Summer 7-12-2016

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Scholarly Commons Citation

Thirtyacre, D., Brents, R., Goldfein, M., Hunter, D., Ison, D., & Terwilliger, B. (2016). Standardization of human-computer-interface for geo-fencing in small unmanned aircraft systems. (pp. 761-771). Cham: Springer International Publishing. doi:10.1007/978-3-319-41694-6_73

Standardization of Human-Computer-Interface for Geo-Fencing in Small Unmanned Aircraft Systems

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Abstract. The use of small unmanned aircraft systems (sUAS) has increased significantly in the past year. Geographic fencing (geo-fencing) is software built into most medium-cost consumer sUAS. This software is typically used to limit the altitude above launch point, the flight distance from the transmitting controller, and/or restrict flight inside a no-fly zone. While the concept of a geo-fence is simplistic, the human-computer-interface (HCI) varies drastically among platforms, and even between software iterations on the same platform. This research examines the HCI of three popular consumer-level sUAS with regard to geo-fencing. The software procedures and human interface for the DJI Inspire-1, 3D Robotics IRIS+, and Yuneec Typhoon Q500+ were evaluated through review of relevant literature, software, and flight-testing. This assessment yielded several recommendations for geo-fencing software for sUAS.

1 Introduction

The Federal Aviation Administration (FAA) and other governmental organizations are looking toward geo-fencing as a major component of unmanned systems integration into the National Airspace System [1]. The safety cushion providing separation of aircraft, manned and unmanned, may become dependent on geo-fencing; software which is not standardized and varies greatly between aircraft. This research identifies and addresses the need for standards in liveware-software-hardware functionality applied to small unmanned aircraft systems (sUAS).

This project featured testing and evaluation of three popular consumer-level sUAS to compare and contrast the methods used in geo-fence implementation. Human factors are a major consideration for proper HCI in any automated system and standardization between manufacturers on critical functions is essential. With in-depth knowledge of each aircraft's geo-fence software, common definitions, monitoring displays, and data input methods are recommended.

The manufacturing and operation of sUAS has increased significantly in the past few years. As of August 2015, www.UAVGLOBAL.com reported 432 UAS manufacturers in the commercial and military industry worldwide. However, very few industry standards are available for the human interface software to follow. This has created a situation where critical functions and information passing between the human operator and the unmanned system are specific to the platform and software load [2]. One of many critical data interfaces involves defining a geo-fence--a "fence" that limits flight beyond a defined distance or altitude [1].

There are a variety of limitations that currently exist or have been proposed by the FAA in the 2015 release of proposed regulations, including creation of Part 107 of the regulations designated to cover sUAS. By creating geo-fencing to identify the airspace, altitudes, or distances required can substantially assist operators and enhance safety. Geo-fencing for airspace allows for the demarcation of places where sUAS operations may be limited or prohibited. For example, the FAA is proposing operators to require air traffic control permission to operate in controlled airspace (Class B, C, D, and E airports), thus a warning geo-fence could be placed to notify users they are approaching or within an area that warrants additional action by the operator [3]. For locations at which sUAS operations are prohibited, such as around Washington, D.C., restricted airspace, or in National Parks, geo-fencing can be used to disable a sUAS from taking off or prevent it from entering the area [3] [4] [5]. Geo-fencing can also limit altitude of operation, e.g. 400 feet above ground level (AGL) or launch.. Altitude geo-fencing may also be incorporated for controlled airspace, as each type varies in shape and altitude [6]. Distance geo-fencing can be used to maintain the necessary proximity to the operator to sustain adequate signal range. Dynamic geo-fencing can also be utilized to prevent a sUAS from entering temporary flight-restricted areas, such as during disaster relief [7]. Future geo-fencing capabilities may include the ability to prohibit flight beyond visual line-of-sight or at night.

Although open manipulation of geo-fencing can defeat the intent of the safety enhancement, these limitations can sometimes prevent legitimate use of sUAS to take place. Ideally, non-recreational, authorized operators would be able to remove restrictions that interfere with approved operations. For example, if a user had FAA authorization to operate at an airport, the geo-fencing for that particular unit could be disabled or removed. Customizable geo-fencing could be potentially helpful for individual operators to avoid certain areas, fly specific paths or altitudes, and to be a good neighbor to surrounding populace. As is clear, geo-fencing can be a very useful, if not necessary tool, to not only assist users fly safely but also to comply with existing and future regulations or limitations [3] [6] [7].

2 Purpose

The objective of this practice-oriented research is to examine the human-computer-interface (HCI) used to manipulate geo-fence settings for three consumer-level sUAS. The HCI to enter and monitor geo-fencing parameters on sUAS varies by manufacturer and platform which may cause input and interpretation errors. Additionally, each of the three platforms incorporates varying levels of access and control of the geo-fence. This lack of standardization may lead to errors of omission (e.g., failure to enable the geo-fence) and commission (e.g., incorrectly entering geo-fence parameters). These errors can contribute to serious safety-of-flight issues including separation of manned and unmanned aircraft. The intent of this research is to identify best practices and recommend a standard interface scheme for sUAS.

3 Background

The concept of a geo-fence and the ability to incorporate it into sUAS software has been around for several years. However, until the sUAS manufacturer DJI made a mandatory software upgrade for its Phantom fleet in 2014 which included No-Fly zones, it was not activated in consumer level aircraft [8]. Since then, several manufacturers have installed similar programs in an effort to curb the rising number of sUAS incursions into high-density controlled airspace, and their liability should an accident occur.

While the FAA works to establish new regulations to govern unmanned aircraft, lawmakers in Washington DC have become impatient. In particular, Senator Chuck Schumer (D-N.Y.) introduced legislation in September 2015, which would mandate the use of geo-fencing. In a press conference, Laing (2015) quoted the Senator, "My amendment, which I am attaching to the FAA Reauthorization bill, would require geo-fencing or other similar technology software on every drone that would prohibit flying near airports and other sensitive areas" [9]. The Senator is recommending legislation to legally establish no-fly zones around airfields by leveraging the geo-fence software.

The no-fly zone is one application of geo-fencing, but the same autopilot algorithms may be used for other services. Some aircraft allow a maximum altitude above launch (often confused with general discussions of height AGL) entered into the system to restrict how high the sUAS can fly. Other manufacturers allow operators to input a maximum range from the launch point that the aircraft may travel, while still others elect to hard-code their maximum range and altitude. None of this matters unless the aircraft is receiving and processing an accurate position and altitude, most likely from global positioning system (GPS) localization. Understanding how the aircraft's geo-fence is defined, how it functions, and how the HCI operates are key factors for flight safety.

The three sUAS examined in this project each use geo-fence software to limit flight range and altitude. However, each platform utilizes a different user interface. The specifics of each UAS geo-fence are described in the following sections.

4.1 DJI Inspire-1

The Inspire-1 employs a mobile device to display information and provide the operational interface with the unmanned aircraft. The mobile device, an iPad in this case, is also used to display the camera view and allow camera control. Many settings are available on the main camera page including one-touch controls for the shutter, return to home, auto takeoff and land, gimbal control, as well as displaying the telemetry data [10].

After entering general settings, the main control menu is selected to bring up the geo-fence dialog. Unfortunately, the same page controls several other control inputs and is not labeled as "Geo-fence," only "MC." Data is entered through the "Set maximum flight altitude" entry dialog allowing settings from 10-500 meters. Interestingly, the geo-fence parameters can only be entered in meters, regardless of the units (e.g., metric or imperial) selected on the general settings page. However, if the height value converts to greater than 400 feet (120 meters), a warning appears that flight above that altitude may not be appropriate. A similar process, first toggling on

"Maximum Distance" then typing in the range from 15-500 meters, is used to enter the maximum distance [10].

The Inspire-1 operates in three main flight modes: F (Function) mode, A (Attitude) mode, and P (Positioning) mode. P-mode is the normal mode used with a strong GPS signal and is the only mode that both the selected altitude and distance geo-fence are active. When A-mode is selected, only the altitude geo-fence is active and a default limit of 120 meters activates, regardless of the entered value [10].

No-fly zones are included in the Inspire-1's database. These 'manufacturer imposed' geo-fences are always enabled as long as a sufficient GPS signal is received. The no-fly zones are comprised of both takeoff restricted zones and restricted altitude zones, depending on the distance from the protected airfield or restricted area. The aircraft response to different no-fly situations is beyond the scope of this paper and consumes four pages of the user manual [10].

4.2 3D Robotics IRIS+

The 3D Robotics IRIS+ functions as more of a traditional remote control (i.e., recreational hobby) aircraft without a mobile device requirement. As with the Inspire-1, both altitude and distance geo-fence parameters are selectable. However, changing from the default values requires a separate software package from the manufacturer. The free software download of Mission Planner is available on the manufacturer's website but is not required to fly the aircraft [12]. Without Mission Planner, the geo-fence defaults to "on" with the factory preset values of 100 meters for altitude and 300 meters for distance. When the aircraft is connected to Mission Planner through either a USB connection or the aircraft's telemetry, the geo-fence parameters can be changed [11].

The Mission Planner software, depicted in Figure 1, is extremely capable and allows manipulation of almost all of the IRIS+ settings, including preprogrammed route of flight. Once connected to the aircraft, the geo-fence parameters are accessed through the configuration button and then selecting geo-fence from the drop down menu. Settings on the geo-fence page include maximum altitude and radius values, selection of altitude and/or range, the action taken when the geo-fence limit is reached, and enabling the geo-fence [12]. The Mission Planner depicts no-fly zones around controlled airfields on the moving map display but does not currently inhibit flight inside the zone. Although the Mission Planner software is not required for flight, 3DR highly recommends its use [11].

Figure 1. IRIS+ Mission Planner Geo-fence Page. Screen capture from "Mission Planner 1.3.32." Developed by M. Osborne, 2015.

4.3 Yuneec Typhoon Q500+

The Yuneec Typhoon Q500+ aircraft and Yuneec ST-10+ controller are delivered as a set. The ST-10+ acts as both a controller and video display for the integrated camera. This display also functions as a limited interface with the system through a touch screen menu. Similar to the other aircraft discussed, the Q500+ has a geo-fence for both altitude (default value 122 meters) and distance (default value 91 meters). However, the geo-fence is not fully active in all modes, only during operation in "Smart Mode" (described in detail below). The geo-fence parameters are only adjustable through the graphical user interface (GUI) program available for download on the manufacture's website [13].

The Q500+ GUI requires access to an interface connection inside the battery bay of the aircraft. Once connected to a computer through USB, the aircraft is powered up and the GUI started. As seen in Figure 2, the geo-fence entry page is labeled "Flight Boundaries," and allows entry of both altitude and range.

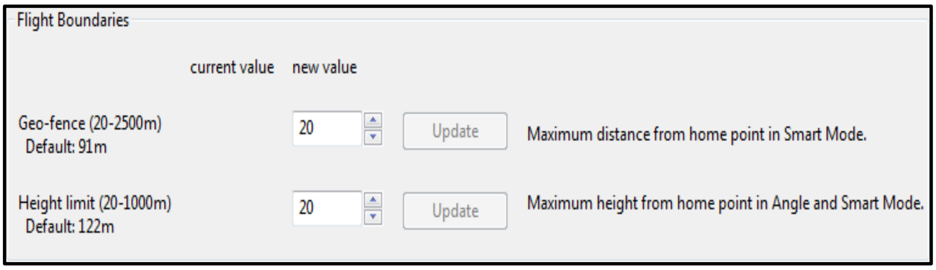

Figure 2. Q500 GUI Flight Boundaries Page. Screen capture from "Q500 GUI 1.01." Copyright by J. Russell, 2013.

The flight boundaries page mentions both Smart and Angle Modes. Smart Mode is primarily used for operators unfamiliar with UAS operations. This mode changes the control mapping from aircraft centric to transmitter centric (e.g., moving the control lever away will move the aircraft away from the transmitter regardless of aircraft heading). Angle Mode is the typical, aircraft centric control method used for most UAS. Interestingly, only the altitude limitation is active when in Angle Mode. To limit the aircraft in both altitude and range, Smart Mode is required. The Q500+ software is factory set with airport no-fly zones similar to the Inspire-1. The aircraft cannot be flown inside these areas [13].

4.4 Aircraft Geo-Fence Summary

While the three aircraft described above all contain geo-fence software, the implementation is very different. The characteristics of each aircraft's software is presented in Table 1. Even the no-fly zones created to deconflict manned aircraft from unmanned aircraft are implemented differently in each aircraft. The need for standardized definitions, status monitoring, and method of data entry is readily apparent.

Table 1. Geo-fence capabilities of three sUAS

Software Options	IRIS+	Inspire-1	Q500+
Installed Geo-fence Software	Y	Y	Y
Auto No-Fly Zone Restrictions	N	Y	Y
User Disabled	N/A	N	N
Altitude Geo-fence	Y	Y	Y
User Input Parameters	Y	Y	Y
Distance Geo-fence	Y	Y	N*
User Selected Value	Y	Y	N*
Data Entry Interface	MP	App	GUI
Live Changes	Y	Y	N

**Geo-fence distance limit in Smart Mode only. Adapted from 3DR [11], DJI [10], and Yuneec [13].*

5 Discussion

Several issues were identified during the aircraft review. Each manufacturer approached the geo-fence concept with different definitions, displays and entry methods. This may lead to confusion, delay, and misunderstanding. These three areas are discussed below.

5.1 Definition

The first apparent issue from the software review is the definition of a geo-fence. The Inspire-1 does not refer to the settings as a geo-fence and the Q500+ only refers to the distance, not the altitude as a geo-fence. Only the IRIS+ defines the menu items under the title geo-fence. Since geo-fence is now common vernacular among sUAS regulators and operators, it should be adopted as the standard label for any range and altitude limiting software. For the purest who believes a "geography fence" does not apply to altitude, the term 3D Geo-Fence could be used to include the third dimension of altitude. There could also be a time component (i.e., when flight is limited to a time "window") resulting in a 4D geo-fence. These terms are unambiguous and could be used when describing a platform's capabilities. For example, the IRIS+ software supports 3D geo-fencing. However, the understood definition of a geo-fence is irrelevant unless the operator understands what aspect of the fence is enabled.

5.2 Monitoring

None of the aircraft tested display the status of the geo-fence on the main control page (other than a ring on the map view). Understanding the status of the geo-fence is critical to flight safety since automation surprise (i.e., the unanticipated actions taken by an automated process) can cause confusion, misinterpretation, and possibly loss of aircraft control [14]. Whether or not the geo-fence is enabled, the modes that are active, and the set values need to be obvious on the main control page. A simple method would be to only display values that are enabled and code them in green (not close to the limits), yellow (approaching limits), and red (limit reached). The operator would only need to crosscheck the information to understand the status of the geo-fence and anticipate the autopilot's reactions to reaching a limit. In addition, when a limit is reached and the aircraft executes the programmed response to the limit, the broken limit could flash to inform the pilot which limit was reached. This could include no-fly zones as well by displaying "NFZ," indicating that the no-fly zone geo-fence is active.

Each of the aircraft tested use GPS as the primary input to determine the location of the 2D geo-fence and GPS and/or barometric pressure for altitude. If these sensors fail to provide data (or accurate data), the operator should be notified; preferably by two methods. The Q500+ employs a vibration coupled with an on-screen message to ensure the operator understands that GPS is lost. This method is an excellent example of attracting attention through the use of salient cues [15]. Variations of this method should be employed to augment visual cues on the main control page with respect to geo-fence status. Understanding what limits are active is critical, but an intuitive, single entry location is also important.

5.3 Data Entry

Entering geo-fence data into the sUAS should be quickly accessible, intuitive, and standardized. Each manufacturer will undoubtedly develop their own interface however, a few general rules should be followed.

1. *Available.* Changes to the geo-fence parameters must be available during flight operations with the basic equipment. Requiring a separate computer

connection to adjust the values reduces the likelihood that an operator will use the geo-fence effectively.

2. *Ease of Access.* Entering the data should be no more than one menu deep. A major issue for an operator of multiple sUAS is recalling where the geo-fence entry page resides. An icon on the home control page, possibly with the letters GF, linked directly to the data entry page, would be ideal.
3. *Intuitive.* All of the parameters associated with the geo-fence should be displayed in the same manner and on one page. A good example of this is on the IRIS+ Geo-fence page shown in Figure 1. Each parameter is displayed in an easy to understand format including the aircraft reaction to encountering a limit.
4. *Standardized.* All manufacturers should label this software as a geo-fence and have a compulsory set of parameters that are displayed and user-selectable. This set should include parameters for the user-defined geo-fence and the no-fly zones; even if the no-fly zones are not selectable:
   - No Fly Zones: Factory Enabled
   - User Geo-fence: Enable/Dis-enable
   - Maximum Altitude: Select
   - Maximum Range: Select
   - Aircraft Response: Hold/Land/Home

5.4 Display Recommendation

Many options exist to accommodate the three requirements of availability, accessibility, and intuitiveness. Building on these requirements from section 5.3, Figures 3 and 4 are offered as examples. This interface is applicable to tablet and built-in-display-based GCS applications. A similar interface with text-only input and display is also possible.

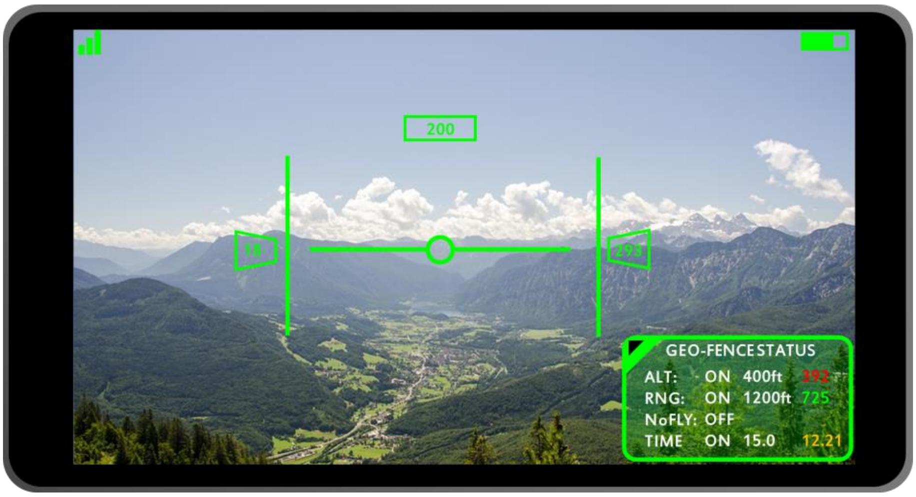

Fig. 3. Geo-fence status and parameter display on main control screen. Base image from: https://pixabay.com/static/uploads/photo/2015/12/08/01/03/aerial-view-1082304_960_720.jpg

Figure 3 illustrates a simplistic main display with embedded geo-fence status information. The operator can quickly interpret which geo-fence is active, the limiting parameter, and how near the aircraft is to each limitation. A color scheme adds intuitive interpretation of aircraft status: green indicating the aircraft is operating inside 80% of the maximum value, yellow inside 95%, and red when within 96-100% of the set parameter. When the limit is reached, the red distance flashes, the controller vibrates, and a voice warning sounds, producing several salient cues.

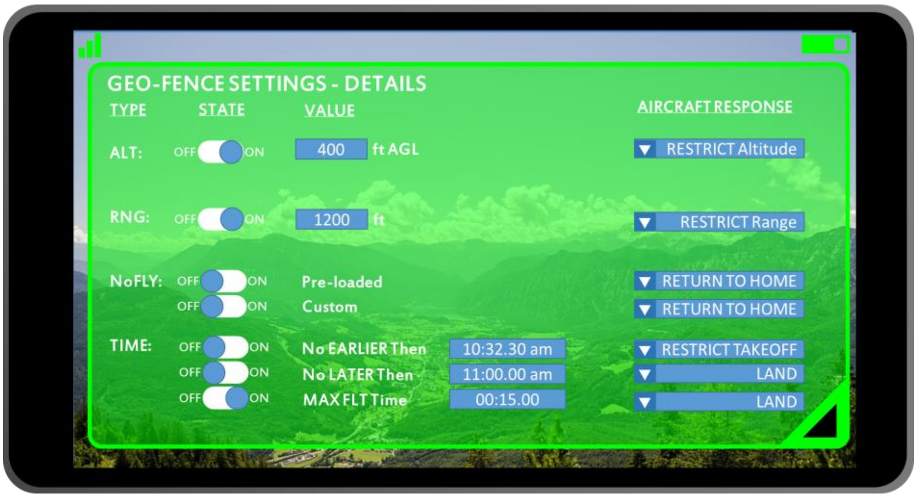

Fig. 4. Geo-Fence settings details data entry page. Base image from: https://pixabay.com/static/uploads/photo/2015/12/08/01/03/aerial-view-1082304_960_720.jpg

The geo-fence setting details are selected by touching the geo-fence status display. An example of the setting details page is illustrated in Figure Y. This display allows input, through an interactive menu, of the state (on/off), value (input parameter), and the desired aircraft response when a geo-fence limit is reached. Aircraft response options include warning only, restrict aircraft from exceeding parameter, hold, return to home, and land immediately.

6 Conclusion

Few standards are used in the development of sUAS. As the complexity, capability, and availability of these systems increase, so does the need for standardization. The cockpits of today's manned aircraft all have a similar control panel and flight display layout, forged from decades of refinement and standardization. The rapidly growing domain of sUAS must begin to standardize not only displays but definitions as well. One area that requires immediate attention is in geo-fencing. The geo-fence technology available for sUAS is robust and well tested. However, the myriad of manufacturer designs for geo-fence implementation is specific to each aircraft which creates confusion and human errors.

The diversity seen in this research on geo-fencing exposes only a small fraction of the issues. The sUAS community must begin to define standards in other areas such as flight displays, low fuel indications and actions, camera manipulation, autonomous flight, and even the definitions themselves. It appears that much of the human factors research conducted on manned aviation were overlooked by many manufacturers of sUAS [16]. Basic human factors concepts must be applied to unmanned systems, especially the area of HCI.

References

1. Stevens, M., Coloe, B., & Atkins, E. (2015). Platform-independent geofencing for low altitude UAS operations. Paper presented at the *15th AIAA Aviation Technology,Integration, and Operations Conference,* http://dx.doi.org/10.2514/6.2015-3329
2. Damilano, L., Guglieri, G., Quagliotti, F., & Sale, I. (2012). FMS for unmanned aerial systems: HMI issues and new interface solutions. *Journal of Intelligent and Robotic Systems, 65*(1-4), 27-42. http://dx.doi.org/10.1007/ s10846-011-9567-3
3. Costello, T., & Fieldstadt, E. (2015). *Flying drones at National Parks can result in penalties, fines.* Retrieved from http://www.nbcnews.com/news/us-news/flying-drones-national-parks-can-result-penalties-fines-n486206
4. Federal Aviation Administration (FAA). (2015). *Overview of small UAS Notice of Proposed Rulemaking*. Retrieved from https://www.faa.gov/regulations_policies/rulemaking/media/021515_suas_summary.pdf
5. Federal Aviation Administration (FAA). (2016). *Washington, D.C. is a NO DRONE ZONE*. Retrieved from https://www.faa.gov/news/updates/?newsId=83267
6. Know Before You Fly. (2015). *For recreational users*. Retrieved from http://knowbeforeyoufly.org/for-recreational-users/
7. DJI. (2015). *No fly zones*. Retrieved from http://www.dji.com/fly-safe/category-mc?www=v1
8. Kakaes, K. (2015, January 28). Governments are cracking down on drones. Why are drone-makers helping them? [Blog post]. Retrieved from http://www.slate.com/blogs/future_tense/2015/01/28/after_white_house_crash_drone_maker_dji_restricts_its_uavs_flying_zone.html
9. Laing, K. (2015, September 14). Schumer moves to require geo-fencing on drones. *The Hill*. Retrieved from http://thehill.com/policy/transportation/253565-schumer-moves-to-require-geo-fencing-on-drones
10. DJI. (2014). Inspire-1 user manual (V1.0). Retrieved from www.dji.com/support
11. 3D Robotics. (2015). IRIS+ operation manual (VH). Retrieved from https://3drobotics.com/wp-content/uploads/2015/02/IRIS-Plus-Operation-Manual-vH-web.pdf
12. Osborne, M. (2015). Mission planner (Version 1.3.32 build 1.15736.30798) [Computer software]. Retrieved from https://3drobotics.com/download_software/
13. Yuneec. (2015). Typhoon Q500+ instruction manual V2. Retrieved from http://www.yuneec.com/download/manuals/typhoon_q500plus_user_manual_v2.0.pdf

14. Mosier, K. (2010).The human in flight: From kinesthetic sense to cognitive sensibility. In E. Salas & D. Maurino (Eds.), *Human factors in aviation* (pp. 147-173). Boston, Mass: Amsterdam: Academic Press/Elsevier.
15. Vidulich, M., Wickens, C., Tsang, P., & Flach, J., (2010). Information processing in aviation. In E. Salas & D. Maurino (Eds.), *Human factors in aviation* (pp. 175-215). Boston, MA: Academic Press/Elsevier
16. Hobbs, A. (2010). Unmanned aircraft systems. In E. Salas & D. Maurino (Eds.), *Human factors in aviation* (pp. 505-531). Boston, MA: Academic Press/Elsevier