DISORIENTATION RESEARCH DEVICE TESTING OF SYNTHETIC VISION DISPLAY TECHNOLOGIES

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A Commercial Aviation Safety Team (CAST) study of 18 worldwide loss-of-control accidents and incidents determined that the lack of external visual references was associated with a flight crew's loss of attitude awareness or energy state awareness in 17 of these events. CAST recommended development and implementation of virtual day-Visual Meteorological Condition (VMC) display systems, such as synthetic vision systems, to promote flight crew attitude awareness similar to a day-VMC environment. This paper describes the results of a joint NASA/NAMRU-D study that evaluated virtual day-VMC displays and a "background attitude indicator" concept as an aid to pilots in recovery from unusual attitudes. Experimental results and future research directions under this CAST initiative and the NASA "Technologies for Airplane State Awareness" research project are described.

A CAST study of 18 loss-of-control accidents determined that a lack of external visual references (i.e., darkness, instrument meteorological conditions, or both) was associated with a flight crew's loss of attitude awareness or energy state awareness (collectively termed, "airplane state awareness") in 17 of these events. The reports (CAST, 2014a; CAST, 2014b) recommended that, to provide visual cues necessary to prevent loss-of-control (LOC) resulting from a flight crew's spatial disorientation and loss-of-energy state awareness, manufacturers should develop and implement virtual day-VMC display systems, such as synthetic vision systems. In support of this implementation, CAST requested the National Aeronautics and Space Administration (NASA) to conduct research to support definition of minimum requirements for virtual day-VMC displays to accomplish the intended function of improving flight crew awareness of airplane attitude.

Virtual Day-VMC Displays

Virtual day-VMC displays or Synthetic Vision (SV), are intended to provide similar visual cues to the flight crew that are available when outside visibility is unrestricted (i.e., observed under VMC). Their intended function is provide continuous, intuitive attitude, altitude, and terrain awareness, reducing the likelihood of unstable approach, inadvertent entry into an unusual attitude, spatial disorientation, and/or collision with terrain. SV is a computer-generated image of the external scene topography from the perspective of the flight deck, derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

Technologies for Airplane State Awareness

CAST, under Safety Enhancement(SE)-200 defined areas of research needed for design and implementation of virtual day-VMC displays to prevent loss-of-control accidents due to loss of attitude awareness and lack of external visual references. NASA research has been completed that evaluated numerous virtual day-VMC display design characteristics (summarized in Ellis, et al., 2019). To date, the research has been conducted in research facilities including high-fidelity Level D-certified airline training simulators. Although the simulations have yielded valuable data, the facilities are of limited fidelity in inducing vestibular illusions. Hexapod motion-based simulators use Stewart-motion platforms with acceleration onset cueing to deceive the pilot sensory systems into experiencing the motion effects.

This paper describes research that evaluated SV technology in the Disorientation Research Device (DRD), located at the Naval Medical Research Unit (NAMRU-D), Wright-Patterson Air Force Base (NAMRU-D, 2019). The DRD is a simulation facility that has advanced motion capabilities across 6 degrees-of-freedom including sustained planetary accelerations up to 3G in x, y, and z planes. The DRD enabled the extension of the SE-200 research to evaluate the efficacy of display technology and visual dominance through the experimentally controlled induction of spatial disorientation and vestibular illusions.

Experimental Method

Research Pilots

A total of 20 qualified ATP pilots currently flying regional jet aircraft and employed by Part 121 US major or regional airline operators were recruited as subject pilots.

Research Simulator

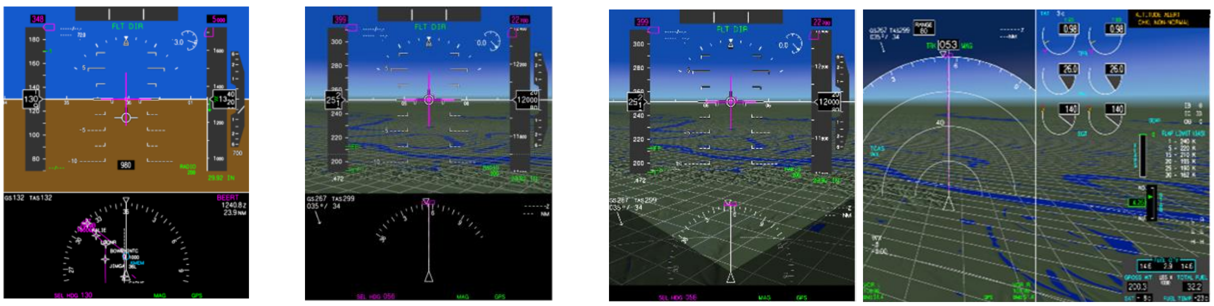
Designed as a reconfigurable advanced centrifuge device to induce spatial disorientation, the DRD provides simultaneous motion in 6 degrees-of-freedom: (a) roll/pitch/yaw of 360^{+} deg rotation; (b) horizontal/vertical travel of 33 ft. and 6 ft., respectively; and, (c) sustained planetary acceleration of 360^{+} deg rotation up to 3 G in x, y, and z planes (NAMRU-D, 2019). The DRD was modified to emulate a large commercial transport aircraft including aerodynamic model and the inside of the capsule included transport aircraft controls and displays (Figure 1).

Research Evaluation

Evaluation pilots flew three tasks: (a) Unusual Attitude Recovery (UAR) evaluations; (b) somatogravic illusion take-offs; and, (c) an attitude awareness task, labeled the “plane-following task”. The results of the last task are not included in this paper.

Research Displays. Three research display concepts (Figure 2) were evaluated: 1) the baseline was a standard conventional “blue-over-brown” primary flight display; 2) an “SV” PFD display emulated the common display characteristics of commercially available SV systems; and, 3) a “background attitude indicator” concept, termed “SV + BAI”. The SV+BAI was presented across the PFD and navigation head-down displays for each pilot, displaying a wide field-of-view attitude horizon to promote ambient vision stimulation (Previc and Ercoline, 2004). The PFD and navigation displays were each presented on 305 x 228 mm LCDs (see Figure 1).

Figure 1. Disorientation Research Device



Blue-Over-Brown SV SV + BAI

Figure 2. Research Displays

UAR Scenarios. The UAR scenarios were designed to determine how effectively a pilot could recognize their attitude and execute the proper corrective action.

The initial conditions for the UAR scenarios were: (a) 55° nose-down, 70° left bank; (b) 60° nose-down, 95° right bank; (c) 20° nose-down, 40° left bank; and, (d) 50° nose-down, 45° right bank. The UAR entries were dynamic, meaning the aircraft approached the prescribed UA initial condition with the simulator in motion and the displays blank. The method ensured that pilots would not be able to determine their current attitude using their vestibular sense. At each UA initial condition for the scenario, the displays returned, signaling the EP to recover the aircraft. Twenty-four (24) UAR scenario recoveries were performed by each evaluation pilot, which were fully randomized for each set across participants. Standard recovery training was provided, and pilots participated in practice trials using training set of UAR scenarios.

Somatogravic Illusion. The take-off scenario was designed to induce the "false climb" somatogravic illusion wherein the linear acceleration environment experienced by the pilot's vestibular system may induce the perception of an erroneously high pitch attitude. If induced, the expected pilot response is a pitch down control input. For this scenario, only two display conditions were tested for their efficacy to establish visual dominance in the face of the somatogravic illusion: (a) blue-over-brown, and (b) SV+BAI.

Results

Unusual Attitude Recoveries

The UAR performance was "scored" by the correctness and timeliness of pilot control inputs after the displays were unblanked.

Control Inputs. A generalized linear mixed models (GLMMs) with log link fit revealed that display did not affect the time to make the initial roll input, $\chi^2(2) = 0.574,\ p = 0.574$. There were 18 total cases of incorrect initial roll input. SV+BAI condition had only 2 cases with 0.16 magnitude in the wrong direction (the stick input takes values from -1 to 1) compared to blue-over-brown (7 cases, 0.31) and SV (9 cases, 0.38). Although SV was observed to have 9 incorrect initial roll inputs, the average time-to-correct was only 1.36 sec compared to 2.12 sec and 2.11 sec for blue-over-brown baseline and SV+BAI, respectively. For pitch inputs, the GLMM also did not show a significant effect, $\chi^2\ (2) = 1.54\ ,\ p = 0.463$. There were 39 total cases of incorrect initial pitch input with all displays showing only an average 0.14 magnitude. SV+BAI was observed with only 9 cases requring average of 2.47 sec time-to-correct pitch input compared to blue-over-brown (13 cases, 3.47 sec) and SV (11 cases, 2.09 sec).

Roll Reversals. Roll control reversals are an indicator that the pilot did not fully recognize the aircraft attitude prior to recovery initiation. The data showed only 10 runs (3%) with a roll reversal. However, 7 of 10 roll reversals were in the blue-over-brown baseline display condition but only 1 and 2 roll reversals for the SV+BAI and SV display conditions, respectively. Using a GLMM with a Poisson link showed that these trends are not significant, X^2 (2) = 4.95, p = 0.08. The pilots exhibited excellent performance across the all display types as 10% roll reversals is the generally accepted UAR testing norm (Previc, 2004).

UAR Score. The control recoveries were "scored" by awarding a +1 for the correct initial control input and a -1 for an incorrect initial control input, for both the pitch and roll controllers. The UAR Score is a metric of pilot performance. UAR scores in this test could take 3 values: 2 if the pilot made both pitch and roll inputs correctly, zero ('0') if one of either pitch or roll inputs were incorrect, or -2 if both initial inputs were not correct. The pilots made the correct initial pitch and roll stick inputs 87% of the time. None of the pilots scored a -2 (Figure 3). The SV + BAI display had the highest number of cases where the initial input was correct (93%); however, the test on the UAR score did not reveal a statistical difference between displays. The likelihood ratio test between the two models did not find a significant difference between displays, using an conservative Bonferroni corrected α of 0.0055, X^2 (2) = 7.84, p = 0.02.

Qualitative Results. A significant effect was found for NASA-Task Load Index (TLX) workload ratings on display, F (2, 36) = 9.831, p < 0.05. The Bonferroni-corrected pairwise comparison post-hoc evinced that the blue-over-brown baseline display condition (μ = 25.68, σ = 14.55) was rated higher in workload than both the SV+BAI (μ = 20.34, σ = 12.90) and the SV display (μ = 23.29, σ = 13.27). A significant effect was found for Situation Awareness Rating Technique (SART) ratings on display condition, F (2, 36) = 11.437, p < 0.05. The Bonferroni-corrected pairwise comparison revealed significant difference between blue-over-brown and the two SV display conditions. Pilot participants rated the blue-over-brown display (μ = 106.54, σ = 59.59) significantly lower for SART scores than the SV (μ = 121.90, σ = 52.74) or SV+BAI (μ = 130.05, σ = 53.32). No differences were found between the SV and SV+BAI display for SART scores.

Somatogravic Illusion

The efficacy of the displays to support attitude awareness during the somatogravic illusion was "scored" by the pilot's pitch attitude control where the somatogravic illusion may be more compelling than visual references and lead to erroneous pitch down inputs.The subjects, post-test, were asked about the quality of the illusion. The pilots judged the scenario to be “excellent”. Overall, the SV+BAI display was equivalent to the blue-over-brown displays. Out of the 40 runs, no incorrect pitch inputs were made although the pitch attitude went below the target 15 degrees of pitch on some of the blue-over-brown baseline trials (N=3 of 20).

An insignificant effect was found for workload using the NASA-TLX, $F(1, 19) = 3.063$, $p = 0.096$. Pilots tended to rate the SV+BAI display ($\mu = 16.04$, $\sigma = 10.58$) to be lower in mental workload (as measured by the NASA-TLX) compared to the blue-over-brown display condition ($\mu = 20.33$, $\sigma = 16.84$). Pilots were also asked to provide a rating of display efficacy for “visual dominance” during the enhanced motion/somatogravic illusion scenario. The Wilcoxon signed-rank test was conducted comparing blue-over-brown to SV+BAI on the Likert scale rating (1 – 5 scale). The results were that pilots significantly rated the SV+BAI ($\mu = 4.65$, $\sigma = 0.587$; higher for visual dominance compared to the blue-over-brown display ($\mu = 3.25$, $\sigma = 0.851$, condition ($Z = -3.713$, $p < 0.001$).

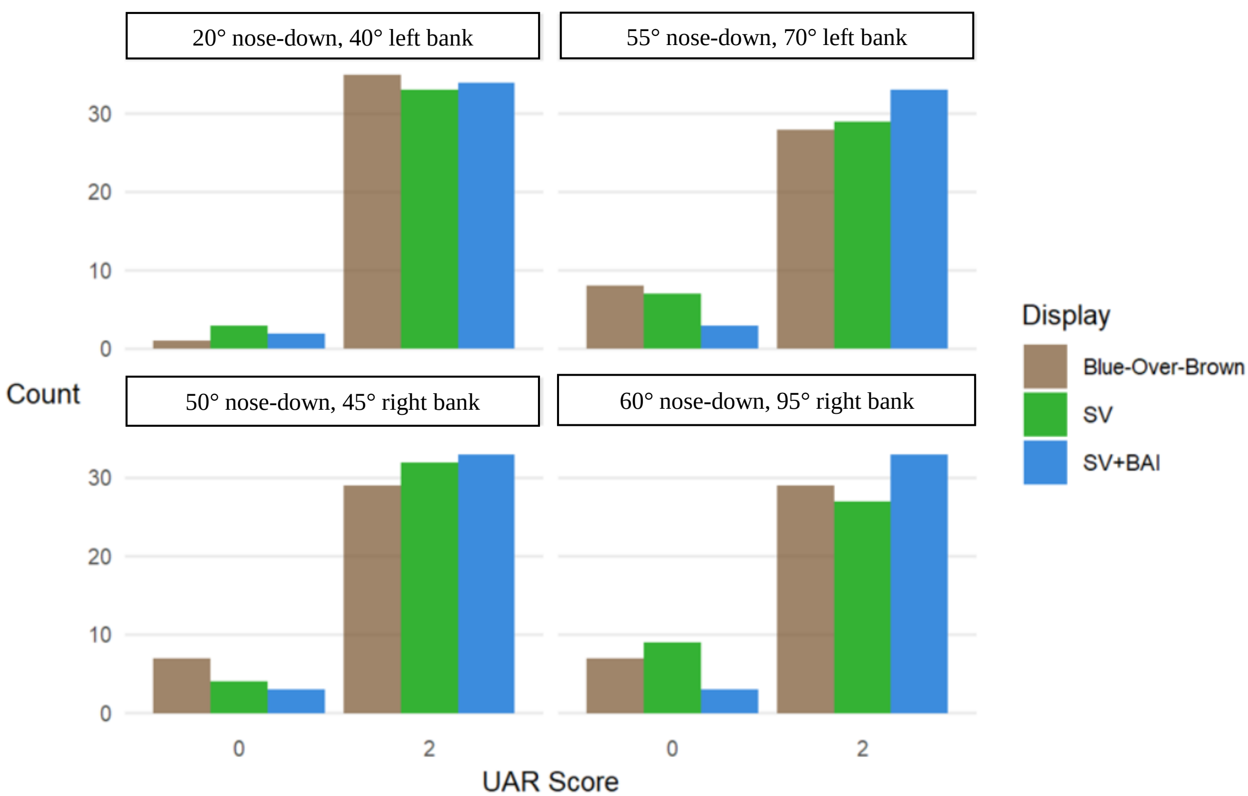


Figure 3. Unusual Attitude Recovery Scores

Conclusions

This research extends the design and development of virtual day-VMC displays for airplane state awareness. The research was a first attempt to evaluate the display visual dominance for efficacy to prevent spatial disorientation induced by experimentally-controlled vestibular illusions. The results confirm previous research that pilots significantly prefer the SV display technology and report much lower workload and higher attitude awareness compared to traditional Blue-Over-Brown PFDs.   However, similar to past research and findings in the literature, no statistically significant quantiative performance differeneces between display concepts were found. It is difficult to obtain enough data points to allow for statistical analysis in uncovering if there are performance differences. The types of events tested are naturally rare events, and it is difficult to simulate conditions that would ensure the data would be collected with the necessary number of observations. At minimum, the data suggests that virtual-day VMC displays provide airplane state awareness similar to the blue-over-brown baseline display. The descriptive data validates the need for further spatial disorientation and illusion (both visual and vestibular) test and evaluation.   The results also support additional study on the background attitude indicator display concept.

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