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TOWARDS WIDE-FIELD DISPLAY OF THE GRIPEN HUD INTERFACE TO COMBAT SPATIAL DISORIENTATION

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The head-up display (HUD) interface of the Gripen fighter aircraft utilizes a sphere concept for supporting attitude awareness or spatial orientation (SO). With the sphere interface fixed to the gravitational vertical and the attitude variant aircraft positioned in the center of the sphere, the HUD field-of-regard scans parts of the sphere inside. The HUD interface depicts segments of latitude circles with meridian markings that convey integrated information of pitch, roll, and yaw. To enhance pilot-in-the-loop maneuvering and SO we suggest a wide field-of-view interface design of the Gripen concept, emphasizing the inclusion of peripheral vision. The suggested interface is subsequently integrated with peripheral visual flow to improve SO primarily in instrument meteorological conditions. Implemented in future head-up flight displays systems it could perhaps contribute to a more successful combating of pilot spatial disorientation.

Introduction

To combat pilot spatial disorientation (SD) in fighter aircraft more effectively is a challenge requiring several types of interventions (e.g. Previc & Ercoline, 2004; Small, Wickens, Oster, Keller, & French, 2004). An evolution towards intuitive and more integrated interfaces is one prerequisite for promoting more reliable and safer pilot peak performance. Interface approaches utilizing several sensory channels play key roles in this respect. Integrated auditory, tactile, and visual displays could have a decisive impact on situation awareness (SA), performance, and perceived spatial orientation (SO) (Bles, 2004; Parker, Smith, Stephan, Martin, & McAnally, 2004; Small et al., 2004; van Erp, Veltman, van Veen, & Oving, 2002; Veltman, Oving, & Bronkhorst, 2004). On the other hand, automatic systems for ground and air collision avoidance (GCAS and ACAS) prevent SD accidents by overriding pilot-in-the-loop control. Peak performance in fighter aircraft nevertheless requires a proactive maneuvering by a pilot in the loop. Thus, these reactive automatic systems do not neutralize the need to enhance the pilot's SA, nor the more specific aim for better support of SO or attitude awareness. Furthermore, the crucial sensory information of external frame of reference and events is visual, and the efforts to improve visual interfaces per se thus continue because of the critical role vision plays.

The risk for SD increases in instrument meteorological conditions (IMC) (e.g. Previc, 2004), and judging pitch and bank by referring to the artificial instruments in fog or darkness is less accurate and compelling than viewing the outside ground with horizon in good visibility (Ercoline, DeVilbiss, & Evans, 2004; Gillingham & Previc, 1993). Thus, the flight instruments or visual interfaces show less than acceptable effectiveness. It can be argued that they ought to be in better resonance with the natural mode of perceiving SO (e.g. Eriksson & von Hofsten, 2005; Leibowitz, 1988; Malcolm, 1984). The interfaces need to intuitively convey integrated information for maneuvering and to generate an accurate and compelling perception of SO (Ercoline et al., 2004; Eriksson, 2005). Along these lines, and anticipating further advances in visual displays technology, we present some ideas aiming for improving pilot-in-the-loop maneuvering and SO. First, we present the basic principles for the head-up display (HUD) interface of the Gripen fourth generation fighter aircraft that conveys integrated information of pitch, roll, and yaw. Second, we apply the Gripen HUD interface to a wide field-of-view (FOV) display format to incorporate peripheral vision. Third, we integrate the interface with flight-adapted peripheral visual flow.

The Gripen HUD interface

Figure 1 illustrates the Gripen HUD interface as principally appearing during horizontal flight in visual meteorological conditions (VMC), including the flight parameters altitude, speed, flight path marker/velocity vector, G-load, angle of attack (AoA), and heading. Horizon-line and "pitch lines" with "yaw markings" are also indicated. (Note: All illustrations of the Gripen HUD interface depict basic principles/configurations and not actual symbology in detail.) The HUD interface incorporates a sphere concept as reference frame for maneuvering and

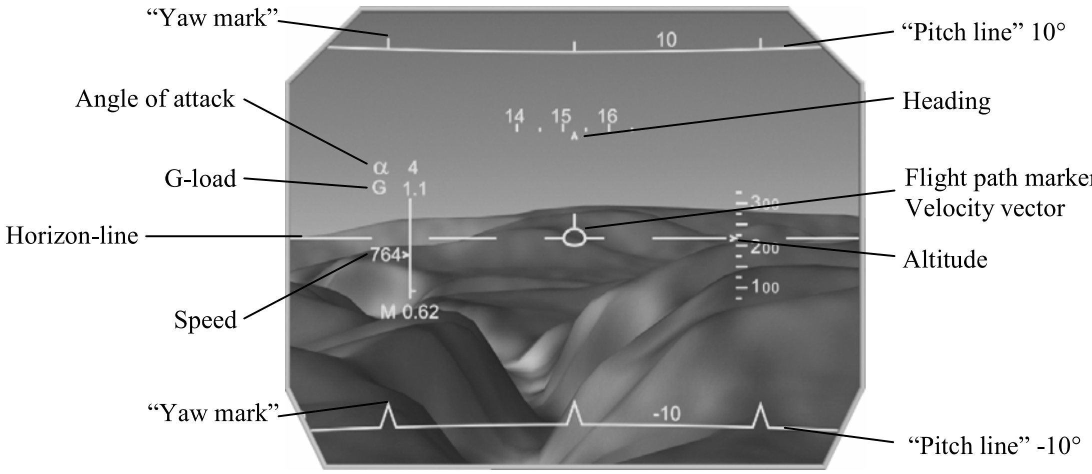

Figure 1. An illustration emphasizing basic principles of the Gripen HUD interface with flight parameters superimposed on the environment in VMC.

perceiving SO with the flight parameters. Although the attitude of the aircraft varies, it is permanently positioned in the center of a sphere that has its vertical axis fixed to the gravitational vertical. The sphere consists of latitude circles at each 10° pitch deviation from the horizontal up to 80°, with the latitudinal great circle of the sphere equal to the horizontal and depicted as a straight line. See horizon-line and "pitch lines" in Figure 1. That is, the HUD depicts segments of latitude circles showing increasing curvature with increasing deviation from horizontal. The full zenith circle is shown when the aircraft is pointing straight up and the nadir circle pointing straight down. Together with meridian markings on the latitude circles, integrated information of pitch, roll, and yaw is conveyed. The meridian markings are different on dive-circles compared to climb-circles to make them easily distinguishable. They could be called "yaw markings" because they indicate yaw position or, more important, change in yaw position. Figure 2 illustrates a pitch-up sequence with no change in yaw or roll position. The sequence goes from horizontal flight with an actual 4° pitch attitude of aircraft, with velocity vector (flight path marker) at 0° and AoA of 4°, to 75° pitch attitude, with velocity vector at 90° and AoA of 15°. Metaphorically put, the sphere concept corresponds to viewing parts of a large ADI ball from its inside (ADI - Attitude Director Indicator).

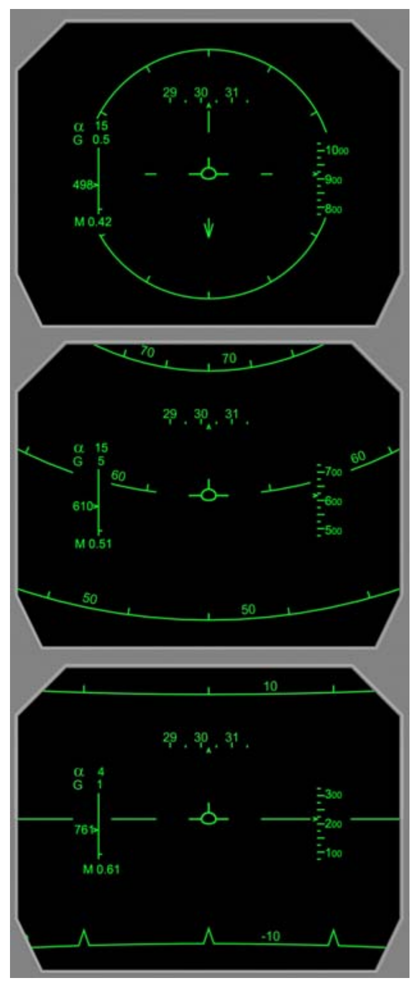

Figure 2. From bottom to top: Pitch attitude of 4° with velocity vector at 0°, 75° pitch-up with velocity vector at 60°, and 75° pitch-up with velocity vector at 90°.

Operative for quite awhile in the Gripen aircraft, the overall intuitive design and the consistent dynamics of integrated pitch, roll, and yaw have received appreciation from pilots. One aspect of the consistent dynamics is revealed in transitioning from flying upwards in upright orientation to flying downwards upside-down when performing a looping. In comparison to a "regular pitch-ladder design" that will turn over the up – down orientation of the horizon-parallel line-segments, the sphere interface shows stability. The transition from flying upwards to downwards only means that the HUD field-of-regard transitions smoothly and stable to scanning the opposite side of the sphere, and flying inverted still entails that climb-circles segments bend upwards and dive-circles segments downwards.

A wide FOV interface design

Visual field coverage is of course an important factor in displays developments, and an increased FOV incorporating the peripheral visual field could improve the support of SO (Leibowitz, 1988; Wickens & Hollands, 2000). Because of the constraints for flight displays technology, however, suggestions of interface designs naturally emphasize central vision (e.g. Flach, 1999; Previc & Ercoline, 1999). The Malcolm Horizon projected on the instrument panel and the Background Attitude Indicator (BAI) on head-down displays can be considered exceptions (Comstock, Jones, & Pope, 2003; Ligget, Reising & Hartsock, 1999; Malcolm, 1984). Still, HUDs and helmet mounted displays (HMDs) allowing peripheral visual field presentation to great extent are yet to be realized. However, it is relevant to investigate the fundamentals for an interface design applied to a large FOV display format simply because of the advancement of displays technology.

One disadvantage with the emphasis of current flight displays on central vision is that they therefore primarily depend on directed attention. Furthermore, the functional dichotomization of vision into focal and ambient subsystems represents two separate perceptual modes (e.g. Leibowitz, 1988). The focal processes the most central part of the visual field and the ambient utilizes the entire visual field. Focal is primarily associated with object and event detection/identification and ambient with spatial awareness and SO (linked to the parallel parvo- and magnocellular channels). Information for SO is thus primarily provided by ambient vision that is typically not contingent on attention, and increasing the FOV to include peripheral vision could improve spatial awareness, SO, and the support of maneuvering. In particular, compared to a Malcolm Horizon, or a head-down BAI, a wide FOV utilizing the Gripen HUD concept has the advantage of integrating not only pitch and roll, but also yaw. An illustration of an application of the Gripen concept to a wide FOV is shown in Figure 3.

Goals in the US Air Force Displays Vision include a definition of a "panoramic" class of SA (Tulis, Hopper, Morton, & Shashidhar, 2001). The *"basis for identifying the panoramic SA goal comprises such factors as the excitation of peripheral vision cues for horizontal viewing fields greater than about 100 degrees and the opportunity to present integrated display formats"* (Tulis et al. 2001, p. 11). The Panoramic Night Vision Goggle (PNVG) has accordingly a FOV of about 100° by 40° (horizontal by vertical) (e.g. Geiselman & Craig, 1999; Jackson & Craig, 1999). Interestingly, a PNVG with superimposed computer-generated symbology is also an emergent further development, i.e. symbology overlay on the PNVG mediated night scene made possible by miniature flat panel displays (or similarly). Thus, applications of interface designs extending far outside the central visual field could perhaps include PNVGs, if not HUDs or HMDs.

Peripheral visual flow integration

The risk for SD accidents increases in IMC despite intense training, experience, and hammered-in instructions to fly by the instruments. It seems as if the pilot's perceptual processing is not in contact with crucial factors that contribute to overcoming erroneous perceptions of SO. Display interfaces not only ought to go beyond central visual field in IMC, they ought to utilize the ambient system more effectively. The ambient visual system is primarily in resonance with motion elements grouped over larger areas, as with locomotion generated optic flow (e.g. Gibson, 1966; Johansson & Börjesson, 1989; Lee, 1980). Visual flow (optic flow) can even dominate proprioceptive and equilibrium sense information (e.g. Lishman & Lee, 1973). In particular, flight-adapted visual flow with combined expanding and rotational motions seems to sensitize the visually guided SO system, demonstrating an effective suppression of vestibular and proprioceptive information. (Unless desired to lose balance, one ought to hold onto something standing in a dome fixed platform flight-simulator and viewing a flight maneuver visually represented as a "roll movement of the ground".) A wide FOV interface could utilize an artificial visual flow to suppress erroneously perceived SO based on proprioception and the vestibular sense.

The opto-kinetic cervical reflex (OKCR) involves a lateral tilt of the pilot's head towards the horizon during aircraft roll maneuvers and reveals itself in VMC but not IMC (e.g. Patterson, Cacioppo, Gallimore, Hinman, & Nalepka, 1997). While the spatial frame of reference lies outside the aircraft in

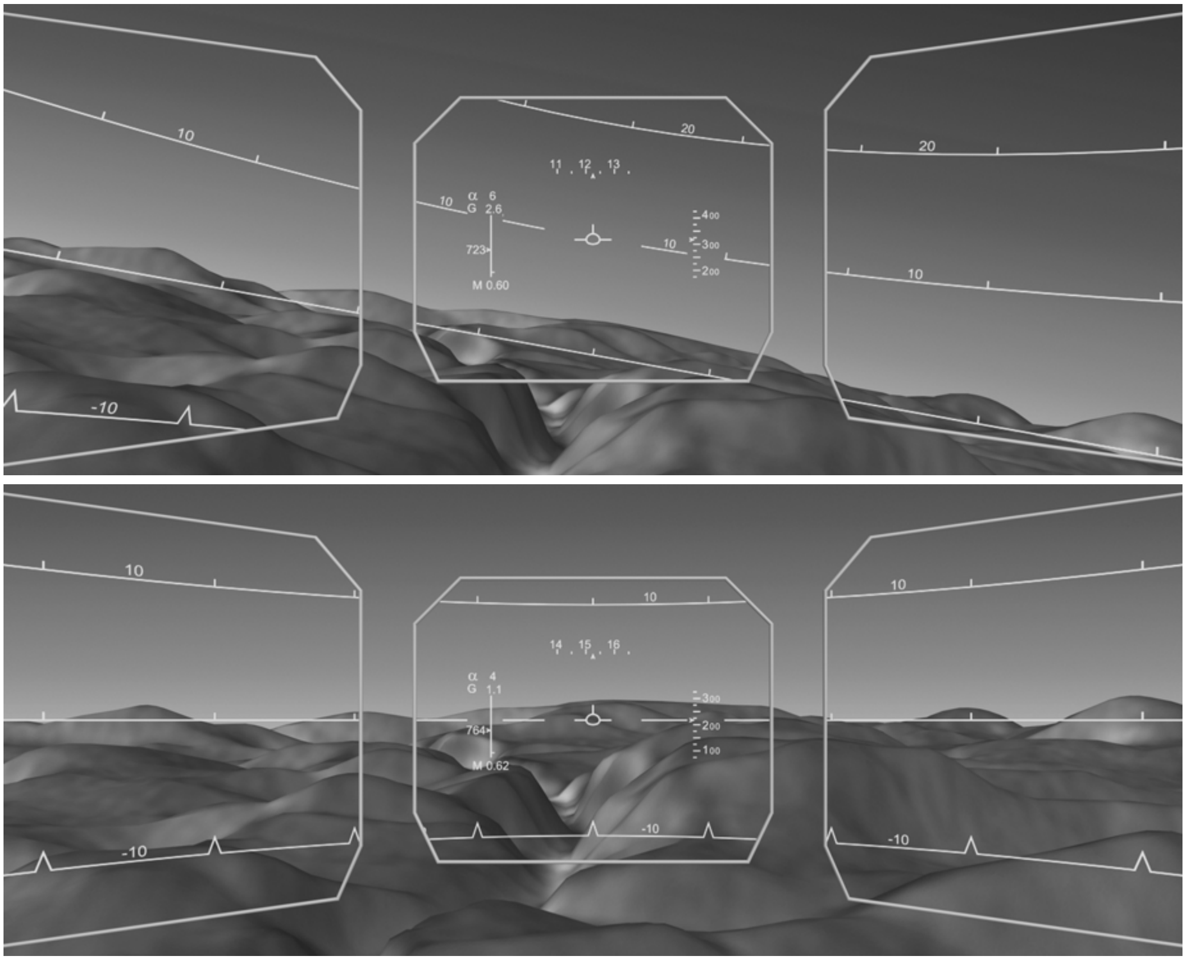

Figure 3. The Gripen HUD concept applied to one version of a wide FOV interface design. The illustrations show horizontal flight at the bottom, and a roll position in a pitch attitude above horizontal at the top.

VMC, it is situated inside the aircraft in IMC (Johnson & Roscoe, 1972; Patterson et al., 1997). A presentation of an artificial peripheral visual flow combined with conformal horizon-line information in central visual field could perhaps trigger the same sensory reflexes in IMC as occur in VMC (e.g. Eriksson, 2005; Eriksson & von Hofsten, 2003, 2005). Figure 4 illustrates a flight sequence with an IMC mode of the suggested interface that includes flight-adapted peripheral visual flow, i.e. visual flow represented by the black & white textured ground. Improved spatial awareness and lowered mental workload could be some of the effects of a triggered OKCR in IMC (see Patterson et al., 1997, for a qualitative model of SO in VMC and discussion of HMD design). On the other hand, a pilot must *"refer to the instrument displays in both good and bad weather conditions in order to fly the aircraft safely"* (Ercoline et al. 2004, p. 382) in that air speed and altitude, for example, are particularly difficult to extract from perceiving the outside world or an artificial visual flow. This is most important during low-level flight to avoid controlled-flight into terrain. The peripheral visual flow integrated interface includes these parameters by utilizing the Gripen avionics system (Figure 1). Furthermore, while the ground proximity warning complements an automatic GCAS, the rate of the auditory stall warning enhances the pilot's proactive performance by indicating the stall margin (cf. Flach, 1999).

Concluding remarks

The utilization of an operative HUD interface concept integrating information of pitch, roll, and yaw provides the important fundamentals of an integrated reference frame for maneuvering. The suggested wide FOV interface design seems to have two advantages for further enhancing pilot-in-the-loop maneuvering and SO. First, the wide FOV

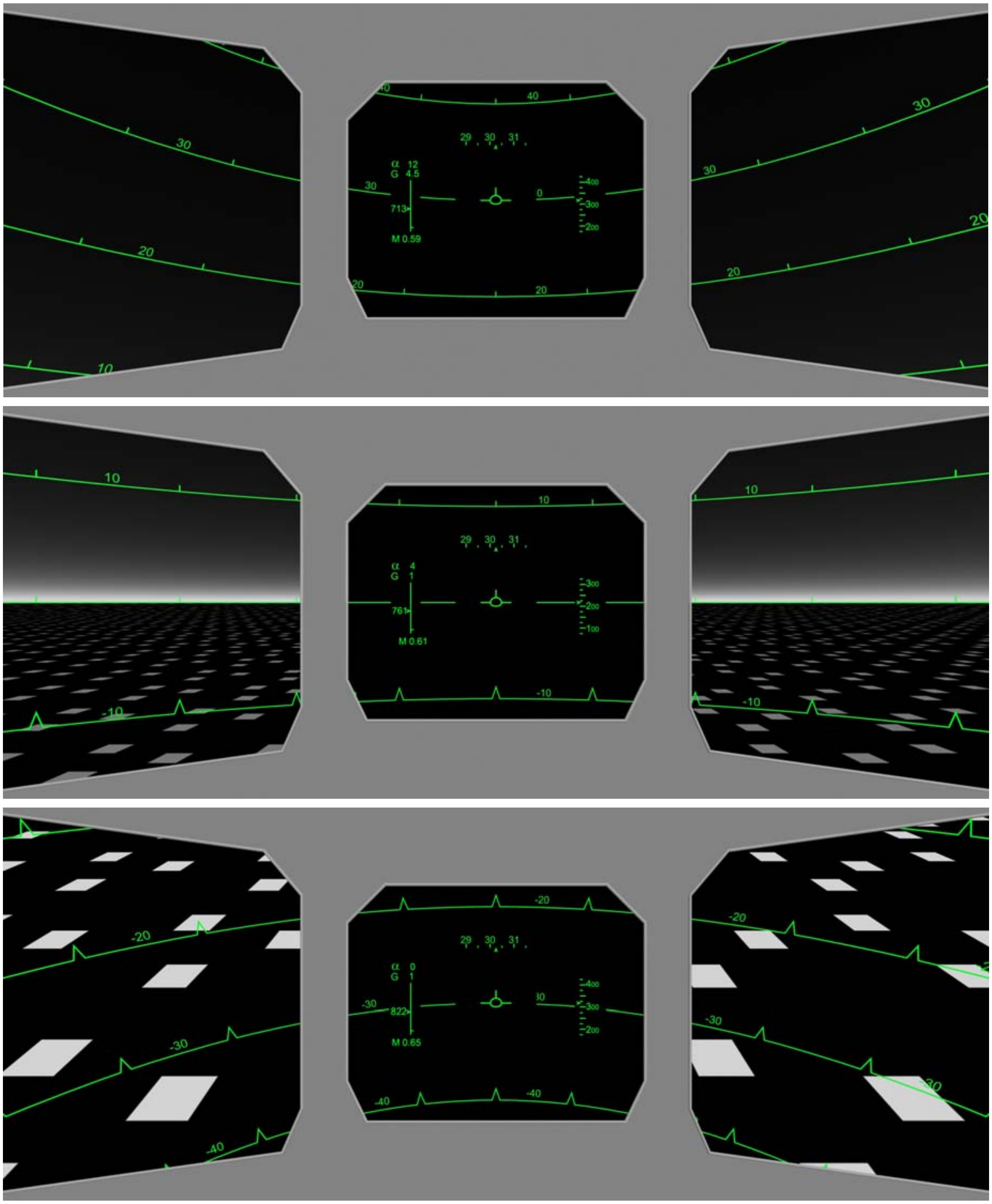

Figure 4. An illustration of an IMC mode of the suggested interface with peripheral visual flow. The flight sequence from bottom to top: From pitch-down to pitch-up including horizontal flight in between.

inclusion of peripheral vision supports perception of SO and maneuvering more effectively. Second, peripheral visual flow is integrated into the sphere concept in a geometrically correct configuration, enhancing visual resonance with the SO mechanism primarily in IMC. Accordingly, it seems to show potential for triggering sensory reflexes critical for SO, reinforcing information for maneuvering, and capturing pilot attention when transitioning into critical aircraft attitudes. It could therefore contribute to a more effective combating of pilot SD in the future.

The ideas presented here emphasize basic concepts that of course need refinement. Head-up flight displays systems allowing a wide FOV interface design are also yet to be realized. On the other hand, the design can be implemented and subjected to empirical scrutiny by experiments carried out in research applications platforms. Another issue is that the Gripen HUD interface provides an intuitive visual frame of reference for three-dimensional cueing with auditory and tactile displays, supporting multisensory approaches to improve pilot peak performance.

Acknowledgments

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