Onboard Weather Situation Awareness System: A human-systems integration approach

Guy Andre Boy, Sebastien Boulnois

▶ To cite this version:

Guy Andre Boy, Sebastien Boulnois. Onboard Weather Situation Awareness System: A human-systems integration approach. HCI-Aero 2016 – International Conference on Human Computer Interaction in Aerospace, 2016, Paris, France. 10.1145/2950112.2964575 . hal-02956586

HAL Id: hal-02956586

https://hal.science/hal-02956586

Submitted on 3 Oct 2020

Onboard Weather Situation Awareness System: A human-systems integration approach

Sebastien Boulnois
School of Human-Centered Design,
Innovation and Art
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901 USA
+1 321 704 7239
boulnois.sebastien@gmail.com

Guy Boy
School of Human-Centered Design,
Innovation and Art
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901 USA
+1 321 506 5073
gboy@fit.edu

ABSTRACT

This paper presents the work in progress on the Onboard Weather Situation Awareness System (OWSAS), designed and refined using a human-centered development approach. More specifically, 3D content (integration of aircraft trajectory, flight-path and environmental dynamics), visualization (graphical integration of context-sensitive meteorological and geographical models) and interaction issues and solutions are presented and discussed.

Keywords

Weather, Situation Awareness, Human-Systems Integration, Human-Centered Design, 3D visualization, Flight deck.

INTRODUCTION

Most commercial aircraft are equipped with radars that provide pilots with weather information (e.g., Honeywell Primus P-660, P-880, RDR-4000, Rockwell Collins TWR-850, WXR-840 and WXR-2100 weather radars). Range is their main limitation (i.e. between 320 and 365 nautical miles). This kind of information is short-term for long-distance flights and pilots can require a greater temporal component for anticipation of trajectory modification for safety. When more time is needed, it may cause safety, efficiency and/or comfort issues. In addition, current weather planning methods are responsible for 68% of delays in airports [National Transportation Safety Board, personal communication]. Consequently, the current tactical approach (short-term weather control) to weather management on the flight deck should be complemented by a strategic approach (long-term weather management). This approach is typically supported by information coming from satellites, ground weather radars and other aircraft radar information [5]. In this paper, we will not present such data integration. However, we will focus on available 3D weather information to propose weather visualization solutions.

Current onboard weather visualization systems are essentially 2D and 2.5D (i.e., information can be 2D or 3D but is presented on 2D displays). For example, National Center for Atmospheric Research (NCAR) designed and implemented such a system [7]. It uses 2D CONUS (i.e., the 48 Contiguous United States) maps as a visualization environment, integrating a different kind of weather information such as Cloud Top Height (CTOP) and Convective Diagnosis Oceanic (CDO) technologies. University of Toulouse (ENAC) has developed two prototypes of an onboard visualization system for integration within navigation displays [9]. The former (2D profile view) has been evaluated by a professional pilot in a flight simulator. The latter (2.5D view) has been evaluated through an interview with the same pilot. NASA also worked on their Cockpit Situation Display similar to a navigation display in which several kind of weather information are presented in 2D or 2.5D (e.g., ground-based weather products, predictions, forecasts) [10]. All these systems are work in progress. On the other side, some onboard weather visualization systems have been developed and commercialized such as Honeywell Weather Information Service [6]. This product offers a lot of weather information to pilots in two different 2D views (bird's-eye and profile views) that are synchronized together (e.g., NEXRAD, satellite, lightning observations). However, these systems have limitations regarding their weather information representation or their interaction and manipulation. For example, [7] and [6] only use 2D visualization. [9] and [10] integrate 2.5D visualization but their manipulation and interaction is limited since they are similar to a navigation display.

The Onboard Weather Situation Awareness System (OWSAS) is currently designed and refined at the School of Human-Centered Design, Innovation and Art (SHCDIA) of Florida Institute of Technology using an agile development approach. This paper presents the current version of OWSAS, OWSAS-3, along with weather visualization and interaction issues and possible solutions.

HUMAN-CENTERED DESIGN APPROACH

OWSAS is not a user interface, in the Human-Computer Interaction (HCI) sense, but a system in its own right and is currently designed (the user interface being a part of it) and

HCI-Aero '16, September 14-16, 2016, Paris, France
ISBN 978-1-4503-4406-7/16/09...$15.00
DOI: http://dx.doi.org/10.1145/2950112.2964575

tested as such. It was designed and developed on a tablet for testing-commodity reasons, i.e., as a Tangible Interactive System (TIS). TISs attributes were recently described as innovation, flexibility, complexity, stability, maturity and sustainability [3].

The OWSAS concept was created using and integrating existing technology (creativity is thought as synthesis and integration). Current commercial tablets are broadly used and therefore eliminate a large part of usability issues. In addition, they have a big advantage at design time because they are easily programmable and consequently provide large flexibility for incremental modifications. This is consistent with the agile approach, which consists of incremental design and formative evaluations of prototypes toward satisfactory solutions [3][4]. OWSAS formative evaluations have been done in a realistic commercial aircraft cockpit (Boeing 737-800 simulator) involving professional pilots (human-in-the-loop simulations). In other words, we privileged expertise and experience instead of statistically significant data gathering from often not-enough experienced end users. Cybersecurity issues are not taken into account at this stage.

At each step, we provide pilots with meaningful versions of OWSAS that they can test. This happened to be a very efficient way of discovering emergent properties that cannot be anticipated by designers. This is the reason why it is important to have realistic virtual environments, such as SHCDIA Boeing 737-800 simulator (Figure 1) and experienced pilots. Typically, each agile development step (i.e., prototype version) takes about 3 months and is tangible. Tangibility is considered both physical (OWSAS prototype is directly manipulable by professional pilots) and figurative (OWSAS prototype information and interaction are meaningful for professional pilots) [3].

Figure 1. SHCDIA Boeing 737-800 simulator.

OWSAS development deals with complexity management (i.e., articulation of system complexity and operational complexity) [2]. System complexity management is a matter of systems integration (i.e., integration of existing technology). Operational complexity management is a matter of Human-Systems Integration (HSI) that leads to incremental discovery of emergent properties through Human-In-The-Loop Simulation (HITLS).

OWSAS needs to be tested in both normal, abnormal and emergency situations to insure its stability. The shift from HCI to HSI requires not only taking into account task models but also activity observation and analysis based on HITLS. This is the only way we can assess the stability of the system being designed. More specifically, normal, abnormal and emergency scenarios need to be defined and used.

Even from the early stages of OWSAS design, maturity should be tested and understood in the technological and practice senses. Maturity of technology is a matter of integration, robustness and reliability. Maturity of practice is a matter of usability, usefulness and familiarity of use. Both types of maturity should be incrementally tested during all stages of the design (Figure 2).

OWSAS-3 is available on a tablet. This may not be the final support. We already advocated this solution for flexibility reasons. However, it may not be sustainable. OWSAS sustainability is difficult to test at this time because interactive technology keeps evolving constantly; however, this will be taken into account in later versions.

These dimensions are used as a high level requirements and testing principles in the agile development of OWSAS.

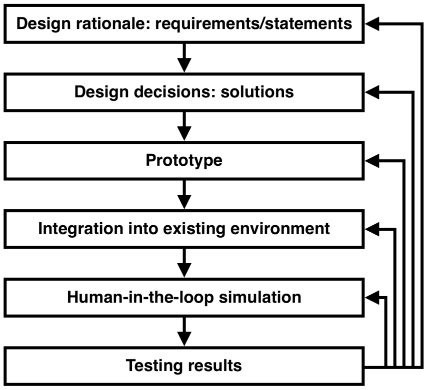

Figure 2. Human-Centered Design loops.

OWSAS AGILE DEVELOPMENT

The first two prototypes were developed to provide professional pilots with a realistic visualization of what OWSAS could offer in terms of 3D weather information [8]. We chose Google Earth as the 3D physical visualization environment integrated with both 3D weather and aircraft flight-path information. The only difference between prototype 1 and 2 is the type of tablet (i.e., Microsoft Surface Pro 2 and iPad Air 2). We did not keep the first tablet because the multi-touch capability was not available and therefore did not allow for easily moving in the virtual environment. This was one of the findings of the first formative evaluations.

Results from the first formative evaluation were already presented in [8]. The authors mainly focused on content and presentation of the system. Pilots who tested it felt comfortable dealing with 3D weather data (i.e., NEXRAD network data and vertical projection of this data represented by 3D cylinders) and the flight-path integrated within Google Earth (Figure 4). They also had to deal with the second feature of OWSAS (i.e., horizontal avoidance of hazardous weather). This feature proposes an alternative flight-path to pilots which is recalculated thanks to an algorithm according to flight-path waypoints to avoid. Most of the evaluation pilots considered the algorithm “far from optimal” however, they agreed with the system when a solution was found.

In addition to changing tablet support (physical tangibility), the second prototype focused on the vertical dimension of weather avoidance.

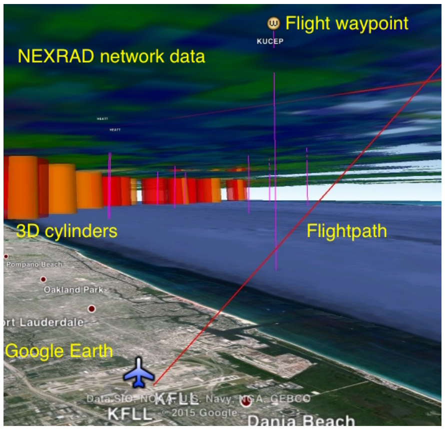

Figure 4. OWSAS-1 visual content.

Current development phase takes into account formative evaluation results of the second prototype and professional pilots’ feedback elicited during interviews. OWSAS-3 is being integrated in the cockpit simulator connecting aircraft parameters, which come from the Prepar3d simulation environment via the SimConnect framework in real-time (Figure 5). The left side of Figure 5 provides weather and flight-path information which are being integrated within OWSAS-3. Also, OWSAS-2 was based on NOAA archives which provided static images. Instead, OWSAS-3 is currently based on close-to-real-time observations coming from NOAA (thredds catalog). We are able to get weather information updates in a period going from 3 minutes to 10 minutes.

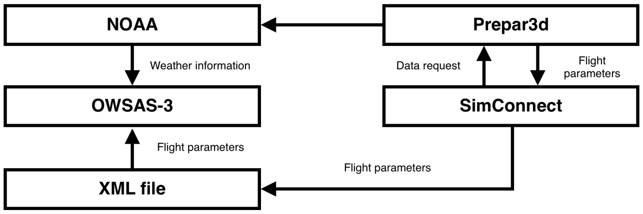

Figure 5. OWSAS-3 high-level architecture.

OWSAS-3 is implemented using context-sensitive software objects (CSSOs), easily modifiable in real-time. Each software object is a specific representation of a concept as a graphical representation on the screen and a corresponding control mechanism (Figure 6). For example, reflectivity is so far represented as a combination of spheres that represent data points of a chosen area. Their color follows the NEXRAD reflectivity scale and can vary with respect to data retrieved from the THREDDS catalog (online data resource). In the same way, a flight-path is represented by connected flight waypoints that can vary with respect to pilots/ATC inputs.

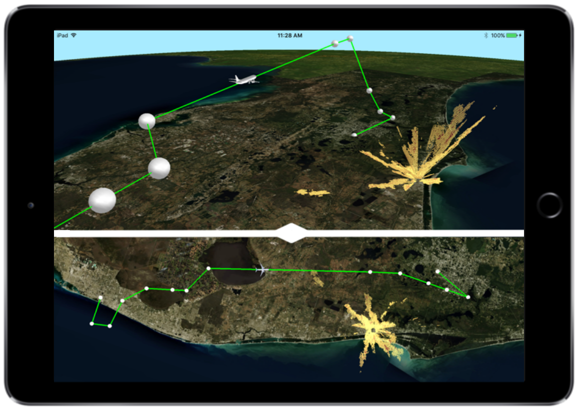

Figure 6. OWSAS-3 visual content.

OWSAS-3 HUMAN-CENTERED ARCHITECTURE

OWSAS-3 architecture requirements are based on technological and human capabilities and constraints.

Technological capabilities

The synchronization between our Boeing 737-800 simulator and OWSAS-3, using the SimConnect SDK, enhances the interactivity of OWSAS content. This provides OWSAS-3 with real-time flight parameters information. OWSAS-3 software objects are therefore implemented as CSSOs that behave dynamically, according to the evolution of flight parameters. Feedbacks from pilots interviews tend to say that CSSOs will provide pilots with better situation awareness (SA) in regard to representation of weather (e.g., spheres which evolve dynamically with respect to weather information gathered from THREDDS catalog) and flight trajectory (e.g., flight waypoints are visualized depending on pilots inputs).

Moreover, OWSAS-3 controls allow pilots to immerse themselves in the 3D environment by going in any direction, rotating left, right, zooming in/out, tilt up and down so they can have access to any information (i.e., they are not limited to their onboard radar range capacity) and get a better weather SA.

Technological constraints

Providing OWSAS-3 with a more accurate weather visualization means dealing with several weather information sources (i.e., onboard radars, grounds radars and satellites). Onboard radar provides pilots with “local” short-term 2D/3D weather information. Ground radar is set up with networks throughout several countries for global raindrop motion and intensity detection. Finally, satellites that detect clouds and several other phenomena (e.g., fires, snow cover, ice mapping, energy flows) can also be used to improve weather visualization. Integrating all of this data sources together could enhance pilots’ weather SA. However, we have not considered all of them in this work in progress because of its complexity and time constraints (i.e., most of these data are available as 2D layers but we do not have any 3D information for more accurate representations). OWSAS-3 currently focuses on 3D NEXRAD information. Moreover, tablets have power and ram limitations. The catalog provides us with a huge amount of data points per ground station (around 5 millions). Representing all these data points with CSSOs (spheres) is not possible because of these hardware limitations. This problem could be partially solved by using latest state-of-the-art tablets. In addition, we still would have to design other representations (e.g., cluster of points) in order to reduce the number of CSSOs and match with pilots' requirements.

Human capabilities

Figurative tangibility (i.e., context-sensitive meaning and purpose of information) is very important to take into account in HCD. In other words, OWSAS-3 should be able to provide pilots with a meaningful and purposeful account of the 3D physical environment (e.g., mountains, airports, and critical structures) and weather (e.g., cloud shapes and dimensions both locally and globally). According to [8], OWSAS-2's 3D cylinders provide a good representation for getting global weather criticality. It may be too much simplified in specific situations. Our goal is to provide pilots with both current and forecast weather information. The former would help pilots enhancing their weather SA regarding current weather everywhere around the flight-path. The latter would help operators to project themselves in a possible near future, thus aid decision-making (DM) and initiate appropriate action.

Human constraints

Design work in progress takes into account fundamental flying and navigation skills. Additionally, it can investigate new knowledge and knowhow on strategic provisions of weather SA and DM. In particular, pilots will have to identify real weather conditions from OWSAS, and make appropriate decisions and take appropriate actions. The question is not using former practice based on previous weather technology, but instead understanding how OWSAS will improve safety, efficiency and comfort within the overall trajectory management and more generally air traffic management.

OWSAS tangibility is not only a matter of a usable system onboard, but also a shift from single agent operations to multi-agent operations (i.e., we need to identify and understand emerging behaviors and properties that the integration of OWSAS generates in practice). For this reason, our research effort is currently focusing on the definition of tangibility assessment, principles and criteria.

For example, OWSAS provides pilots with 3D weather information that can be taken into account to optimize their trajectory sooner than current radar information can. Consequently, in the framework of trajectory-based operations, the link between weather management and traffic management becomes crucial.

DISCUSSION

OWSAS-3 features are intended to enhance pilots' navigational information processing for weather-based trajectory optimization. Our research effort is based on the claim that 3D global weather information combined with aircraft trajectory visualization improve pilots' SA and DM as early results showed it [8].

More specifically, we try to demonstrate that 3D weather information is more tangible than what most current onboard weather systems offer. Such tangibility should reduce cognitive workload because it would provide more accurate mental representation of the weather, and consequently would enhance SA. In addition, the global dimension provides more strategic anticipation of weather conditions. On the other hand, pilots will have to learn how to deal with this new type of information to manage their flight and more generally within the framework of trajectory-based operations. In particular, they will be able to visualize, in real-time, their trajectory with respect to weather and traffic, and therefore make appropriate decisions. OWSAS also enables pilots to manipulate such integrated information and anticipate various kinds of situations (e.g., figure out possible what-ifs).

The first versions of OWSAS are stand-alone systems. We expect that OWSAS-3's synchronization with aircraft parameters will reinforce and enhance pilots' trust and figurative tangibility.

The provision and representation of weather information in OWSAS is still a main issue. A huge amount of weather information is available in different formats (e.g., textual, graphical) from different services (e.g., NASA, NOAA). Most of this information is relevant for 2D representations. So far, we focused on NEXRAD representation because the THREDDS catalog provided us with enough 3D information to represent it accurately (i.e., elevation, azimuth and distance from the ground station). However, we have not found relevant information to represent forecasts yet. In addition, professional pilots agreed during their interview on the fact that they would need other critical weather information such as wind shears and clear air turbulence. Our goal is to find visualization solutions for these phenomena and to integrate them in OWSAS as well.

Finally, HCD is not only about taking into account the potential users of the system but also the organizational aspect (i.e., the set of stakeholders that orchestrate aviation traffic in weather). Feedback from interviews with pilots mainly showed that air traffic controllers, dispatchers and airliners have a crucial role when flight trajectory modification is needed. Although these entities have not been taken into account in previous prototypes, they are currently and will be more developed in forthcoming work.

CONCLUSION

OWSAS-3 is work in progress, which integrates results from OWSAS-1 and OWSAS-2 formative evaluations. These test results are based on the use of realistic simulation means and involvement of professional pilots. We are working on OWSAS-3 context-sensitivity that involves connectivity with flight parameters and uses the protocols as the Onboard Context-Sensitive Information System [1], already developed at SHCDIA. We are also focusing on viewpoints that will be integrated in OWSAS in order to provide pilots with meaningful SA.

ACKNOWLEDGMENTS

We thank pilots De Vere Kiss and William Whipple for their knowledge and experience. We also thank Doctor Lucas Stephane for his advices and Quentin Grandin and Jasmine Abdelkrim for having helped designing weather representation solutions.

REFERENCES

1. Boulnois, S., Tan, W., Boy, G. A. (2015, August). The Onboard Context-Sensitive Information System for Commercial Aircraft. In *Proceedings 19th Triennial Congress of the IEA* (Vol. 9, p. 14).
2. Boy, G. (2012). Orchestrating human-centered design. Springer Science & Business Media, U.K.
3. Boy, G. (2016) Tangible Interactive Systems. Springer, U.K.
4. Chatty, S., Magnaudet, M., Prun, D., Conversy, S., Rey, S., Poirier, M. Designing, developing and verifying interactive components iteratively with djnn. In *Proceedings of the 8th European Congress on Embedded Real Time Software and Systems (ERTS2)*, 2016.
5. Evans, J. E., & Ducot, E. R. (2006). Corridor Integrated Weather System. *Lincoln Laboratory Journal*, *16*(1), 59.
6. Honeywell aerospace (2015). Weather Information Service. Available at: https://aerospace.honeywell.com/en/services/aerospace-services/weather-information-service.
7. Kessinger, C., Frazier E., Blackburn G., Lindholm T., Rehak N. (2015, January). A Demonstration to Validate the Minimum Weather Services for Oceanic and Remote Airspace., in *17th Conference on Aviation, Range, and Aerospace Meteorology*.
8. Laurain, T., Boy, G.A., Stephane, L. (2015, August). Design of an On-board 3D Weather Situation Awareness System. In *Proceedings 19th Triennial Congress of the IEA* (Vol. 9, p. 14).
9. Letondal, C., Zimmerman, C., Vinot, J. L., & Conversy, S. (2015, March). 3D Visualization to Mitigate Weather Hazards in the Flight Deck: Findings from a User Study, in *3DUI 2015, 3DUI 2015 IEEE 10th Symposium on 3D User Interfaces*. IEEE.
10. Wu, S. C., Luna, R., & Johnson, W. W. (2013, October). Flight deck weather avoidance decision support: Implementation and evaluation. In *Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd* (pp. 5A2-1). IEEE.