Flight Simulator Evaluation of an Integrated Synthetic and Enhanced Vision System for Terrain Avoidance

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SUMMARY

This paper describes a military flight simulation study that occurred in 2004 and 2005 at the Operator Performance Laboratory (OPL) at the University of Iowa. The purpose of the SE-Vision project was to develop a technological framework for integrating SVIS (Synthetic Vision Information System) with EVS (Enhanced Vision System).

Controlled Flight into Terrain (CFIT) is still a concern in the US Air Force, particularly when low flying aircraft are traveling at high speeds in less than optimal visibility conditions. Sensors provide real-time threat information and allow for a level of integrity in monitoring however incidents may still occur. For over a decade, researchers have been trying to develop better pilot vision systems that aid in reducing workload and maintaining minimum clearances from terrain and other aircraft. The following points are made in the review of related research from the past 10 years. (Each number is a reference item in the bibliography of this paper.)

1. Research has pointed out that conventional 2-D plan-view maps are limited in range or in resolution of map detail. Properly designed exocentric guidance displays can combine a high position resolution with a large visible range.
2. Research has been conducted on guidance displays with regard to the requirements for route awareness and guidance.
3. Research compared a perspective pathway HUD with a conventional 2-D HUD. The results showed the perspective pathway HUD was better for guidance. Overall, pathway HUDs combine the independent advantages of pathway displays and head-up displays, particularly during ground operations (e.g., taxi).
   a. Most of the SVS research has measured performance in terms of FTEs (flight technical errors), workload, subjective probes for SA and user preference.
   b. Flight technical performance obtained with pathway-based SVIS is far superior to conventional Flight Director based EFIS because workload is lower.
4. The concept of equivalent safety was used to develop a way of evaluating SVS/EVS technology. It is hypothesized that the SVS displays can replicate the safety and operational flexibility of flight in daytime Visual Meteorological Conditions (VMC), regardless of the actual OTW (out of the window) visibility.
5. SE Vision symbology is mentioned in the paper but not presented in detail.
6. A description of Operational Concepts for SVIS/EVS is mentioned in the paper but not described in detail.
7. Digital Elevation Model resolution and texture requirements were studied and, as a result, it was recommended that the DEM resolution should be at least 6
arc seconds in mountainous terrain and that a shaded checkerboard terrain should be used for best terrain awareness performance. (The comparison conditions are not listed in this paper.)

8. The texture of underlying terrain in SVS/EVS displays has been studied but was not covered in this paper.

13. Pilot performance improved when display resolution was increased up to 105 pixels per inch. Higher resolutions had similar performance.

14. Flight performance (vertical and horizontal path error) was not influenced by the FOV (field of view) or display size.

18. The paper presented some research concerning sensor integration, and automatic configuration of EVS/SVS blending.

There were three main objectives for the SVIS and SE-Vision program, which was conducted under a multi-year Dual Use Science and Technology (DUS&T) grant funded by Rockwell Collins, NASA and AFRL:

1. Development and optimization of pathway-based guidance concepts
2. Development and optimization of Synthetic Terrain depiction
3. Integration of real-time EVS sensor imagery:
   a. Inset of alpha-blending of FLIR on PFD;
   b. Optimal Fusion of FLIR and SVIS; and
   c. Integration of FLIR on HUD raster channel.

The particular study presented in this paper focused on low-level terrain following and terrain avoidance (TF/TA) missions applied to aircraft such as the MC-130H Talon II. All display formats were mapped onto the OPL Boeing 737 flight simulator. The independent variables were the HUD (with/without), FLIR (Forward Looking Infrared) (with/without), the use of Synthetic Vision Terrain (with/without) and the use of a guidance pathway vs. flight director (FD). Missions were flown at 600 ft AGL and at a ground speed of 240 knots. The dependent measures were the FTE (flight technical errors), workload scores (AFFTC/AWRES), and SART (Situation Awareness Rating Technique) scores. Ten Air Force pilots participated in this study. All pilots had Talon II experience and some served as flight instructors on MC-130H aircraft. The participants were sorted into teams of two for pilot and co-pilot operations and these roles were switched throughout the study. Each pilot was given 12 sorties lasting approximately 20 minutes each. Six of the sorties were conducted with experimental SVS formats; 2 were of the baseline formats and 4 were designated for training. The baseline formats were, “Blue over brown Attitude Indicator (AI) on the PFD, flight director TF cue, MFD moving map with shaded relief terrain and TAWS coloring” (Page 4.E. 4-5). On-time performance at a particular waypoint as well as in a self-contained approach were both stressed as mission objectives. The pilots were required to arrive at the waypoint as close to on-time as possible. Mission time cues were provided through the MFD, which told pilots where they needed to be (spatially) in order to be on time for the next waypoint.

Measures of effectiveness (MOEs) were both objective and subjective. Subjective measures were collected with questionnaires and verbal narrations of each pilot’s experiences. Objective measures were generated from the simulator log files. They
included Cross Track Error, Vertical Track Error, Track Angle Error and Flight Path Angle Error. Cross Track and Vertical Track MOEs indicated how well the pilot maintained the ground track and flight path under different conditions. Track Angle Error is expressed in degrees relative to the desired ground track. It is an involuntary angular deviation measure from the desired ground track. Flight path angle error is the involuntary angular deviation from the desired flight path and is not directly related to pitch attitude. It is expressed in degrees relative to the desired flight path. The data analyses presented the minimums, maximums, means, SDs and root mean squares of these MOEs. The MOEs were considered a function of the experimental SVS formats and if they were better than the baseline formats, a negative statistic was expected. The subjective evaluations were collected with “between-run cards” and the SA and workload measures were evaluated. There were also a few probe questions included on these cards. The first question to answer was whether the flight guidance path was better than the flight director guidance.

One test isolated the effect of the terrain presented on the MFD and a Tukey’s pairwise test was performed on the two baseline conditions. The only difference between the baseline formats was the terrain on the MFD and the lateral FTEs were statistically significant. Also the minimum, SD and RMS of cross track error, as well as the SD of the track angle error were statistically significant. The presence of the HUD primarily improved performance in the vertical axis, likely due to the conformal nature of the HUD image when compared to the heads down image. The HUD however resulted in more overshoots in steep turns, which were mostly right turn pathways. There were also a large proportion of left-hand overshoots as indicated by negative Cross Track Errors and a slight shift of the mean Cross Track Errors. It is likely that a HUD with a wider field of view would remedy this situation. When the HUD was used there were fewer undershoots on the inside of turns as indicated by the mean of the Cross Track Error. The presence or absence of IR sensor images in the displays had no effect on FTEs. SA was assessed using the SART and workload was assessed using the AFFTC/ AWRES (Air Force Flight Test Center workload assessment scale).In terms of workload and SA, the baseline condition fared worse. By adding terrain and TAWS coloring on the MFD, both SA and workload scores were improved. The best condition was the HDD (heads down) SVS. The HUD with wireframe terrain produced lower SA scores and slightly higher workload scores. SA scores with IR formats were somewhat lower than for the SVS format and the extra information in the IR formats increased workload. The purpose of the IR sensor was to overcome limits of the terrain database by providing the crew with real-time information of terrain obstacles and threats. However, the combination of the SVS and FLIR appeared to have a negative effect on SA. The FTE analysis indicated that IR sensors could be integrated without detriment to guidance.

Another primary purpose of this study was to determine the effect of HUD for TF (Terrain Following) missions, the effect of pathway guidance when compared to standard TF flight director guidance, and the effect of synthetic terrain and IR sensor integration on the PFD. All experimental formats performed better than baseline formats. TF pathway guidance significantly improved performance compared to the TF flight director; especially in vertical control. Vertical control appeared to be critical in low-
level, high-speed TF applications. By adding terrain information on the MFD it improved lateral control when compared to baseline conditions. The HUD produced superior vertical guidance for TF missions over the HDD (heads down display). Vertical control is of utmost importance in TF flight; however, there was a slight tendency to overshoot steep turns when the HUD was used. The HUD is not able to provide global SA and, consequently, information needed for SA must be perceived from the MFD, which requires the pilot to drop their head. The authors of this paper recommend a dual-HUD installation for both pilot and co-pilot.

COMMENTS

From the results, it is not clear how the IR Sensor condition would help the pilot and co-pilot achieve better SA and lower workload. Although it is not stated that this was a hypothesis of the study, it was implied that the IR sensor may be a beneficial format. From the photographs in the paper of the IR versus non-IR conditions, the IR seems to illuminate terrain features more, which might add to the clutter of the display. Some features might be illuminated sufficiently, such that they could be mistaken for HUD symbology at glance.