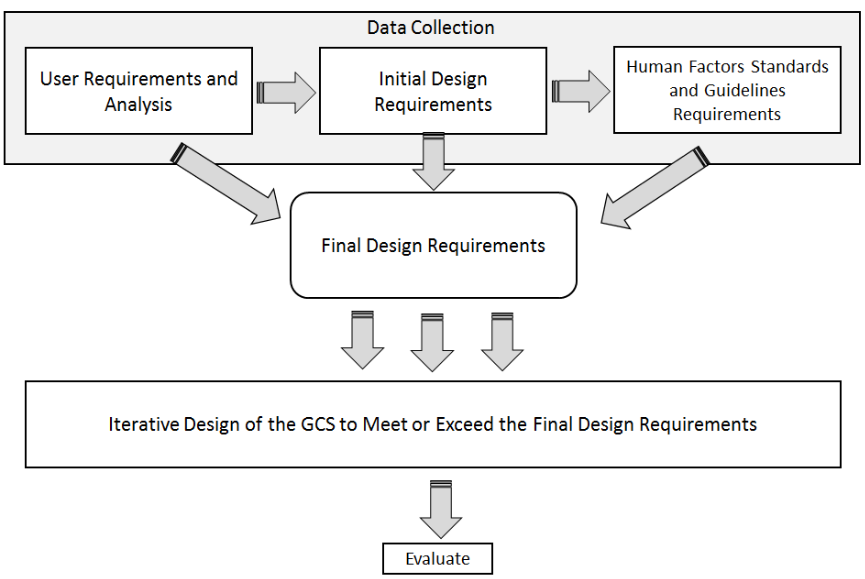

Figure 1: Human-Centered Design Plan For GCS Design

On the other hand, human-centered design is an approach to system design and development that focuses on making an interactive system more usable by applying the human factors/ergonomics and usability knowledge and techniques [7]. According to the ISO 9241-210:2010 [7], in order to apply a human-centered development, four major human-centered design activity must take place:

- Understand and specify the context of use.
- Produce a well detailed plan for specifying the user requirements.
- Use applicable techniques/technology to produce the design solutions.
- Evaluate the design.

Following the above steps, we created our own plan for achieving a human-centered design. The overview of our plan is presented in figure 1 above.

User Requirements

User data gathering is a crucial first step for designers and human factors practitioners. It is important because it sets the pathway for redesigning an existing system or developing an entirely new one from scratch. It gives the designer an in-depth view of the user; who they are, what they expect to perform, constraints, and the qualitative and quantitative usability level they expect in the system. This is usually achieved by conducting a direct or indirect questioning session with either a specialist with abundant knowledge of the user group, the stakeholders, or the primary group of users that are currently using the existing or closely related system. The questioning session can be in either questionnaire, interview or observation form, depending on the type of information and detail required.
The user data gathering technique used during this research is the direct interview method. For us to do this, we spoke with the specialist behind the design of the existing tandem rotor UAV GCS and some of the primary users and stakeholders of the existing system. By interviewing these groups, we could generate a clear picture of who the real users are and what they expect to achieve by using the system.

User Domain Description

Domain refers to the area of expertise and specialized knowledge needed to perform tasks and accomplish goals. The process of gathering information about the domain is known as domain analysis. In order to gather accurate information, interviewing and observation of people with specialized knowledge about the domain is mandatory [8]. In describing the user domain of the tandem rotor UAV, the founder of Roy Aircraft and Avionic Simulation (RAAS) was interviewed, he was the designer and domain specialist behind the existing tandem rotor UAV GCS. With his long years of experience, he could provide all the essential knowledge needed by the user to use the GCS and safely control the UAV.

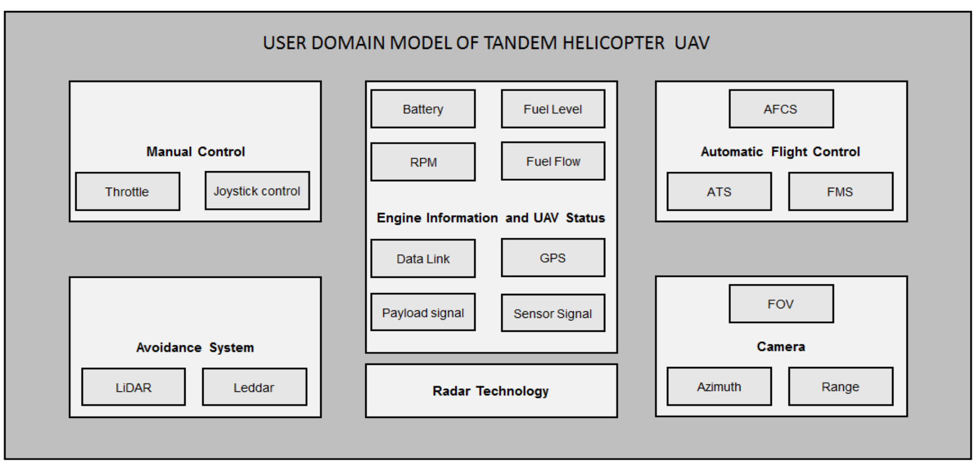

Figure 2: User Domain Model

Tandem Rotor UAV User Goal and Sub-Goals

Before specific goals, tasks and actions related to tandem rotor UAV can be highlighted safety critical system shall be defined. A safety critical system takes the safety of humans and the environment as the most important goal. Therefore, the system must be designed in a way that every user action that could affect the safety of the crew, environment or the aircraft itself, must be achievable without any confusion or ambiguity. Examples can be seen in nuclear power station, air traffic control systems and aircraft cockpit design. In modern aircraft cockpit, the pilot must be able to clearly distinguish between when the autopilot is engaged and when it has been disengaged. Any ambiguity in the representation of these two states could bring about a disastrous outcome.

The tandem rotor UAV is a safety critical system, even though it is an unmanned aircraft and no human pilot is present on board, the safety of the environment and the UAV itself is very important. For this reason, it is paramount to have a clear design to ensure that the pilot does not, at any point, put the safety of the environment or the UAV in danger. Having this in mind, there is a need to clearly categorize every user action into primary and secondary action groups. The primary action group will refer to the actions that are critical to the safety of flight. A clear example of this will be the speed control in modern aircraft. This is a very critical action because if the pilot does not know the speed at which the aircraft he is flying is, it is almost certain that a disaster is going to occur. On the other hand, the secondary action group will refer to the actions that are specifically related to the payload control. An example of this is the camera control. The representation of the camera orientation, for instance, does not have any effect on the state of the aircraft/UAV. However, designing it badly could distract the pilot from carrying out the important primary actions.

In this research, the main goal of the user controlling the tandem rotor UAV via the GCS is to carry out a continuous target surveillance mission while keeping the safety of the UAV and the environment as the main priority. Continuous target surveillance mission refers to a mission where the pilot is expected to search and follow a ground based stationary or moving target. The target in this case could be a building, vehicle or human. While carrying out such a mission, the pilot must also avoid anything that could put the environment or the UAV in potential danger.

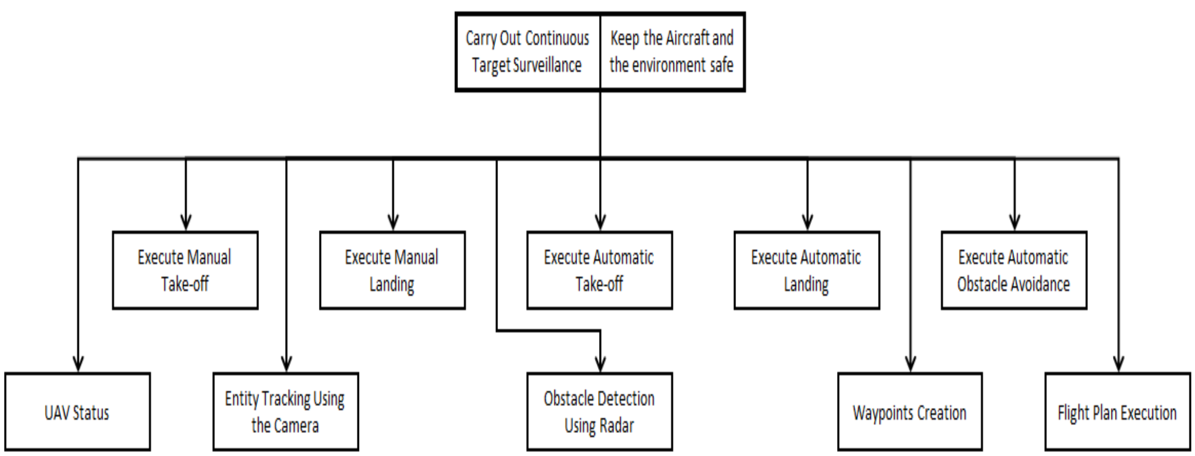

Figure 3: Tandem UAV User Goal and Sub-goals

Hierarchical Task Analysis (HTA) of Tandem Rotor UAV

Hierarchical task analysis is the most popular method used in task analysis. HTA describes the activities under analysis in terms of a hierarchy of goals, sub-goals, operations and plans to give an exhaustive description of the task activities [9]. The HTA representation used in this project follows the concept presented in Huddlestone's conference publication [10]. Usually, the overall main goal always retains the zero level, however, for simplification; Sub-goals are assigned to this level. The HTA is used to analyze the user's sub-goals and the final node in each analysis is added to the final design compilation, which is then categorized into Primary and Secondary actions. Figure 4 showcases one of the analysis results.

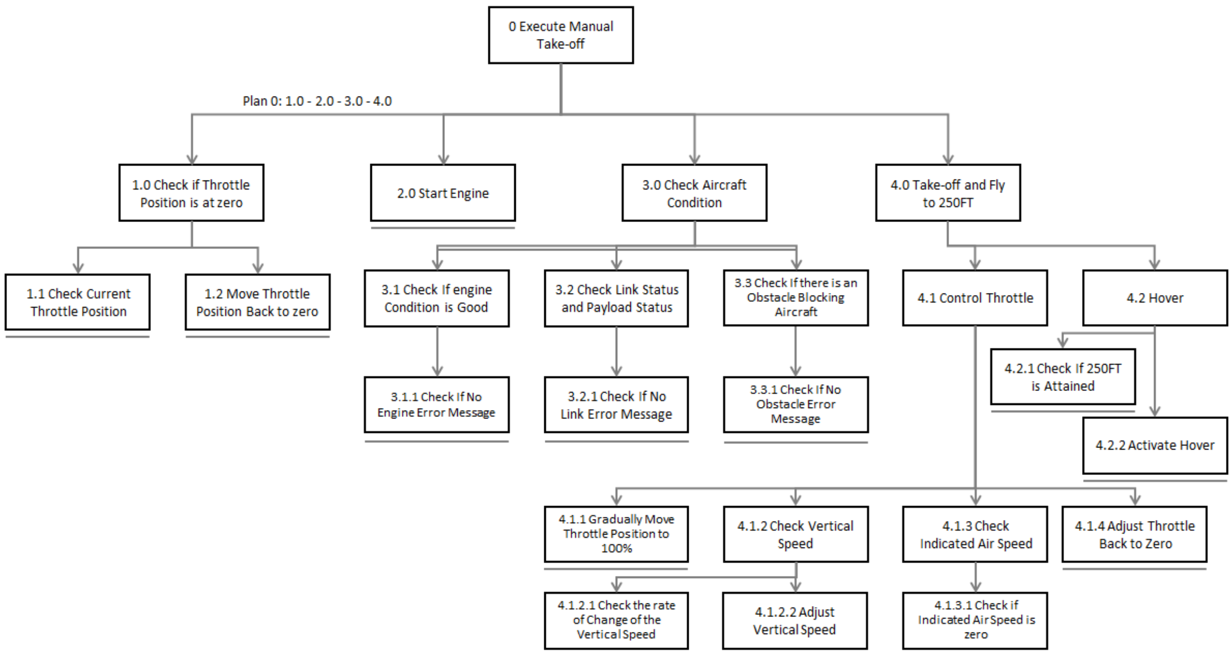

Figure 4: HTA Result for Executing Manual Take-off

An example of how such analysis result can be used as a user requirement is, taking the first final node of the above result (1.1 Check Current Throttle Position), the final user requirement would be: User must be able to see throttle position. From the definition of primary and secondary task above, we know for sure that this is a primary action.

Initial Design Requirements

Just as much as the user requirements data gathering, the initial design requirements data is also crucial. The process of gathering this specific type of data is important because it takes into account the project related aspects such as: stakeholders' instructions regarding the design, constraints and budget. For instance, the user domain analysis and user requirements data may result in a requirement that is way above the budget of the project. The initial design requirements reform this type requirement to make it more realistic for the designer to achieve. In summary, the data acquired during this process can be considered as a much more realistic version of the user design requirements.
During this project, the data collection for the design requirements was carried out using a questionnaire. All the companies involved were given a questionnaire regarding the GCS design and they all gave their opinion on what must be presented in the interface.
The information gathered in this process includes:

- Attributes the GCS must have
- Attributes that are nice to have
- Constraints and Budget

Standards and Guidelines Requirements

In order to apply standards and guidelines, information available to the public should compiled and be set as part of the design requirements. The information that was studied for this project include crucial publications such as the Human Factors Design Standard (HFDS), handbook for Human Engineering Design Guidelines (MIL-HDBK-759C), Department of Defense Design Criterial Standard (MIL-STD-

1472F), Standard Interfaces of UAV Control System for NATO UAV Interoperability (STANAG 4586 Edition 2) and the Human-Centered Design for Interactive System (ISO 9241-210:2010).
Human factors design standards (HFDS) is a well detailed human factors document compiled by the Federal Aviation Administration (FAA) for designing a commercial off-the-shelf subsystems, non-developmental items or development systems. It was originally designed as a guidelines document; however, since it has been transformed into a standard document, it can now be considered as part of the requirements when integrating human factors in any design [11]. The MIL-HDBK-759C on the other hand, is a guidelines document on human engineering design for military systems, equipment and facilities. Since the system being designed is a safety critical system carrying out a surveillance mission just like most military aircraft do, some parts of the military system design concepts can be applied to the system [12]. The MIL-STD-1472F offers to the designer the general human engineering criteria for design and development of military system, equipment and facilities. The document aims to help achieve required performance of operator and reliability of system while minimizing the skill and personnel training time [13]. The STANAG 4586 is a more technical standards regarding the design, defining the architectures of the data element and the message formats. This document will mainly be used as a guideline when programming some parts of the GCS such as the mission control and map representation [14]. Other guidelines used include the human factors guidelines for unmanned aircraft system GCS journal article and report published by NASA UAS researcher, Alan Hobbs [15] [16].

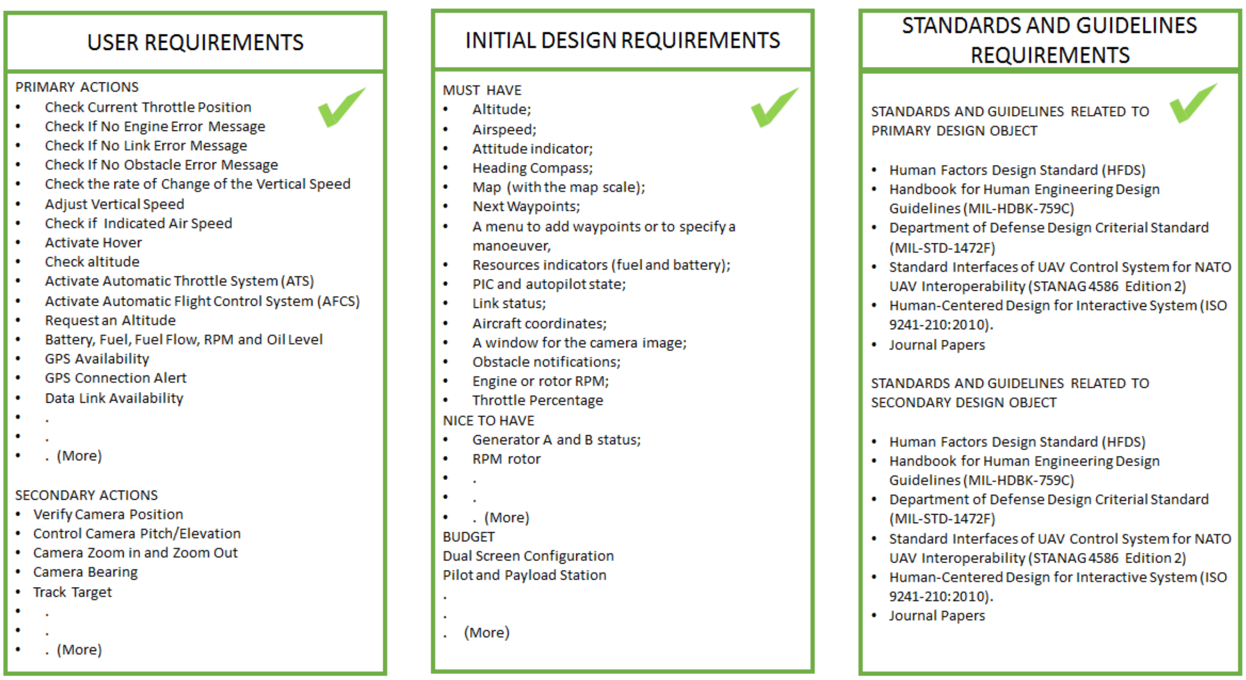

Figure 5: Final Design Requirements (completed)

Summary of Other Design Decisions taken

- Primary objects such as the primary flight display, MAP, alerts and UAV status were all constrained to the main screen
- Pilot can easily resize and reposition all the objects for better view
- Primary objects cannot be covered or obstructed, and must be easily accessible
- Design Must be consistent and simple

- Must be able to lock the resizing and repositioning attributes of the objects
- LiDAR and Leddar images should be viewed with reference to the UAV position
- The current state of the UAV must be displayed in 3D

GCS Design

The GCS design was carried out using Visual Studio C++ (OpenGL) and Presagis software. OpenGL was used to design the GCS interface that receives the LiDAR and LEDDAR information from the UAV and displays it to the pilot. Below are the brief description of the Presagis software used to design the GCS and the visual simulation environment used for testing and demonstration.

- HeliSIM **–** High fidelity flight dynamics modelling and simulation for rotary wings aircraft.
- STAGE **–** High fidelity scenario set up for training (Air, Ground, and Sea).
- Terra Vista – Terrain generator.
- VAPS XT **–** High quality user interface and HMI creator.
- Vega Prime **–** High quality visual simulation graphics toolkit.

Figure 6: Final Design Set-up (Main Pilot and Payload Pilot)[17]

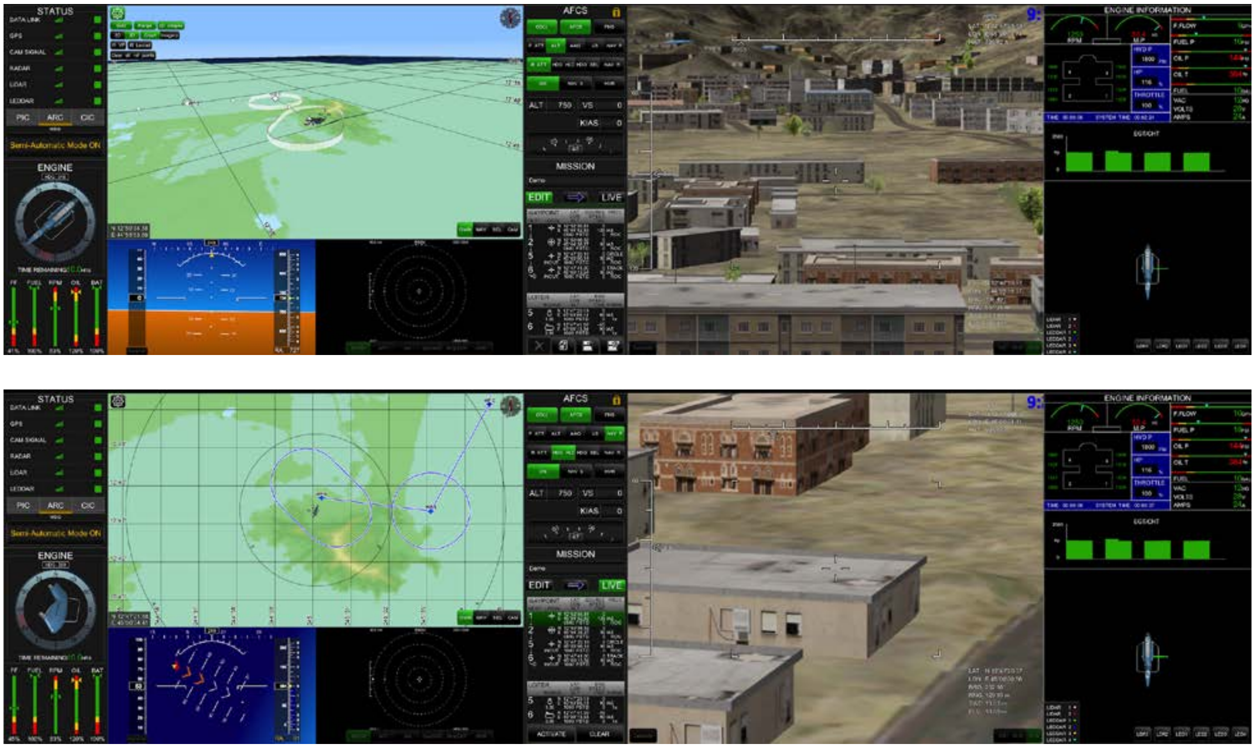

Figure 7: Final Design [17]

Initial results

In order to finalize the design an evaluation experiment was set up after receiving the Ryerson University research ethics board approval [18]. The GCS and the missions the pilots carried out were taken as the independent variables, while the pilot's workload was taken as the dependent variable. The pilot workload was measured using NASA task load index (TLX) [19]. Below is the initial result of the pilot workload.

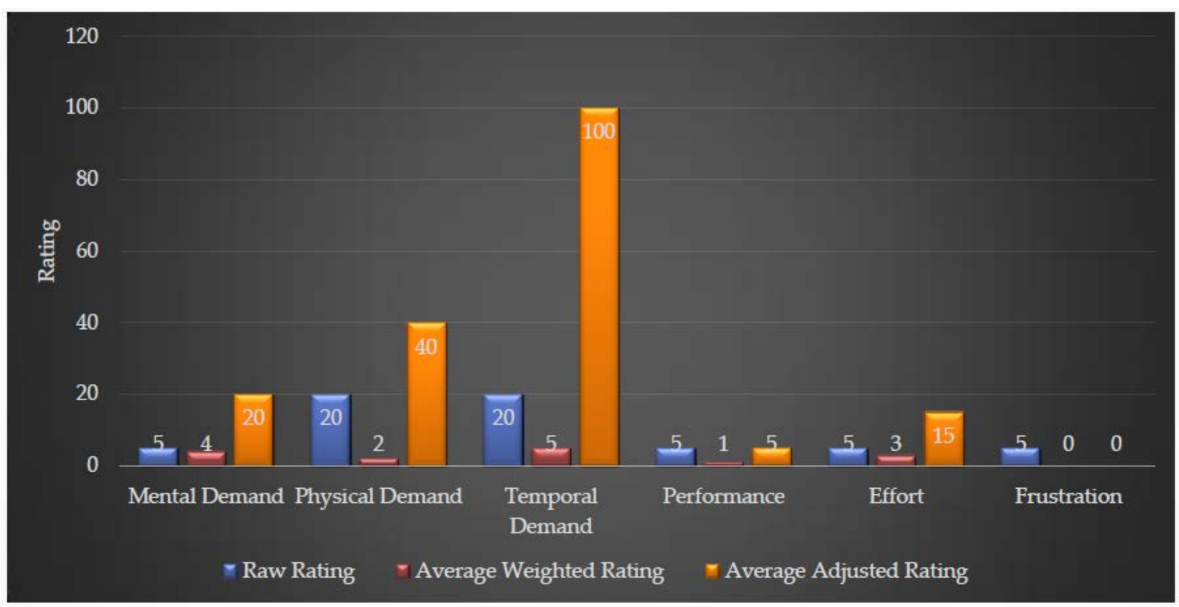

Figure 8: Initial NASA TLX results for GCS

The degree at which the design complies with the applicable human factors standards selected and compared was also evaluated. The results to the existing reconfigurable GCS designed by Ryerson University.

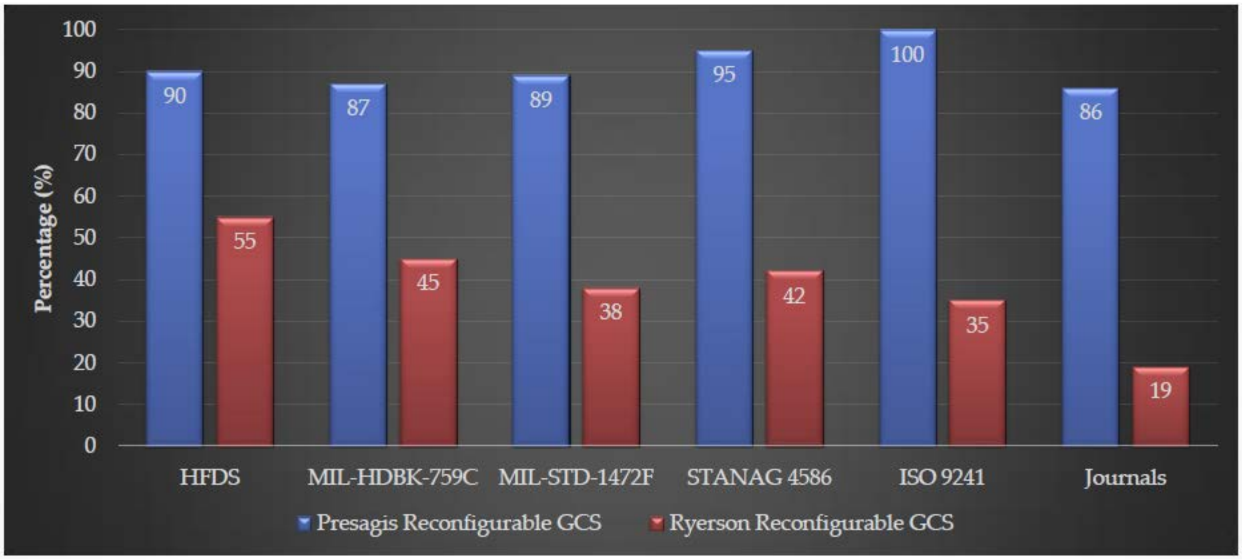

Figure 9: Degree of Compliance with Compiled Human Factors Standards and Guidelines

Conclusion

It was demonstrated that the design approach is in conformance with the ISO 9241 (Human-centered design for interactive systems) by using the ISO 9241:210 checklists [7]. Moreover, the initial results shows a good reduction in the frustration level when compared with the old reconfigurable GCS designed by Ryerson University's MIMS laboratory. In general, the pilot workload was lower than the baseline reconfigurable GCS.

Future Works

In order to further improve the quality of the results the sample size needs to be increased and more trials need to be performed. The design approach used in this research can be applied to different fields such as cockpit design for improving usability and performance of the pilots. Finally, other evaluation methods such as: usability, performance and error evaluation can be applied for further validation of the design methodology.

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