SIMULATION EXPERIMENT FOR DEVELOPING THE SYMBOLOGY FOR THE APPROACH AND MISSED APPROACH PHASES OF FLIGHT OF HEAD-DOWN SYNTHETIC VISION SYSTEMS DISPLAYS

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ABSTRACT

The Synthetic Vision Systems General Aviation (SVS-GA) element of NASA Langley Research Center's (LaRC) Aviation Safety and Security Program (AvSSP) is developing SVS technology to eliminate low-visibility induced GA accidents. SVS displays present computer generated 3-D imagery of the surrounding terrain, integrated with flight information and guidance symbology, on the Primary Flight Display (PFD). The SVS displays therefore provide the pilot with greatly enhanced Situation Awareness (SA) and a level of safety and operational flexibility equivalent to Visual Meteorological Conditions (VMC). A three-part series of Symbology Development for Head-Down Displays (SD-HDD) experiments were conducted to quantify the relationship between Terrain Portrayal Concept (TPC) and Guidance Symbology Concept (GSC) combinations on a PFD. This paper focuses on the first part of this series in which four TPCs and four GSCs were studied in LaRC's GA Work Station (GAWS). The primary dependent variables in this study were pilot performance in terms of Flight Technical Errors, workload, and SA. Twenty-one pilots with three distinct levels of aeronautical experience evaluated the sixteen display combinations for both an approach and a missed approach scenario within Alaska's Juneau terminal area. For the approach scenario, the GSCs concepts with more complex tunnels and path guidance had better results. For the missed approach scenario, the GSCs with the speed-on-pitch guidance did better than the path-based concepts. Significant differences among the TPCs were noted for subjective SA in which the baseline Blue-Sky-Brown-Ground gave the least SA. No interactions were found between GSCs and TPCs.

[This paper's acronyms are listed in Appendix A.]

INTRODUCTION

The Aviation Safety and Security Program (AvSSP) at NASA Langley Research Center (LaRC) is striving to reduce the frequency of fatal aviation accidents. The Synthetic Vision Systems (SVS) for General Aviation (GA) is one element of the AvSSP. The SVS-GA element aims at developing an SVS displays with integrated advanced symbology for GA applications. One goal of SVS displays is to provide a safety level and operational flexibility similar to current-day Visual Meteorological Conditions (VMC) operations regardless of weather and time-of-day by enhancing the pilot's Situation Awareness (SA). Increasing SA will reduce Controlled Flight-Into Terrain (CFIT) and Low-Visibility Loss of Control (LVLOC) accidents. The SVS displays also increase pilot's technical performance while maintaining or reducing workload and thus enabling certain advanced Instrument Meteorological Conditions (IMC) operations.

The SVS-GA's Symbology Development for Head-Down Displays (SD-HDD) experiment described in this paper was part of the AvSSP effort. Its objectives were to 1)establish the relationships between Guidance Symbology Concept (GSC) and Terrain Portrayal Concept (TPC), 2) develop recommendations for SVS-GA Primary Flight Display (PFD) symbology to support SVS development and certification efforts, such as FAA's Capstone II and its follow-on programs, and 3) demonstrate realistic operational concepts.

The SD-HDD experiment was divided into three parts. Part A (SD-HDD-A) focused on the approach and missed approach phases of flights at a terrain challenged airport. Part B concentrated on low-altitude advanced en route

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maneuvers. Part C dealt with the minification issues of the SVS's Head-Down Display.

This paper presents the design, implementation, and results of the SD-HDD-A.

PREVIOUS STUDIES

One of the primary challenges facing SVS development is the effective integration of terrain with other information (such as airspeed, altitude, and guidance). Past research (e.g. [1] and [2]) has focused on developing advanced GSCs, such as Highway-In-The-Sky (HITS) or ghost aircraft concepts, to demonstrate their potential for increasing pilot performance while maintaining or decreasing workload. In general, these studies were conducted with simple Terrain Portrayals (TP) such as the standard Blue-Sky-Brown-Ground (BSBG). Many studies (e.g., [3] to [5]) addressed only the issues of TP on the PFD. For SVS display integration, most studies focused on studying single levels of synthetic terrain and guidance symbology [6]. Only a few (e.g. [7, 8, 9, and 10]) have partially addressed what elements should be available on an SVS display.

RELATED GA STUDIES

Prior to the SD-HDD experiment, the Terrain Portrayal Head-Down Display (TP-HDD) experiments were conducted ([11] to [13]). The TP-HDD experiments investigated the benefits of an SVS display with various texturing, Digital Elevation Models (DEMs), and Field-Of-Views (FOVs). Three levels of symbology (baseline round dials, Course Deviations Indicators (CDI) only, and CDI with HITS guidance) were evaluated in a partial-factorial format. The results of this experiment indicate that introducing various TPCs and HITS increased SA on all SVS concepts without decreasing the Evaluation Pilots' (EPs') performance or increasing their workload. Texturing concepts influenced the EP's SA much more than DEM. Moreover, larger FOV (60 degrees) was favored, which is different from the results of another SVS experiment with larger aircraft [14]. The TP-HDD experiment thus provided clear evidence that the characteristics of the TP are critical; however, it had only one level of guidance symbology.

OBJECTIVES OF SD-HDD-A

The SD-HDD-A experiment increased the number of GSCs from one in TP-HDD to four. The objective was to compare the EPs' Flight Technical Errors (FTEs), workload, and SA with sixteen display combinations of TPCs and GSCs for the approach and missed approach phases of flights.

EXPERIMENT DESIGN

This experiment used a multi-factor within-subject design. This section summarizes the design of this experiment.

Scenarios

The two scenarios examined in this study were the approach and missed approach. Both scenarios simulated advanced VMC-like operations in IMC at Alaska's Juneau International Airport (PAJN).

Approach Scenario

A challenging approach scenario to PAJN RWY 26 was constructed that resembled a VFR pattern with four segments. The first segment was a straight-and-level flight starting at 2120 MSL in a VMC. Within a minute into the flight, the visibility was reduced from 10 statue mile (sm) to 1 sm during the second segment. The third segment consisted of a descending turn to the Final Approach Fix (FAF). The fourth segment consisted of a 1.4-nautical mile (nm) final approach descent with a 4-degree slope to the Missed Approach Point (MAP). The entire scenario was about 5 minutes.

Variable wind and light turbulence were present throughout the scenario to increase the EP's workload. At the beginning of the scenario, the wind was from a heading of 210 degrees at 25 knots. The wind speed then gradually decreased to 15 knots and changed to 310 degrees in a counter-clockwise fashion.

Missed Approach Scenario

The Missed Approach scenario of PAJN had four segments. The first segment was a straight decent from the FAF to the MAP at PAJN RWY 8. The second segment began at the MAP. Upon arriving at the MAP, the EP initiated a straight climb and selected the Take-Off-Go-Around (TOGA) guidance symbology mode with a switch on the throttle lever. Engaging the TOGA switch changes the GSC from approach to TOGA logic. The third segment was a constant-radius climbing right turn. The fourth segment was a straight climb that ended 6 minutes into the run. Variable wind and light turbulence similar to the approach scenario were present. Wind direction began from a heading of 200 degrees at 25 knots and gradually decreased to 15 knots from 300 degrees.

Basic PFD Symbology

Like many high-end GA, commercial, and military aircraft, the basic symbology on the PFD resembled that from typical PFDs. Unlike typical PFDs, however, the CDI displayed linear vertical and horizontal path deviations. The vertical scale had a range of +/-60 ft and a scale of 30 ft per dot. The horizontal scale had a range of +/-400 ft and a scale of 100 ft per dot.

Independent Variables (INDV)

The INDV included four TPCs, four GSCs, and three types of EPs. They are summarized in this section.

Independent Variables - TPCs

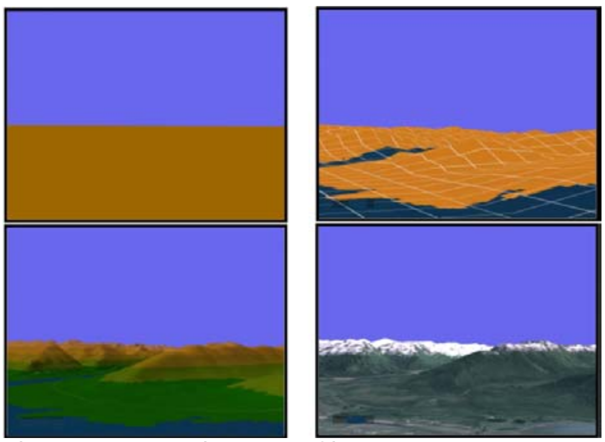

Figure 1. BSBG (Upper Left), CCFN 60 arc-sec DEM (Upper Right), EBG 6 arc-sec DEM (Lower Left), PR 2 arc-sec DEM (Lower Right)

The TP-HDD experiment helped to narrow the number of TPC levels for SD-HDD down to three. They are 1) the 60 arc-seconds DEM resolution terrain database with Constant-Color Fishnet (CCFN) texturing, 2) the 6 arc-seconds DEM resolution database with Elevation-Based Generic (EBG) texturing, and 3) the 2 arc-seconds DEM resolution database with Photo-Realistic (PR) texturing. The SD-HDD-A looked at these three SVS TPCs plus the baseline non-SVS BSBG. Figure 1 contains the pictures of these four TPs.

Independent Variables - GSC

There were four GSCs studied in the SD-HDD-A. Each one had an approach and a TOGA mode. These GSCs are summarized below.

Independent Variables - GSC - Split-cue (Pitch/Roll) Flight Director

The split-cue (Pitch/Roll) Flight Director (PRFD) was the visually simplest GSC in this study. For the approach mode (Figure 2), the PRFD employed the logic of typical current-generation flight directors. It used the displacements of vertical and horizontal magenta error bars from the water-marker to indicate errors in pitch (horizontal line) and roll (vertical line) with respect to the preplanned flight path.

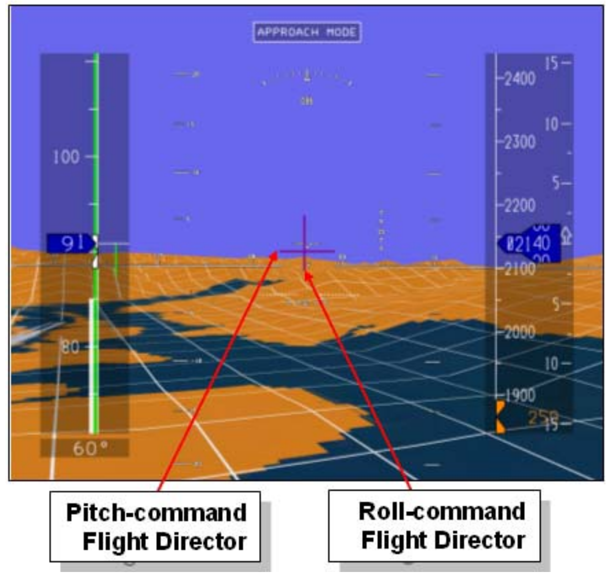

Figure 2. PRFD in Approach Mode

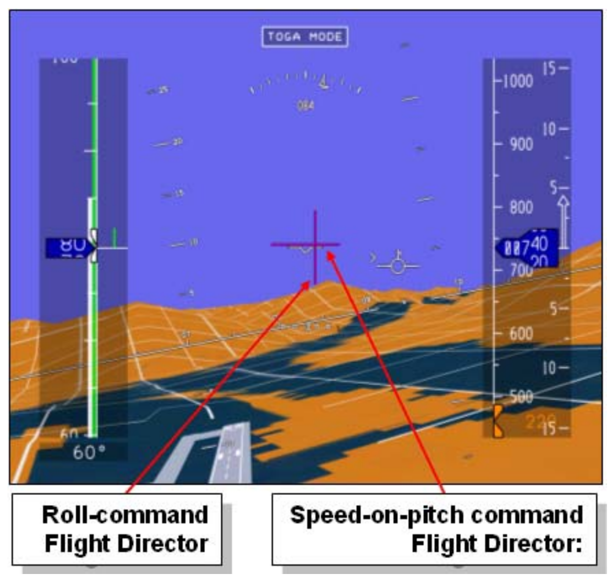

Figure 3. PRFD in TOGA Mode

For the TOGA mode (Figure 3), the roll guidance used the same logic as in the approach mode. A speed-based logic was used instead for the pitch guidance. In TOGA mode, the displacement of the horizontal error bar from the water-marker indicated pitch commands needed to eliminate airspeed error with respect to the assigned climb-speed of 80 knots. The EPs were asked to apply full throttle and adjust the pitch of the aircraft to place the horizontal pitch error bar on the water-marker.

Independent Variables - GSC – Unconnected-Box Tunnel with No Guidance

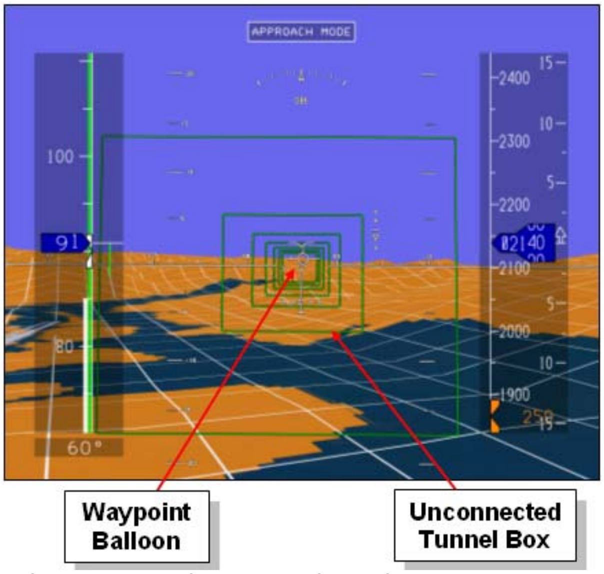

Figure 4. UBT in Approach Mode

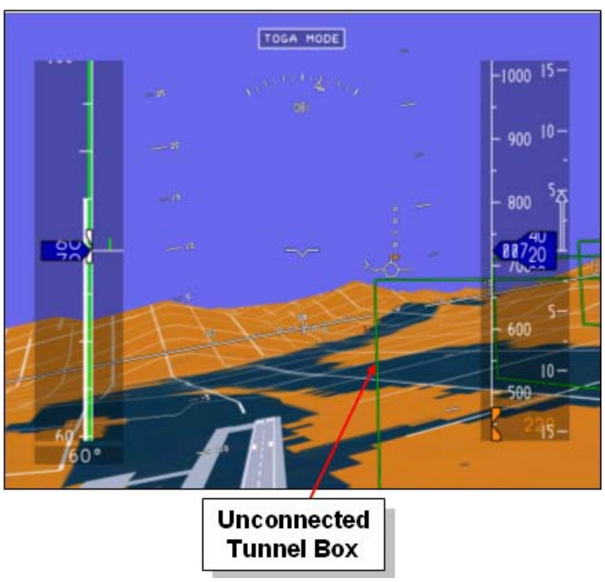

Figure 5. UBT in TOGA Mode

The Unconnected-Box Tunnel (UBT) was based on an FAA certified highway-in-the-sky technology. The UBT had five boxes every mile. Boxes were tilted 20 degrees indicating turns that needed more than 5 degrees bank angle to complete. The first tunnel box was 400 ft wide by 320 ft tall. The boxes were reduced in size (tapered) linearly to 146 ft wide by 100 ft tall at the MAP. The EP needed to place the flight path marker, a.k.a velocity vector, in the center of as many boxes as possible to fly the course accurately. Fine course adjustments were made by using the CDI and the help of the waypoint balloons (Figure 4).

For the TOGA mode (Figure 5), the UBT had a fixed vertical profile based on target climb gradient (3 degrees for this experiment). The rest of the elements were similar to the approach mode. Pilots needed to adjust thrust to maintain the assumed best rate of climb speed (i.e. 80 knots) for this experiment.

Independent Variable - GSC - Crow-Feet Tunnel with Guidance Ghost Plane

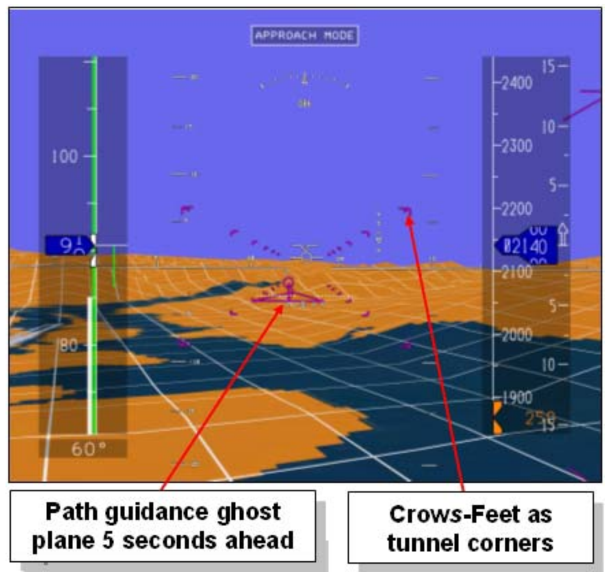

Figure 6. CFTGP in Approach Mode

The Crow-Feet Tunnel (CFT) with guidance Ghost Plane (GP), or CFTGP GSC (Figure 6), was developed at LaRC. The two characteristics of this concept were the use of “crow-feet”-type markings to depict the corners of the tunnel frames and a “ghost airplane” symbol for path guidance. Similar to the UBT concept, the approach mode had a tapered tunnel. The tunnel reduced from initially 600 ft wide by 350 ft high to 400 ft by 110 ft, respectively, at the MAP. The guidance GP depicted the flight path position five seconds ahead of the ownship. The EP needed to aim the velocity vector at the circle on the tail of the GP to stay on course. Should the EP wander off course to the point the GP would be off the display, the GP would be pegged to the edge of the display and change from magenta to amber. A line connecting between the GP and the velocity vector would appear to indicate the direction the EP needed to fly back on course.

The TOGA mode of the concept is called the Sideway Ts Tunnel (STT) with Guidance Circle (GC), or STTGC (Figure 7). It used a series of sideway "Ts" to depict the tunnel sidewalls and a circle to provide path guidance. The tunnel vertically followed the aircraft at all times. The GC used the same speed-based logic as the TOGA version of the PRFD except that the GC was associated with the velocity vector instead of the water-marker.

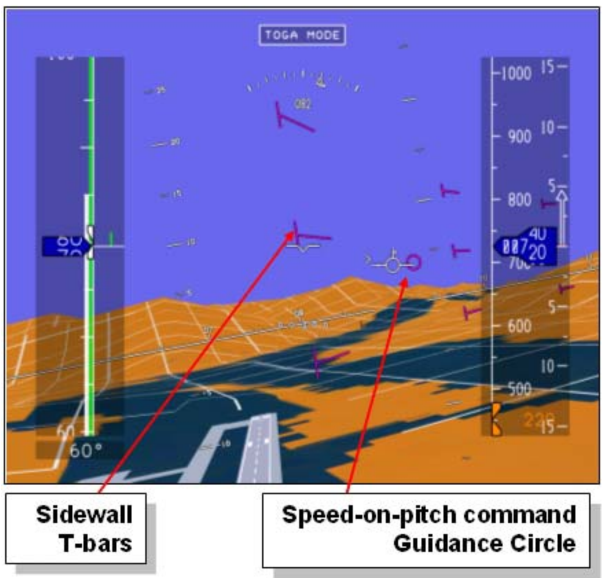

Figure 7. STTGC in TOGA Mode

INDV - GSC - Connected-Box Tunnel with a Guidance-Square/Velocity Predictor combination

The Connected-Box Tunnel (CBT) with Guidance-Square (GSQ) and Velocity Predictor (VP) combination concept, or simply referred to as CBT (Figure 8), had a tunnel depicted by a series of boxes connected by lines at the four corners. This was the most visually complex GSC in the experiment. A magenta GSQ box was situated five seconds ahead of the aircraft along the desired flight path. Another characteristic of this tunnel was the replacement of the velocity vector with the VP. The VP provided a 5-second lateral velocity prediction to provide a quickened velocity vector [14]. The vertical component of the predictor behaved the same as that of a typical velocity vector.

Besides having an open-top design, the TOGA mode CBT (Figure 9) differed from the approach counterpart in that the tunnel followed the ownship vertically at all times unless the ownship was below a preset Minimum Safe Altitude (MSA).

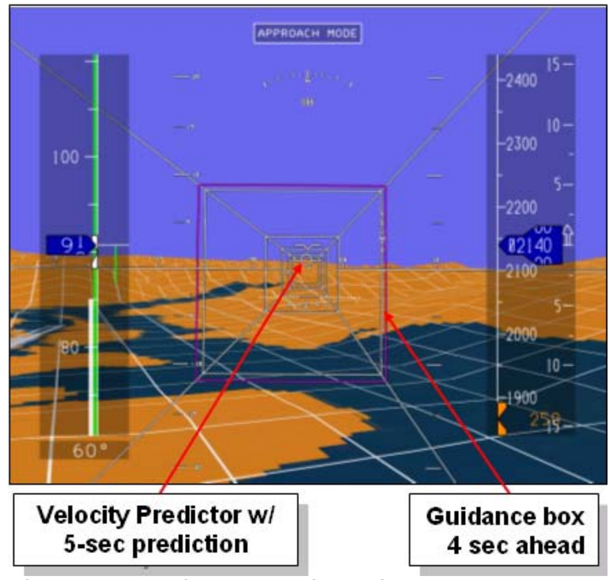

Figure 8. CBT in Approach Mode

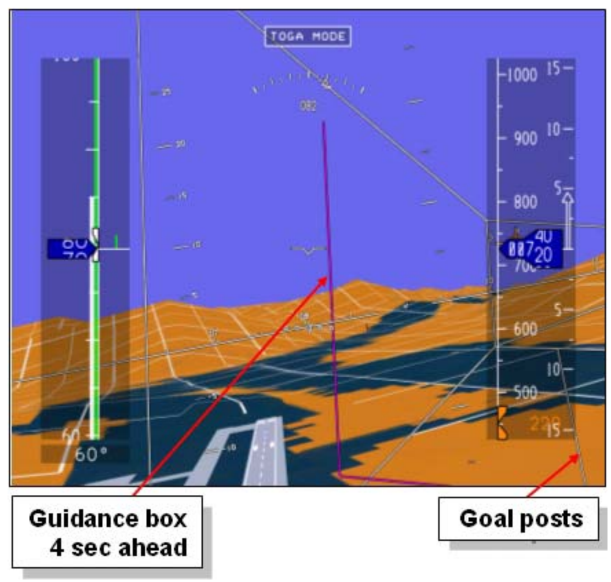

Figure 9. CBT in TOGA Mode

Independent Variable - Pilots

Three groups of EPs were recruited from around the US for this study. The first group consisted of nine GA pilots with VFR only private pilot certificates. There were six IFR EPs in the second group. They had less than 1000 hours of total flight time. The last group, the High-time IFR (HIFR) group, consisted of six EPs. These pilots had more than 1000 hours of total time and had flown many types of GA, commercial, and experimental aircraft.

Dependent Variables (DV)

The DVs included four objective and two subjective measures and are summarized below:

Dependent Variable - Objective Measures

Objective measures included tracking errors from the assigned values and control inputs. Tracking error measures included the Root Mean Squares (RMSs) of the Indicated Airspeed Errors (IASE), Lateral Path Deviations (LPD), and Vertical Path Deviations (VPD). The EPs were required to maintain, to the best of their abilities, a Level 1 Performance (L1P). They were considered within a L1P when their IAS was within +/-10 knots of the required IAS and their LPD and VPD were within 1 dot on the CDI. Since there was no vertical path constraints for the TOGA symbology, VPD was not used as a measure for the missed approach. The Standard Deviation (STD) of the pilots Lateral Control Inputs (LCIN) indicates the lateral control input smoothness and was considered an objective workload indicator. Due to the nature of the maneuvers employed, the vertical control inputs data will require more detail data analyses to appropriately represent the vertical control inputs. It was thus not used as an objective workload indicator for this paper.

For the approach scenario, the analyses began five seconds after the onset of the IMC and ended at the MAP. For the missed approach scenario, the analyses started immediately after the initiation of the TOGA symbology, which was indicated by the first time the throttle was repositioned from partial to 100%. The missed approach analyses terminated at the end of the runs.

Dependent Variable - Subjective Measures

Subjective measures included the standard NASA-TLX workload index, the 3-D SA Rating Technique (SART), block, and final questionnaires. As part of the final questionnaires all EPs were asked to rank the display combinations presented to them for each scenario and all scenarios as a whole.

Test Matrix

Each EP participated in two 8-hour sessions for two consecutive days. On the first day, the EP was first trained to fly the simulator. The EP then flew the approach scenario sixteen times, one for each of the sixteen display combinations in approach mode. On the second day, after the TOGA training, the EP flew sixteen runs in TOGA mode for the missed approach scenario. The displays were presented to each EP in a randomized fashion. At the end of each run, the EPs completed the NASA TLX and SART questionnaires for the run just completed.

HYPOTHESES

Objective Measures

The FTEs will support the following results: 1) All pilots, regardless of their flying experience, will have acceptable levels of FTEs. 2) The more visually complex GSCs will have lower FTEs. 3) The TPCs will not significantly affect the FTEs.

Subjective Measures

The workload measure will support the following results: 1) The GSCs with tunnels will require less workload than the PRFD. 2) The CCFN, EBG, and PR TPCs will require the same or less workload than the BSBG.

The SA measure will support the following results: 1) The CCFN, EBG, and PR TPCs will improve pilot's SA compared to the BSBG. 2) The higher-fidelity TPCs will support lower clutter GSCs. 3) The EBG will be preferred over the PR. 4) The EBG and PR will be preferred over the CCFN.

THE EXPERIMENT SETUP

The SD-HDD experiment was conducted at LaRC's General Aviation WorkStation (GAWS). It is a fixed-based GA simulator running on four networked PCs.

EPs flew from the left seat of the simulator. The head-down SVS PFD was a 6-inch LCD mounted in front of the pilot. Pilots were able to toggle the PFD's FOV between 30 and 60 degrees. Another 6-inch head-down LCD located in the middle of the flight console was the Strategic/Navigation Display (SND). The SND provided a god's-eye-view of the PAJN environment around the ownship in EBG texturing and a zoom level of 5 nm. The SND also provided the desired flight path with an ownship symbol and a predictor noodle. A PR terrain database of the PAJN environment was used to generate the out-the-window view.

GAWS was isolated from the researcher's station to maintain a "sterilized" test environment. The simulator was remotely controlled and monitored at the researcher's station where pilot communications, questionnaire administering, as well as real-time data display/recording/reduction were carried out.

TEST RESULTS

Generally, most pilots performed within the L1P, although five of the 288 runs had excessive excursions. The five excursions were due to either pilot errors, or due to loss of SA from using BSBG or a less complex GSC. The results also revealed no significant interactions among Pilots, TPCs, and GSCs. The ANOVA results for the FTEs and run questionnaires are tabulated in Tables 1-6. Results that are non-significant are indicted with "NS" in the Tables. The post hoc groupings are indicted with colored brackets. Additionally, the significant objective test results are presented in bar charts.

Approach – Pilots

Table 1. Means and Groupings of Objective and Subjective Measures for Pilots in Approach

DV	Pilot Ratings and Corresponding Means
IASE, RMS (knots)	NS; VFR=4.2, HIFR=4.1, VFR=3.7
LPD, RMS (ft)	NS; HIFR=94.4, IFR=56.3, VFR55
VPD, RMS (ft)	NS; VFR=22.6, HIFR=22.3, IFR=19.9
LCIN, STD (%)	F(2, 288) = 35.579 (P<0.01); {HIFR=23.1}, [VFR=20.6], (IFR=18.6)
TLX	F(2, 288) = 42.42, P<0.01; {HIFR=57.64}, [VFR=45.44, IFR=44.63]
SART	F(2, 288) = 28.80, P<0.05; {HIFR=27.98}, [IFR=66.88, VFR=70.74]

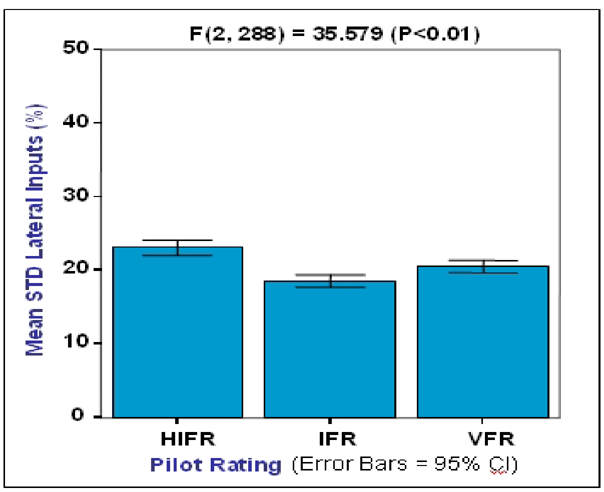

Figure 10. Mean STD Lateral Input vs. Pilot Rating for Approach

The ANOVA results for the approaches in Table 1 reveal that the EP's rating was not a significant factor for the RMSs of the IASE, LPD, and VPD. Each pilot group was on average within the required L1P and thus performed well in terms of FTEs. The HIFR pilots had significantly more lateral control activities, as indicated by the mean STD of the LCIN, than the other two groups in this scenario (Figure 10). This increase in the LCIN's mean STD for the HIFR EPs was supported by the TLX results, as shown in Table 1. The SART results show that the HIFR EPs had significantly worse mean SA than the other two pilot groups. These SA results could be related to their higher age or the different strategies they adopted from flying a wide variety of aircraft.

Approach – GSC

Table 2. Means and Groupings of Objective and Subjective Measures for GSCs in Approach

DV	GSCs and Corresponding Means
IASE, RMS (knots)	NS; PRFD=4.3, UBT=4.1, CBT=4.1, CFTGP=3.6
LPD, RMS (ft)	F(3, 288) = 3.50 (P<0.02); {UBT=113.2, [PRFD=71.2, CBT=53.8} CFTGP=28.3]
VPD, RMS (ft)	F(3, 288) = 6.31 (P<0.01); {UBT=27.7, PRFD=23.7, CBT=23.0}, [CFTGP=12.4]
LCIN, STD (%)	F(3, 288) = 79.34 (P<0.01); {CFTGP=24.9}, [UBT=22.7], (PRFD=18.7), <CBT=18.5>
TLX	NS; UBT=49.88, CBT=49.83, PRFD=48.2, CFTGP=46.85
SART	NS; CBT=52.29, PRFD=55, CBT=55.8, CFTGP=66.58

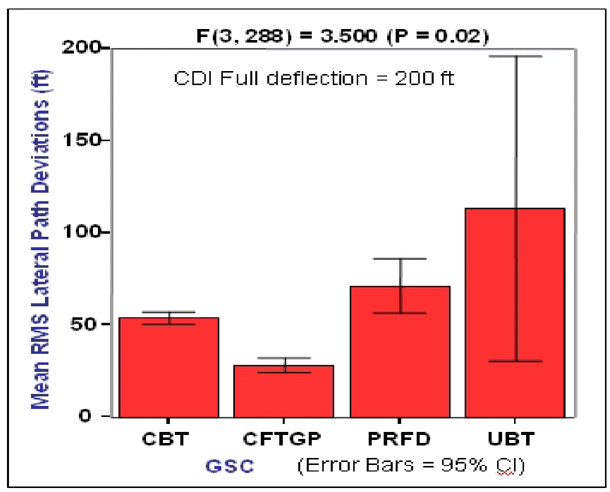

Figure 11. Mean RMS Lateral Path Deviations vs. GSC for Approach

The results for approach GSC are summarized in Table 2 and Figure 11 to 13. For the mean RMS of the IASE, no significant differences were found among the different concepts. For the LPD and VPD, the CFTGP had significantly lower mean RMS deviations than the UBT. Generally, the mean RMSs of the FTEs were lower for the GSCs with both tunnel and path guidance. These two features together provided a pathway and precise guidance cue for more accurate control of the aircraft. The precise nature of the guidance cue also required significantly higher workload (as indicated by their mean STDs of the LCINs), which induced the EPs to apply more control inputs to stay on the path. However, the subjective TLX results reveal that the EPs did not feel that their workload was any higher when using the more complex GSCs. The SART results also show that all GSCs gave similar SA.

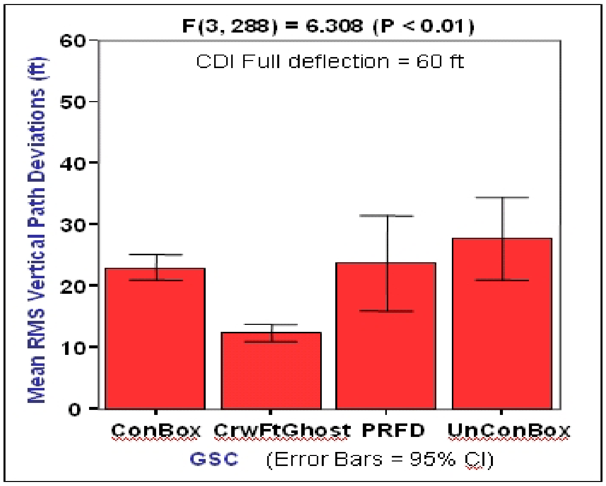

Figure 12. Mean RMS Vertical Path Deviations vs. GSC for Approach

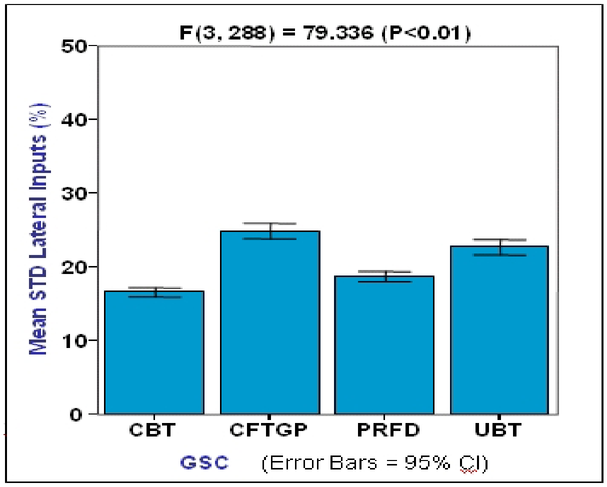

Figure 13. Mean STD Lateral Inputs vs. GSC for Approach

Approach – TPC

The approach TPC results are summarized in Table 3. For this scenario, the results indicate that TPC is not a factor for FTEs and workload. The EPs also averagely thought that the BSBG provided the least SA. Therefore, the data reveal that, for the approach task, pilot's SA could be enhanced through integrating SVS terrain on the PFD without degrading performance or increasing workload.

Table 3. Means and Groupings of Objective and Subjective Measures for TPCs in Approach

DV	TPCs and Corresponding Means
IASE, RMS (knots)	NS; BSBG=4.2, PR=4.1, EBG=4.1, CCFN=3.9
LPD, RMS (ft)	NS; BSBG=98.6, EBG=56.5, PR=56.3, CCFN=55.1
VPD, RMS (ft)	NS; EBG=22.4, CCFN=22.3, PR=21.2, BSBG=21.1
LCIN, STD (%)	NS; BSBG=21.3, CCFN=20.3, PR=20.4, EBG=20.3
TLX	NS; PR=50.94, CCFN=40.51, EBG=48.06, BSBG=47.25
SART	F(3, 288) = 10.01 (P<0.01); {BSBG=36.79},[CCFN=59.8, EBG=60.42, PR=72.67]

Missed Approach – Pilots

Table 4. Pilots' Means and Groupings of Objective and Subjective Measures in Missed Approach

DV	Pilot Ratings and Corresponding Means
IASE, RMS (knots)	F(2, 288) = 6.36 (P<0.01); {VFR=3.6}, [HIFR=3.2, IFR=2.9]
LPD, RMS (ft)	NS; VFR=50.6, IFR=48.0, HIFR=44.2
LCIN, STD (%)	F(2, 288) = 17.46 (P<0.01); {HIFR=18.4}, [VFR=17.7], (IFR=16.4)
TLX	F(2, 288) = 18.66 (P<0.01); {HIFR=51.25}, [VFR=46.27], (IFR=40.29)
SART	F(2, 288) = 18.82 (P<0.01); {HIFR=61.93}, [VFR=74.76], (IFR=94.95)

Pilots' subjective and FTE results for the missed approaches are summarized in Table 4, Figure 14, and Figure 15. The VFR EPs had a significantly larger mean RMS of the IASE than the other two pilot groups, which could be a reflection of the VFR EPs' experience. No significant difference existed on the LPD's mean RMSs among all three pilot groups. Since all the LPD's mean RMSs are within the L1P criterion, it can be said that all TPC and GSC combinations enabled the EPs to precisely navigate the course. Like the approach scenario, the average actual and perceived workloads of the HIFR EPs were higher than the other two pilot groups. The HIFR EPs also reported the lowest mean SA.

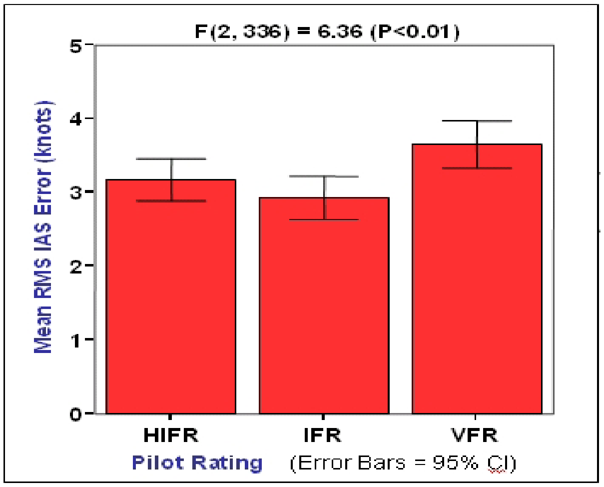

Figure 14. Mean RMS IASE vs. Pilot Rating for Missed Approach

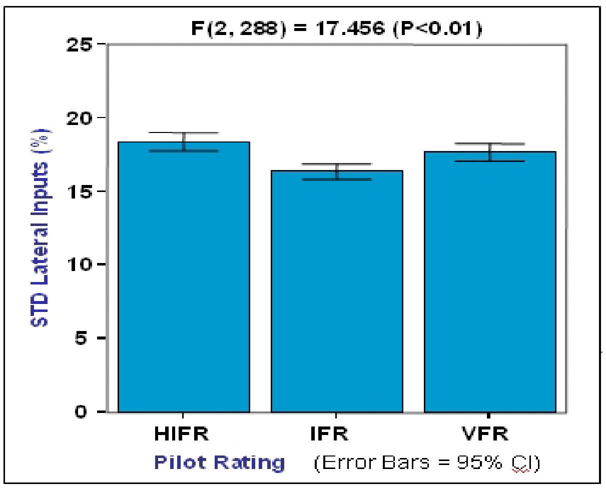

Figure 15. Mean STD Lateral Inputs vs. Pilot Ratings for Missed Approach

<u>Missed Approach – GSC</u>

The results for missed approach GSCs are summarized in Table 5, and Figure 16 to 18. The FTE results for both the STTGC and the PRFD are similar because they used a similar speed-on-pitch guidance logic. The result on the STD of the LCIN agrees well with the TLX, with the UBT having the highest workload. Also, the mean STD of the LCIN for the CBT was significantly higher than the STTGC and PRFD. Therefore, the speed-on-pitch guidance logic seems to have helped reduce workload for the missed approach. But based on subjective workload, the CBT was identical to the PRFD and the STTGC. Also on average, the EPs thought that the STTGC gave the best SA.

Table 5. GSCs' Means and Groupings of Objective and Subjective Measures in Missed Approach

DV	GSCs and Corresponding Means
IASE, RMS (knots)	F(3, 288) = 11.28 (P<0.01); {UBT=4.0, CBT=3.7}, [PRFD=3.0, STTGC=2.6]
LPD, RMS (ft)	F(3, 288) = 8.92 (P<0.01); {UBT=62.5}, [PRFD=40.8, CBT=38.0, STTGC=36.8]
LCIN, STD (%)	F(3, 288) = 77.19 (P<0.01); {UBT=20.7}, [PRFD=17.3, STTGC=17.1], (CBT=14.9)
TLX	F(3, 288) = 8.08 (P<0.01); {UBT=50.01}, [PRFD=46.87, CBT=46.55, STTGC=40.74]
SART	F(3, 288) = 15.87 (P<0.01); {UBT=58.6}, [CBT=73.76, PRFD=76.8], (STTGC=97.71)

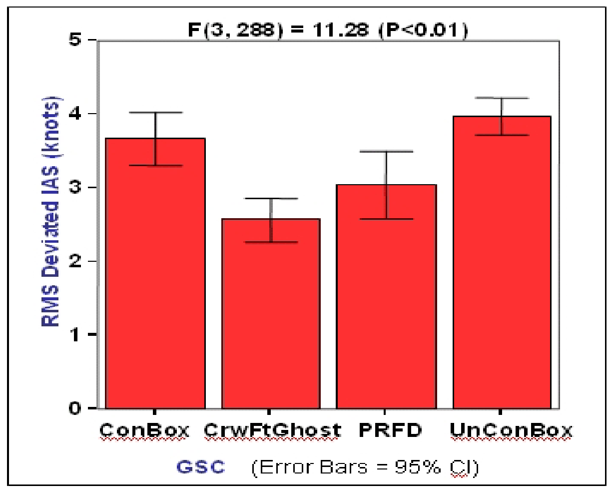

Figure 16. Mean RMS IASE vs GSC for Missed Approach

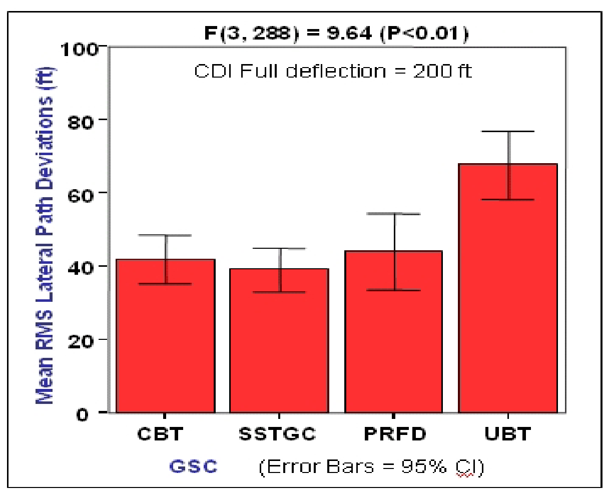

Figure 17. Mean RMS Lateral Path Deviations vs. GSC for Missed Approach

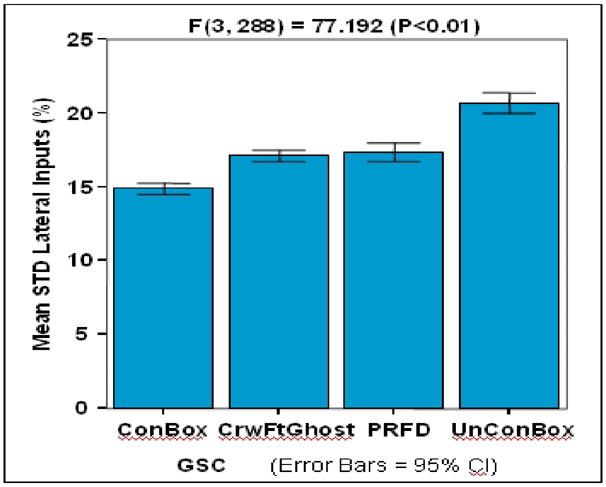

Figure 18. Mean STD Lateral Input vs. GSC for Missed Approach

Missed Approach – TPC

The results for the TPC for missed approach are summarized in Table 6. The subjective and FTE results are similar to the approach. The results show no significant differences among TPCs except for SA; the EPs felt that the BSBG gave significantly less SA than the other TPCs.

Table 6. TPCs' Means and Groupings of Objective and Subjective Measures in Missed Approach

DV	TPCs and Corresponding Means
IASE, RMS (knots)	NS; CCFN=3.4, PR=3.3, EBG=3.3, BSBG=3.2
LPD, RMS (ft)	NS; BSBG=51.1, PR=50.1, EBG=48.2, CCFN=42.9
LCIN, STD (%)	NS; BSBG=18.1, EBG=17.4, PR=17.3, CCFN=17.2,
TLX	NS; BSBG=48.25, CCFN=45.87, EBG=45.30, PR=44.75
SART	F(3, 288) = 6.87 (P<0.01); {BSBG=62.35},[CCFN=75.25, EBG=81.42, PR=87.76]

CONCLUSION

An extensive piloted simulation experiment was conducted to address critical issues facing Synthetic Vision Systems (SVS) development at NASA Langley Research Center (LaRC). A matrix of four Terrain Portrayal Concepts (TPCs) and four Guidance Symbology Concepts (GSCs) was tested using approach and missed approach operations similar to those for advanced Visual Meteorological Conditions (VMC). These simulated operations were conducted within Instrument Meteorological Conditions (IMC) at Juneau International Airport.

The results indicate that the selection of GSC for a given SVS display can be made independent of the background TPC. This research also found that the SVS TPCs provided significantly higher Situation Awareness (SA) than the non-SVS Blue-Sky-Brown-Ground without increasing Flight Technical Errors (FTEs) or objective and subjective workloads. For the approach scenario, the GSCs with more complex tunnels and path guidance cues produced significantly lower FTEs. For the missed approach scenario, the speed-on-pitch guidance of both the Sideway Ts Tunnel with a Circle guidance cue and the Pitch/Roll Flight Directors facilitated speed control and helped reduce workload. Within the missed approach scenario, the Unconnected Box Tunnel provided the worst FTE, workload, and SA because the pilots needed to maintain speed via throttle inputs instead of adjusting the pitch. In general, the IFR pilots had the best performance, although all pilot groups performed within the required test standards.

Overall, the combination of advanced GSCs with SVS TPCs provided lower FTEs and significantly increased SA for the advanced approach and missed approach operations in IMC. The results therefore suggest that the SVS displays tested could enable advanced VMC-like operations in IMC. However, further testing should be performed to examine the capabilities of these SVS displays to provide safe and flexible VMC-like operations for all phases of flight in IMC.

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Appendix A. List of Acronyms

BSBG	Blue Sky Brown Ground
CBT	Connected-Box Tunnel
CCFN	Constant-Color Fishnet
CDI	Course Deviation Indicator
CFIT	Controlled Flight Into Terrain
CFT	Crow Feet Tunnel
DEM	Digital Elevation Model
DV	Dependent Variable
EBG	Elevation Based Generic
EP	Evaluation Pilot
FAF	Final Approach Fix
FOV	Field Of View
FTE	Flight Technical Error
GAWS	General Aviation Work Stations
GC	Guidance Circle
GP	Ghost Plane
GSC	Guidance Symbology Concept
GSQ	Guidance Square
HIFR	High-time IFR
HITS	Highway In The Sky
IASE	Indicated Airspeed Errors
IMC	Instrument Meteorological Condition
INDV	Independent Variable
L1P	Level 1 Performance
LaRC	Langley Research Center
LCIN	Lateral Control Input
LPD	Lateral Path Deviations
LVLOC	Low-Visibility Loss of Control
MAP	Missed Approach Point
MSA	Minimum Safe Altitude
PFD	Primary Flight Display
PR	Photo Realistic
PRFD	Pitch Roll Flight Directors
RMS	Root Mean Square
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SD-HDD	Symbology Development for Head-Down Display
SND	Strategic Navigation Display
SST	Sideway Ts Tunnel
STD	Standard Deviation
SVS	Synthetic Vision Systems
TLX	Task Workload Index
TOGA	Take Off Go Around
TPC	Terrain Portrayal Concept
TP-HDD	Terrain Portrayal Head-Down Display
UBT	Unconnected-Box Tunnel
VMC	Visual Meteorological Condition
VP	Velocity Predictor
VPD	Vertical Path Deviations