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Toward an Integrated Ecological Plan View Display for Air Traffic Controllers

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To cope with increasing demand on the air traffic management system, this paper proposes a novel user interface which supports air traffic controllers in conflict detection and resolution. The concept is based on previous work on 3D solution space displays for air traffic control, but then aimed at improving the interaction by better integrating speed, heading, and altitude constraints on the Plan View Display. A preliminary, subjective human-in-the-loop evaluation study was performed using five participants with various experience levels in real-life air traffic control. Results from the evaluation indicate that both successful use of the interface as well as the perceived support from the user interface depend on the participant's experience in air traffic control. The most experienced controller relied much less on the interface and found it the least useful. Future work is recommended for improving the user interface to better suit a controller's tasks.

The main responsibility of air traffic control (ATC) is the safe separation of aircraft. To resolve separation conflicts, controllers provide aircraft with heading, speed, and/or altitude clearances. Currently, the primary source of information to formulate such conflict-avoiding clearances is the Plan View Display (PVD). The PVD, however, is far from ideal as it requires controllers to integrate lower order aircraft state information, presented in flight labels, to action-relevant information in terms of what can and cannot be done to resolve a conflict. With the expected availability of high-quality digital datalinks between airborne and ground systems, the next generation PVD would allow for better information integration and improved visual representions that allow controllers to think more productively about the control problem they need to solve.

In previous research, the Delft University of Technology has designed a constraint-based interface for controllers to support aircraft separation by applying principles from Ecological Interface Design. The first version of this interface, called the Solution Space Diagram (SSD), provided conflict detection and resolution support in the horizontal plane by showing constraints on heading and speed of the aircraft to ensure separation from other traffic (Mercado Velasco, Mulder, & van Paassen, 2009). More recently, the SSD interface has been adapted by extending it to include the vertical dimension into its representation, allowing controllers to issue speed, heading, and/or altitude clearances (Lodder, Comans, Van Paassen, & Mulder, 2011). Despite a successful initial human-in-the-loop simulator trial, several issues came to light that made clear that the extended SSD could be improved by better integrating the available information.

First of all, the SSD display was a separate interface and thus not well integrated into the PVD. This made it difficult for controllers to divide their attention between the SSD and the PVD, especially in high traffic densities. Second, the controllers could not (quickly) relate the constraints rendered in the SSD with the aircraft shown on the PVD. This is especially a disadvantage for air traffic controllers, as they are responsible for multiple aircraft. Controllers would benefit from a more exocentric perspective that makes the relationships between aircraft salient, for example to solve a conflict cooperatively. Third, the SSD required cumbersome controller inputs to preview constraints on various flight levels before actually implementing an altitude clearance. For upper area control, where altitude clearances are usually the preferred means to solve conflicts due to small speed margins, such cumbersome interactions showed to be counterproductive, especially under high traffic densities.

This paper will describe the design and a preliminary subjective evaluation of an enhanced PVD that relies on the concepts of the original SSD for controllers, but is augmented with the goal to resolve aforementioned issues.

Previous Work

Solution Space Diagram

The solution space presents the constraints imposed on an aircraft's velocity envelope by the horizontal part of the conflict zone in a velocity diagram as shown in Figure 1. It shows which combinations of speed and heading will eventually lead to a loss of separation. The diagram is constructed by first calculating the velocities that will lead to a conflict with each surrounding aircraft, called the intruding aircraft. The calculated conflict zones (i.e., Forbidden Beam Zones (FBZs)) are then clipped by an annular section that has an internal radius equal to the minimum velocity, V_{min}, and an outer radius equal to the maximum velocity, V_{max}, of the controlled aircraft.

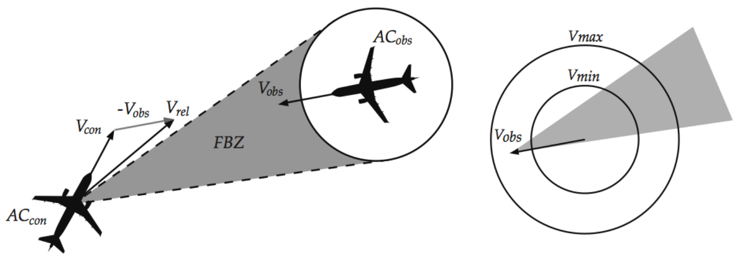

Figure 1. Conflict geometry and the resulting Solution Space Diagram (SSD) for the controlled aircraft AC_{con}.

A drawback of the solution space is that it is only presenting conflicts in the horizontal plane. Flying, on the other hand, is a three dimensional activity. This vertical component becomes especially important in climb and descent maneuvers. When only aircraft on the same altitude are shown on the display, it can not be used during climb and descent maneuvers.

Altitude-extended Solution Space Diagram

Lodder et al. (2011) showed how the FBZs from the SSD can be filtered when taking into account that aircraft can also be separated in altitude. When aircraft are separated in altitude and they stick to their altitude, the SSD of a selected aircraft just shows the conflict zones of all aircraft that are on the same flight level. However, when an aircraft is cleared to climb or descend to a different flight level, the conflict zones induced by aircraft on intermediate and the target flight level need to be taken into account. To this end, Lodder et al. (2011) proposed a method called Altitude Based Filtering to truncate the conflict zones of aircraft on intermediate flight levels by the time the cleared aircraft is located on a particular flight level. To add a safety margin to the truncated conflict zones, they took into account the fastest time and slowest time it takes for an aircraft to reach a particular flight level. These times not only included the aircraft climb and descend performances, but also fast and slow response times of the flight crew to react to an altitude clearance. For air traffic control, Lodder et al. (2011) designed a user interface based on this filtering of FBZs (Figure 2). The interface showed the PVD and next to it the conventional SSD for a selected aircraft. The controller could press ‘FL-’ and ‘FL+’ buttons to inspect for a target altitude of this selected aircraft, and the SSD would show the FBZ filtered for that target altitude.

(a) Plan View Display (b) Altitude-Extended SSD

Figure 2. The altitude-extended SSD interface as proposed by Lodder.

The disadvantage of this interface, is that it requires the controller to use these ‘FL-’ and ‘FL+’ buttons to find a resolution in altitude. The user will therefore have to mentally integrate these different altitude-filtered SSDs for different altitudes to build an image in three dimensions. Looking at the experimental results from the altitude-extended SSD, it seems that this caused problems for participants. Ideally, all constraints at all flight levels are visualized simultaneously to better plan an altitude clearance. Second, participants also had problems linking the conflict zones to the aircraft shown on the PVD. Third, the SSD was a separate interface next to the PVD, causing controllers to devide their attention between the PVD and SSD.

Proposed Improved Concept: Integrated Solution-Space Diagram (iSSD)

This section will introduce a new user interface for conflict detection and resolution: the Integrated and Interactive Solution Space Diagram (iSSD). The iSSD aims to provide the air traffic controller with better insight into inherent constraints and relations of the ATC work domain compared to the altitude-extended SSD. The iSSD mainly consists of the Speed-Heading Diagram (SHD) and the Altitude-Heading Diagram (AHD) (Figure 3). It is assumed that the iSSD, consisting of the AHD linked to the SHD, will give the air traffic controller a more integrated three-dimensional image of the work domain constraints and relations, so that the air traffic controller can more easily use altitude, heading and speed clearances as a means for separation. By also making the links between aircraft the conflict zones more salient, the iSSD should have the potential to overcome the disadvantages of the altitude-extended SSD.

The first noticable improvement is that the iSSD is now directly portrayed on the PVD instead of a separate interface. When selecting (i.e., clicking on) an aircraft on the PVD, the iSSD of the selected aircraft is opened. The diagram between the inner dashed circle and the outer thick circle represents the SHD, which is in fact the altitude-extended SSD, as was previously described. In this diagram it is possible to click on the conflict zone to highlight the aircraft that is responsible for the conflict zone. The Altitude-Heading Diagram (AHD) is a new visualisation, which shows safe combinations of altitude and heading to maintain separation for a selected aircraft. This diagram directly shows all altitude constraints on different flight levels. The AHD is a visualisation which uses a polar coordinate system. The radial angle is equal to aircraft heading. An increase in radius equals an increase in altitude. Since screen estate is limited, it is impossible to always display all possible altitudes with this coordinate system. Considering upper area control, there are reasonable limits that can be put on the range of altitude that is depicted. To address the issue of low display resolution in altitude, it was chosen to locally magnify altitude based on the position of the mouse cursor on the AHD. As an example, Figure 3 shows that the selected aircraft (on FL 330) has a conflict with another aircraft on the same flight level. This conflict is shown in the SHD. To resolve the conflict, a heading and/or speed change in the horizontal plane can be considered. Alternatively, a flight level change can be commanded using the AHD. The AHD in Figure 3 shows that at the current flight level and heading (i.e., green marker) a conflict is present, and also that by increasing the flight level another conflict will be triggered with the aircraft on FL 340. Because there are no conflict zones a flight level below, the selected aircraft can safely be cleared to FL 320 and continue to fly straight. Another possible solution visible within the iSSD is a heading change to the left with an altitude increase.

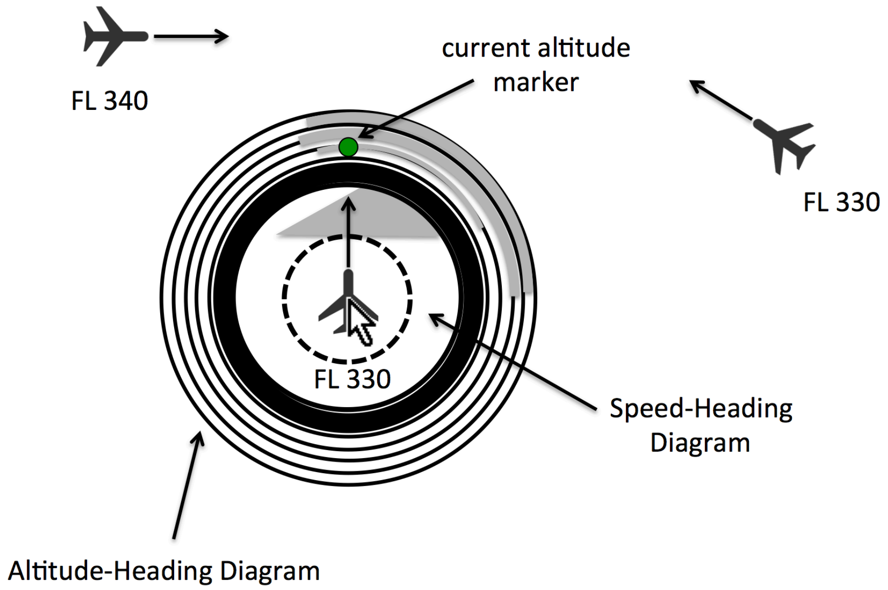

Figure 3. The iSSD interface consisting of the SHD and AHD centered around a selected aircraft.

Subjective Evaluation Study

Goal and Tasks

An initial human-in-the-loop evaluation was conducted to verify whether the iSSD was indeed able to provide support in conflict detection and resolution in various traffic scenarios (Figure 4). It was not expected that in the short available amount of time (i.e., one day per participant), participants would be able to use all the information from the iSSD. This would require extensive training. The goal, therefore, was to get initial understanding on the user interaction, get feedback on the interface and verify some of the expected support that the iSSD should provide, with particular regard to the novel interface elements of the iSSD.

An important criterion for the design of the evaluation was that participants would use the iSSD in such a way that it would reflect real-world behaviour in a demanding situation. It was therefore decided to let the participants control traffic in a sector, in which the traffic was simulated without speed- up, so that participants had some time to plan and consider options. During the simulation, the goals for the participant were threefold. In order of importance they were:

1) Maintain separation, either five nautical miles horizontally or 1,000 feet in altitude.
2) Ensure that aircraft exit the sector at the required exit altitude and within five nautical miles from the required exit point.
3) Let aircraft fly towards the required exit point at the required altitude as soon as possible.

The secondary goal reflects a restriction that occurs in real-world settings as a hand-over criterion between sectors. The tertiary goal can be seen as a more immediate request for a specific aircraft state, which for example occurs when an aircraft wants to fly at an optimal flight level. Together, the secondary and tertiary goals were introduced to allow for more control of the evaluation, in order to see whether the iSSD supported participants to meet such a specific demand for aircraft state.

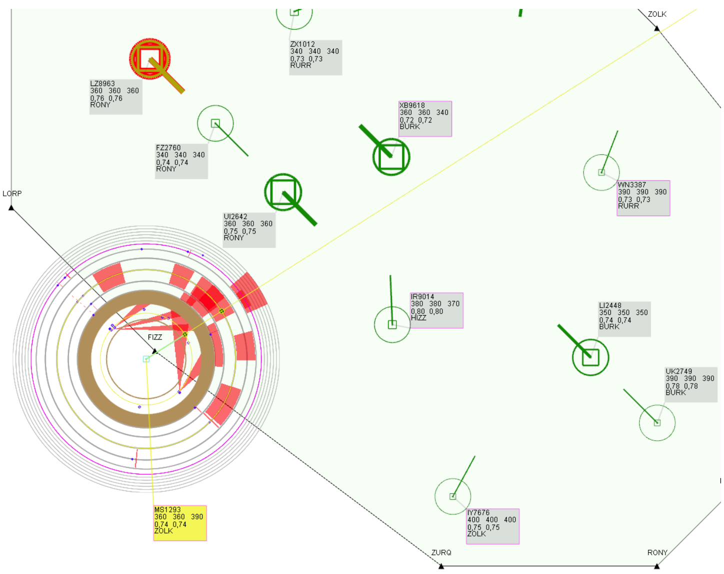

Figure 4. The iSSD prototype as integrated on the PVD, showing one of the four traffic scenarios used in the evaluation.

Participants

The sample of participants were all familiar with the aviation domain. Participants were chosen such that a wide mix existed in the level of experience that participants had with the original SSD and their experience in air traffic control. This resulted in participants with no experience with the SSD to participants who were experts with the original SSD. Regarding previous ATC experience, the lowest level of experience consisted of some hours of experience with simulated arrival management, while the most experienced participant had many years of active service at different control stations.

Results

The results of the questionnaires and the observed interaction with the iSSD showed large differences between participants. All participants without real-world ATC experience seemed to appreciate and heavily rely on novel elements of the iSSD. Without the iSSD, they indicated that controlling the various traffic scenarios would have been very difficult. However, the more experience a participant had in ATC, the less the participant made use of the iSSD to control traffic. The most experienced controller reported an increase in workload due to the iSSD and mainly used the iSSD as a "verification tool" to confirm the solution he already invented by simply using the information from the flight labels. As such, the proposed iSSD was in his opinion too wild to be of any use in a real operational setting. Finally, it was also found that the iSSD provided too much information and that the diagrams occasionally obscured the traffic pircture, resulting in clutter under high traffic densities.

Conclusion

The newly proposed interface, called the iSSD, was designed to support air traffic controllers in maintaining safe separations between aircraft by integrating low-level state information in a way that allows them to deduce action-revelant information (i.e., heading, speed, and/or altitude clearances). A brief subjective evaluation of the interface revealed that the level of ATC experience played an important role in finding the interface useful and how it was used. Whereas inexperienced participants relied most on the iSSD to control traffic, the most experienced controller mainly used the iSSD to verify his own solutions and found the iSSD to increase the workload and hinder the traffic picture on the PVD. Future work will look into integrating heading, speed, and altitude constraints in a better and perhaps simplified way to reduce clutter.

References

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