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A REVIEW OF INSTRUCTION METHODS FOR COLLISION DETECTION AND AVOIDANCE

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Abstract

Timely detection and avoidance of collisions is crucial in both road and air transportation. Automated collision warning and avoidance systems use sensors, algorithms and actuators for collision prediction and avoidance. People must rely on their senses and mental models to detect traffic and accurately estimate collision parameters. Unfortunately, the failure to detect other traffic and to prevent imminent collisions is a major safety risk for both road and air transportation. Research on the use of traffic advisory systems in visual flight rules (VFR) flight shows that an automatically generated warning does not eliminate the safety risk by itself because many pilots select avoidance manoeuvres that are not conforming to the rules and may even be unsafe. In parallel to the spread of automated collision warning systems the training of VFR pilots must progress. This study reviews scientific studies and safety recommendations for collision detection and avoidance in flight according to visual flight rules. In addition, the study presents training aids and gives an overview of instructional methods that have been tested in experiments. Generally, research shows that specific training performed in the flight simulator is effective for improving the estimation of collision parameters (e.g., time to collision, relative distance), the decisionand performance of rule-conforming avoidance manoeuvres. Future theoretical and practical developments, including the potential benefits of virtual and augmented reality are discussed.

Keywords: Collision avoidance, instruction methods, pilot training, visual flight rules, virtual reality, augmented reality.

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1. Introduction

A critical ability of people involved in vehicle control is the avoidance of loss of separation and collisions with other vehicles. Automated systems for collision warning and avoidance use sensors, algorithms and actuators for collision prediction and avoidance (Haberkorn, Koglbauer, Braunstingl, &Prehofer, 2013; Haberkorn, Koglbauer, & Braunstingl, 2014; Koglbauer, Braunstingl, & Haberkorn, 2013; Koglbauer et al., 2014; Koglbauer, Holzinger, Eichberger, & Lex, 2017). Notwithstanding the usefulness of automated aids when available, people in charge for controlling vehicles must be able to use their senses and knowledge for detecting traffic and accurately estimate collision parameters. Research shows various biases in the estimation of collision parameters such as the time to collision and relative distance between vehicles (Hancock, & Manser, 1997; Koglbauer 2015a,b; Koglbauer, Braunstingl, Haberkorn, & Prehofer, 2012; Koglbauer, Eichberger, Lex, Bliem, Sternat, Holzinger, Schinko, & Battel, 2015). Furthermore, research on collision avoidance shows that people often use heuristics for conflict resolution and that they do not always conform to the rules (Coso, Fleming, & Pritchett, 2011; Koglbauer & Braunstingl, 2018; Rantanen & Wickens, 2012).

2. Main Body

In air transportation the failure to detect other traffic and to prevent imminent collisions is a major safety risk (EASA, 2015; FAA, 2015). Midair collision was shown to be one of the most frequent occurrences during flight training (Lee, Bates, Murray, & Martin, 2017). An improvement of the flight training procedures for including traffic awareness and collision avoidance has been recommended by several authors (Koglbauer & Leveson, 2017; Lee et al., 2017; Shook, Bandiero, Coello, Garland, & Endsley, 2000). This study aims to provide a checklist for flight instruction on collision detection and avoidance based on scientific concepts and experimental studies. Besides the content of the instruction, the study also discusses pros and cons of the simulated and real environments that can be used for such training. Future theoretical and practical developments are discussed.

This study identifies relevant concepts, models and research relevant for the specification of a training guideline for collision detection and avoidance in flight according to visual flight rules (VFR). Using the SEEV model of selective attention (Wickens, 2015; Horrey, Wickens, & Consalus, 2006) it can be postulated that the probability of detecting traffic depends on the characteristics of the traffic salience, the effort for scanning the environment, the expectancy to encounter traffic and the value or importance of detecting traffic. As both traffic detection and collision avoidance take part in a dynamic, multitasking environment, the prediction of human performance must consider the multiple resource model (Wickens, 2002). In addition, the study discusses instructional methods for collision detection and avoidance. These methods were effective in improving the timeliness of traffic detection (Eichberger et al., 2018), the estimation of collision parameters (e.g., time to collision, relative distance), and the selection of rule-conforming avoidance manoeuvres (Koglbauer, 2015b).

3. Methodology

In this study qualitative methods such as task analysis and the literature review are used. The task of collision avoidance in Visual Flight Rules (VFR) flight can be divided in the following sub-tasks:

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scanning, traffic detection, estimation of time to collision and relative distance, decision about the conflict and VFR rules for collision avoidance depending on the type of traffic and collision geometry, action selection, execution, and evaluation. In case that the collision was successfully avoided, the pilots must return to their route. In case that the collision is still imminent the pilots must adjust their avoidance manoeuvre.

3.1. Content of the Training

- Visual Scanning

The methods for visual scanning of the environment outside the cockpit and monitoring the radio communication are described in detail in the Safety Bulletin (AOPA, 2018; EGAST,2011). However, the successful detection of traffic depends not only on the scanning technique, but also on psychological factors. For improving the performance predicted by the SEEV model (Wickens, 2015) training should address the effortful head movements necessary for detecting traffic, task-sharing in multitasking situations, the expectancy to encounter traffic and the importance of detecting traffic.Anticipative information processing in flight can be trained using a method described by Koglbauer (2009). In addition, benefits and limitations of new and conventional traffic displays for VFR have been assessed during simulation experiments (Haberkorn et al., 2013; 2014).

- Estimations of the time to collision and relative distance

In a flight simulator study Koglbauer (2015b) showed that student pilots initially overestimate the time to collision and relative distance to other airplanes. Thus, the student pilots that identify other traffic on collision course think that they have longer time to collision and relative distances than they really have (Koglbauer, 2015b). However, Koglbauer (2015b) showed also that when student pilots received feedback on their estimations during training in the flight simulator, they significantly improve the accuracy of their estimations.

- Decision and Action

Two decisions are crucial for successful collision avoidance: decision if there is a conflict or not, and the decision about the avoidance manoeuvre. VFR pilots need not necessarily use a traffic display for detecting traffic. They can rely on their visual scanning and radio communication messages (AOPA, 2018; EGAST, 2011). The effect of traffic displays on the accuracy and timeliness of pilots' conflict decisions was investigated by Haberkorn et al., (2014). The study showed that new displays that use predictive cues and present icons for the type of traffic, directional and relative track cues allow faster conflict decisions and are preferred by pilots as compared to conventional displays (Haberkorn et al., 2014). After the pilots decide that there is an imminent collision, or after they receive a warning from a traffic advisory system they must select an avoidance manoeuvre. Pilots' difficulties in selecting and executing rule-conforming collision avoidance manoeuvres were demonstrated in several studies (see for example Koglbauer et al., 2013; Haberkorn et al., 2013; Wickens, Hellenberg, & Xu, 2002). Using the Systems-Theoretic Process Analysis (STPA) Koglbauer and Leveson (2017) identified potential causes and counter-measures for unsafe avoidance actions, including non-actions. However, Koglbauer (2015b) showed that student pilots significantly improve their avoidance decisions after practical training in the flight simulator. In addition, Koglbauer and Braunstingl (2018) showed that training in a network of flight

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simulators significantly improves the situational awareness and performance of flight students in complex traffic situations where more aircraft are involved in taxi, departure, and approach procedures. The multitasking training designed and evaluated by Koglbauer and Braunstingl (2018) can be applied effectively with *ab initio* student pilots at the beginning of their training program. The limited multitasking capacity of individuals is well explained by the multiple resource model (Wickens, 2002). However, research shows that training with the Variable Priority (VP) method can improve the ability of individuals to juggle several tasks (Eichberger et al., 2018; Gopher, Weil, & Siegel, 1989).This is important because research shows that skills acquired during part-task training may not transfer to a multitasking situation (Gopher et al., 1989).

3.2. Training Aids

In Table 01 an overview of training aids for collision avoidance in VFR flight is presented. The table lists advantages and disadvantages of the training aids.

Table 01. Analysis of training aids for collision avoidance in VFR flight

Type	Advantage	Disadvantage	Relevant Study
Written briefing	Text and drawings are easy to produce. The information can be provided in the intranet or as a portable hand-out version.	Written information does not seem to be enough. Students need practice and feedback for improving their collision avoidance performance.	AOPA, 2018; EGAST (2011); Koglbauer (2015b); Koglbauer & Braunstingl (2018)
Tablet PC	The position of the own aircraft and other traffic displayed on a moving-map helps student pilots to develop a mental model of the traffic situation.	A wireless connection with the flight simulator is necessary and may not be available in every flight simulator. Currently there are only proprietary solutions available.	Koglbauer (2015b,c); Koglbauer & Braunstingl (2018)
Conventional flight simulator	Other traffic can be displayed in the environment outside the cockpit. Typical traffic configurations can be saved in a “Traffic generator” module (non-collision and collision geometries: overtaking, opposite and crossing traffic with different vertical profiles - climb, descend, cruise)	Traffic generators are currently not available for every flight simulator. Currently there are only proprietary solutions available. The visual system of conventional flight simulators is limited (e.g., 190-degree lateral outside visual scenery)	Koglbauer (2015b)
Network of flight simulators	Students can see other traffic and develop a mental picture of the traffic situation based on the simulated radio communication.	Currently there are only proprietary solutions available.	Koglbauer (2015c); Koglbauer & Braunstingl (2018)
Virtual Reality (VR)	The head-mounted display has a limited field of view, but if head movements are used, it provides all-round view of the outside scenery. It is cheaper to produce than a conventional hardware simulator.	A performance decrement and an increase in workload and simulator sickness have been reported with the current VR technology.	Oberhauser, Braunstingl, Dreyer, & Koglbauer (2018)
Augmented Reality (AR)	Elements that the student otherwise must imagine can be augmented into the real world view (e.g., correct scanning patterns, position of other traffic). It is cheaper than a conventional hardware simulator.	Currently, AR goggles have a limited field of view and need an relatively large unobstructed space for the projection of AR contents	Koglbauer et al. (2018); Oberhauser et al. (2018)

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3.3. Practical applications

For aiding the design of training programs, examples of exercises described in research studies are presented in Table 02.

Table 02. Examples of exercises for collision avoidance in VFR flight

Objectives of the exercises	Exercises
The student demonstrates a correct visual scan	**In the aircraft and in the flight simulator** The instructor demonstrates the appropriate scanning pattern using written briefing materials (AOPA, 2018; EGAST, 2011), VR or AR technologies. The student performs visual scanning during taxi and flight and receives feedback from the instructor. The time share of scanning the cockpit and the outside scenery, as well as the use of traffic displays should be considered (EGAST, 2011).
The student accurately estimates the time to collision and relative distance	**In the flight simulator with at least 190° lateral outside visual scenery** This exercise is particularly important because most of the *ab initio* students are not used to estimate distance in Nautical Miles and their estimation of time to collision may be biased (Koglbauer, 2015a). The instructor generates traffic in the flight simulator and gives the traffic information as usually provided by the flight information service (e.g., "opposite traffic at 1 o'clock, 2 Nautical Miles, same altitude"). The student flies in the simulator, acknowledges the traffic information, scans the environment and announces "traffic in sight" and tries to estimate the time to collision and relative distance. The instructor freezes the simulation and gives the student feedback about the real time to collision and relative distance. With feedback and repetitions the students improve the accuracy of their estimations (Koglbauer, 2015b). Key elements are students' understanding of how the relative speed varies in different collision geometries: Higher relative speed in opposite configurations, lower relative speed in overtaking situations.
The student decides and acts according to the rules of the air and within the safety envelope of the aeroplane	**In the flight simulatorwith at least 190° lateral outside visual scenery** The instructor generates traffic in the flight simulator and gives the traffic information as usually provided by the flight information service. Exercises can include non-collision and collision scenarios (e.g., overtaking, opposite and crossing traffic with different categories of air vehicles that determine the right-of-way) (Koglbauer, 2015b). The student flies in the simulator, acknowledges the traffic information, scans the environment and announces "traffic in sight". At this time the instructor can freeze the simulation, checks three elements and gives feedback to the student: (1) Does the students interprets the situation as a conflict? (2) If an avoidance manoeuvre is necessary, does the student select a rule-conforming manoeuvre? (3) Is the avoidance manoeuvre performed correctly (e.g., appropriate bank and return to the planned route). Initially the freezing of the simulator is necessary, but as soon as the students are able to take the right decisions there should be a number of repetitions without freezing. Key elements are students' understanding of relative kinematics in crossing conflicts because many students erroneously believe that manoeuvring "behind" the other traffic would aggravate the conflict. Common failures are descent instead of turn, but this could lead to a conflict if the other traffic descends, too. Students need to think of coordination with the conflicting traffic and see themselves as a part of a larger system (Koglbauer & Leveson, 2017). Students may also fail to recall that the type of conflicting air vehicle can change the right of way. **In the aircraft** These types of exercises can be performed in the aircraft, too, but without real traffic. The instructor gives traffic information (e.g., "opposite traffic at 1 o'clock, 2 Nautical Miles, same altitude"). The instructor checks two elements and gives feedback to the student: (1) Does the student select a rule-conforming manoeuvre? (2) Is the avoidance manoeuvre performed correctly? **In a network of flight simulators** Exercises for procedures in the congested traffic pattern are described by Koglbauer and Braunstingl (2018).

4. Conclusion

Loss of separation between aircraft is a major safety risk in air transportation (EASA, 2015; FAA, 2015). In addition to the introduction of traffic displays and warning for VFR flight an improvement of the flight training procedures for collision avoidance has been recommended (Koglbauer & Leveson, 2017; Lee et al., 2017; Shook et al., 2000).The use of simulation technology can be seen as a safer training alternative (Koglbauer & Braunstingl, 2018). This study provides a checklist for flight instruction

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on collision avoidance based on a review of scientific studies and safety recommendations of aviation expert groups (AOPA, 2018; EGAST, 2011).Research shows that specific training performed in the flight simulator is effective for improving the estimation of collision parameters (e.g., time to collision, relative distance), the selection and the performance of rule-conforming avoidance manoeuvres. The use of complex multitasking training scenario is recommended (Eichberger et al., 2018; Gopher et al., 1989; Koglbauer & Braunstingl, 2018). Future improvements are expected from the use of virtual and augmented reality technologies.

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