Turbulence ahead – Using JavaScript to Design a Web-based 3D Turbulence Simulator

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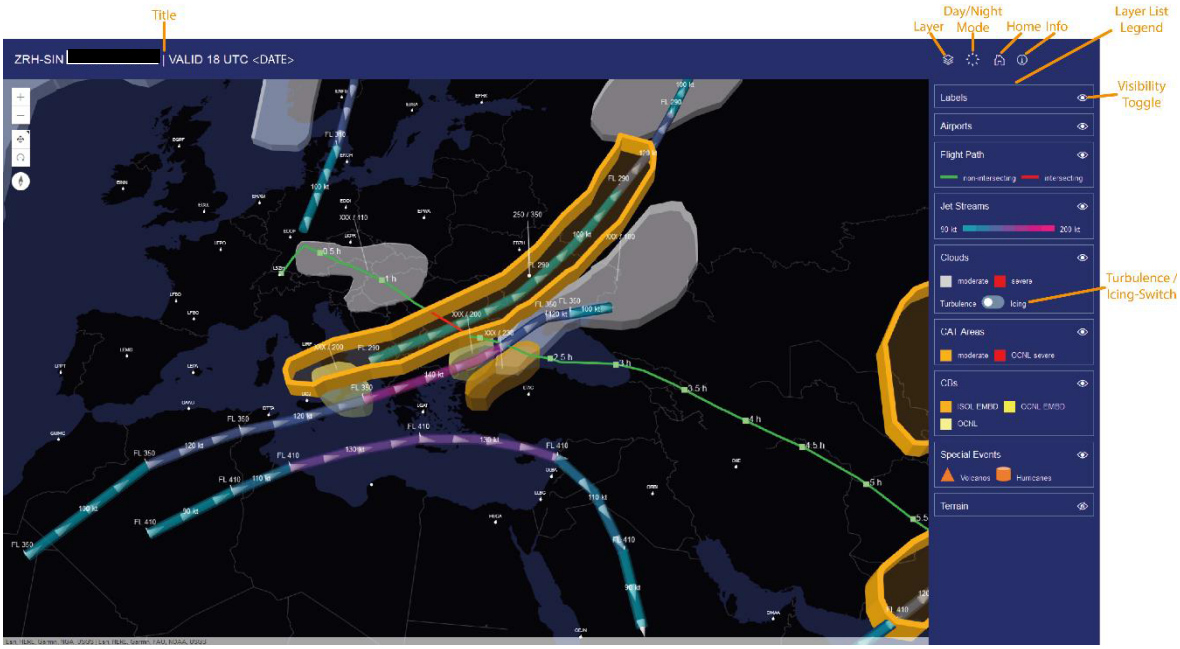

Figure 1: User Interface Design of the web-based 3D turbulence simulator as used in the user study

Abstract Although severe aircraft accidents have been reduced in the last decades, the number of injuries and fatalities caused by weather phenomena leading to turbulence is still rising. Current aviation weather products are unable to provide a holistic and intuitive view of the overall weather situation, especially in terms of turbulence forecasts. This master thesis introduces an interactive 3D prototype developed with a user-centered design approach. The prototype focuses on the visualization of significant weather charts, which are utilized during flight preparation. An online user study was conducted to compare the prototype with today's 2D paper maps. A total of 64 pilots from an internationally operating airline participated in the study. Among the major findings of the study is that the prototype significantly decreased the cognitive load and enhanced spatial awareness and usability. To determine the spatial awareness, a novel similarity measure for spatial configurations of aviation weather data was introduced.

Background Turbulence is still a major threat in commercial aviation. Whereas severe aircraft accidents have been reduced in general in the last decades, the number of injuries and fatalities caused by turbulence is still rising. Both prior to and during the actual flight, pilots evaluate their route for potential hazards. One of the aspects they consider, is the weather. Before each flight, pilots use weather forecast maps, so called Significant Weather Charts (SWC), to judge if and when they will encounter turbulence. Included in the Operational Flight Program (OFP), SWCs are forecast maps that are issued by the World Area Forecast Center (WAFC) four times a day and are used by pilots to prepare for flights. SWCs are 2D black and white maps depicting a selection of weather objects and hazard zones for potential turbulence. Also, pilots have only limited access to weather information in-flight. They assess the situation primarily by analyzing information from built-in weather radars, but those are difficult to interpret, even by experienced pilots, due to a limited range as well as a missing connection between the real-world situation (3D) and the information on the weather radar display (2D).

There is an ongoing discussion on the appropriate dimensionality of the weather data representation. Current weather products in general primarily utilize two-dimensional (2D) visualizations, even though the nature of airspace is three-dimensional. The lack of three-dimensional (3D) weather forecast systems used in commercial aviation is partly explained by the technical challenges of both data preparation and visualization but there are also mixed research findings concerning the potential of 3D displays. Technological advancements in the field of 3D graphics on the web as well as streaming services have opened up new possibilities for data visualizations of large amounts of weather-related data. However, to date, no 3D web-based application for forecast weather data has been introduced or evaluated in the context of commercial aviation.

Methods This master thesis presents a solution that exploits the recent technological advancements and creates a web-based 3D solution that visualizes significant weather charts. An interactive 3D prototype was developed with a user-centered design approach that displays the weather objects from the Significant Weather Charts (SWC). The front-end of the 3D web-based prototype is developed in JavaScript and primarily utilizes the ArcGIS JavaScript API, a 3D mapping framework which allows efficient streaming and displaying large amounts of 3D data. For the development of the application, the different weather objects depicted on the SWC map (e.g., jet streams) were projected into the third dimension by applying appropriate 3D web symbology. The design and functionality of the application was developed and evaluated in a pilot study with subject matter experts.

In a second step, the 3D prototype was compared to the 2D SWC map in an online user study. In total, 64 commercial aviation pilots from an international airline participated in the online survey. The major findings of the evaluation of the user study include significant improvements in cognitive load (-18.3\%), usability (+29.4\%) and spatial awareness (+24.4\%) when using the 3D application. A reduced cognitive load is desirable because pilots need to allocate information which requires a certain amount of mental resources and working memory. Releasing cognitive load allows pilots to shift their concentration to other tasks. Usability is described as the question of how well a user can use a system. Improving usability correlates with enhanced efficiency and accuracy of how pilots access a weather situation. Finally, spatial awareness describes the perception, comprehension and projection of objects in 3D space in relation to the individual location. As this is naturally linked to the task of assessing weather situations around an aircraft that is moving through 3D space, it is considered as one of the key factors that influences the design of instrument displays in aviation.

In order to assess spatial awareness, a novel similarity measure for spatial configurations of aviation weather data was introduced in this master thesis. The measurement calculates the similarity between a real weather situation and a mental representation drawn by the participants as sketch maps. The score is calculated based on topological and metric indicators as well as by considering qualitative and quantitative measurements.

In a final step, the 3D application was improved by adding dynamic content and features such as a wind simulation, an animated aircraft and animated weather objects over multiple time stamps to better predict where weather objects are moving. The final prototype is discussed with regard to general recommendations for aviation weather displays at the end of the report.

Conclusion and Outlook To conclude, this thesis explores and investigates the use of 3D web-based visualizations to display weather forecast data for commercial aviation pilots. The main contributions of this thesis are the development of a prototypical 3D SWC application, the execution of a user study which compares the prototype with the currently-in-use 2D SWC maps, and a further development of the application to a 4D prototype based on feedback from the pilots. In a next step, user studies with tablets will be executed to test the validity of the results. Additional weather sources such as grid-based atmospheric model data from meteorological services as well as weather radar will also be included to test in-flight use cases.