

## EFFECTS OF ADVANCED COCKPIT DISPLAYS ON GENERAL AVIATION PILOTS' DECISIONS TO CONTINUE VISUAL FLIGHT RULES FLIGHT INTO INSTRUMENT METEOROLOGICAL CONDITIONS

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Thirty pilots flew a simulated VFR cross country flight into deteriorating weather with one of three levels of display support: a control display with standard instruments, a synthetic vision system (SVS) display depicting terrain and a highway in the sky (HITS), and a configuration in which the same SVS HITS display was augmented by an electronic moving map depicting weather. Results revealed that nearly all pilots in the control condition avoided penetrating the IMC clouds. Significantly, 60% of pilots across both SVS conditions penetrated the clouds and continued to their destination in zero visibility conditions. Their failure to notice the deteriorating weather outside the cockpit was documented by a dominance of head-down scanning for the pilots in these two groups who penetrated the weather. The presence of the moving map weather display did not mitigate these manifestations of attentional tunneling. Possible solutions related to display design and training are discussed.

### INTRODUCTION

Visual flight rules (VFR) flight into instrument meteorological conditions (IMC), or unqualified flight into adverse weather, continues to be a significant safety hazard within general aviation (GA). Although VFR flight into IMC accidents typically only account for a small proportion of total number of GA accidents, they account for a disproportionate percentage of GA fatalities. For example, the National Transportation Safety Board (NTSB) found that while VFR into IMC accidents made up only 4% of the total number of accidents from 1975 to 1986 they resulted in 19% of the total GA fatalities (NTSB, 1989). These statistics point to the fact that the *fatality rate* of VFR into IMC accidents is significantly greater than that of other types of accidents.

Clearly then, safety initiatives are required to help reduce the number of VFR flight into IMC accidents. One approach is through the use of new cockpit technology to either help pilots avoid adverse weather in the first place or recover from hazardous situations should they encounter, inadvertently or otherwise, instrument meteorological conditions.

VFR flight into IMC is often characterized by pilots' inadequate evaluation or misinterpretation of weather information (Goh & Wiegmann, 2001; Wiegmann, Goh & O'Hare, 2002). Consequently, advanced cockpit displays that focus on improving pilots' situation awareness and weather assessment might improve pilot decision-making. Technologies such as on-board

graphical weather information systems (Latorella and Chamberlain, 2002) can provide pilots routine weather information and weather radar images via data-link and perhaps help improve en-route decision making.

Another technology driven approach to reducing the number of VFR into IMC accidents is to provide pilots with displays that help them avoid both controlled flight into terrain and spatial disorientation leading to loss of control of the aircraft in low or zero visibility conditions. Synthetic vision systems (SVS) that provide pilots with an in-cockpit, 3-dimensional representation of terrain in front of the aircraft (Prinzel, Comstock, Glaab, Kramer, Arthur, & Barry, 2004; Schnell, Kwon, Merchant, & Etherington, 2004) can potentially increase terrain awareness and help prevent spatial disorientation while pilots maneuver out of IMC.

However, the benefits of synthetic vision systems need to be considered with their potential negative effects on pilots' attention management. A concern with synthetic vision displays is that the 3D immersed perspective of such displays can cause pilots to look extensively at the display at the expense of time spent sampling the outside world (Wickens, 2005). This attentional tunneling can have significant detrimental effects on pilots' situation awareness, possibly causing them to miss vital weather cues that are only visible in the outside world.

This report presents an investigation into the effects of two technological interventions, the synthetic vision system display and a graphical weather information system, on weather-related pilot decision-making, in

order to examine the extent to which either or both mitigates or exacerbates the tendency to continue flight into deteriorating weather.

**METHODS**

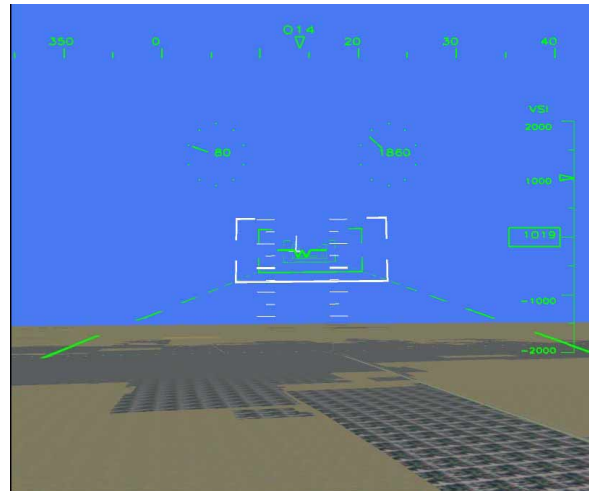
Thirty pilots (28 male, 2 female) from the Institute of Aviation at the University of Illinois participated in the flight simulation. Twenty-nine pilots held their private pilot certificates and of these, five held instrument ratings. The remaining pilot was a student pilot nearing completion of their private pilot certificate. All pilots had completed at least 5 cross-country flights and accumulated at least 10 cross-country flight hours. Pilots’ total flight experience ranged from 57 to 205 hours (mean = 120.1 hours) while their IFR experience ranged from 0.9 to 50 hours (mean = 22.1 hours). Pilots’ ages ranged from 18 to 26 years (mean = 20.5 years).

Participants flew a simulated VFR cross-country flight into deteriorating weather with one of three levels of display support (10 pilots per display condition). Pilots in the control group flew with standard instruments. Pilots in the SVS group used a synthetic vision system display depicting terrain and a highway in the sky (Figure 1). Pilots in the third group (SVS/MM) flew with a display configuration in which the same SVS display was augmented by an electronic moving map (MM) depicting graphical weather information (Figure 2). The moving map contained parameters from routine weather reports (METARs) such as ceiling, visibility, wind direction and flight condition.

Weather conditions at takeoff were 10 statute miles (SM) visibility and 5000 feet above ground level (AGL) cloud ceilings. Three-quarters of the way to their destination the weather began to deteriorate to below VFR minimums with visibility and cloud ceilings being reduced to 2 SM and 1500 feet AGL respectively by the time pilots reached their destination. Pilots would fly into the cloud ceiling approximately seven minutes after the weather began to deteriorate. Pilots were free to either divert to an alternate airport or continue flight to their original destination after encountering the deteriorating weather.

Participants were instructed to take as much time as necessary to review pre-flight material that included the flight plan and weather forecasts. In addition to the pre-flight briefing, pilots were specifically instructed to monitor for traffic, weather changes and mechanical malfunctions and reminded that all Federal Aviation

Regulations would apply to the flight as they do in the real world. Pilots also wore a head-mounted eye tracker.



**Figure 1. Synthetic Vision Display used by pilots in the SVS and SVS/MM groups.**



**Figure 2. Moving Map display used by pilots in the SVS/MM group.**

The simulation was stopped when participants landed at their original destination, were clearly diverting to an alternate airport (as judged from their flight path) or became lost.

**RESULTS**

One pilot from each of the SVS conditions chose to divert to an alternate airport, although these decisions occurred at different points of the flight. While the vast majority of pilots chose to continue the flight, their response to the deteriorating weather can be examined in terms of whether they decided to follow the SVS highway in the sky (HITS) and *penetrate* the clouds or

avoid the clouds by diverging from the HITS and descending below the clouds at first encounter.

All pilots in the control condition, except one, descended below the clouds when encountering the deteriorating weather. In the SVS only condition, three pilots elected to avoid the clouds, while the remaining seven flew on into zero visibility IMC by following the HITS. Pilots with the SVS/MM display were split evenly in their responses with five avoiding the clouds and five continuing into them. It should be noted that all of the twelve pilots with SVS displays who penetrated the clouds, continued following the HITS *through* the clouds until they landed at the destination airport.

Chi-square analysis revealed a significant difference in the proportion of pilots continuing in each group ( $\chi^2=7.6, p<0.05$ ). Chi-square comparisons showed a significant difference in the number of pilots continuing between the SVS only and control groups ( $\chi^1=7.5, p<0.01$ ) and a marginally significant difference between the SVS/MM and the control group ( $\chi^1=3.8, p=0.051$ ). The comparison between the two SVS groups did not show a statistically significant difference.

Eye tracking measures were extracted from either the first forty five minutes of the flight or the seven minute period over which the weather deteriorated. The eye tracking areas of interest (AOIs) included the primary flight display used in the given condition (PFD), the Moving Map display (MM) and the outside-world (OW) (Figure 3).



Figure 3. Visual Scanning Areas of Interest (AOIs)

The allocation of visual attention as measured by percent dwell time (PDT) to the various AOIs is shown in Figure 4.

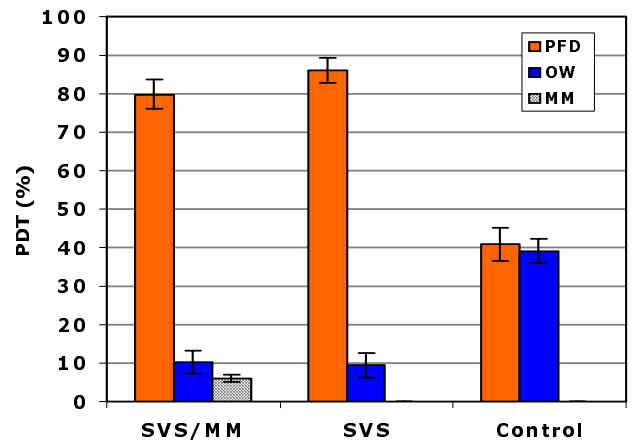
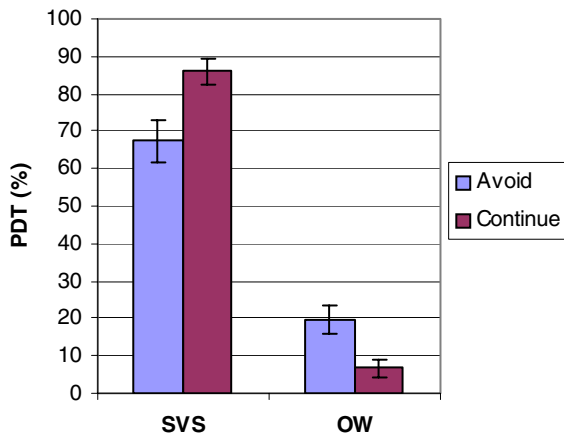


Figure 4. PDTs to AOIs by pilots before encountering weather.

Pilots in the both SVS conditions spent the vast majority of time attending to the SVS display and very little time looking at the outside world. Averaged across the two SVS conditions, pilots attended to the SVS approximately 83% of the time while scanning the outside world only 10% of the time. In contrast, pilots in the control condition, who by navigational necessity must seek cues in the outside world, spent almost 40% of their time looking out the window.

One-way ANOVAs revealed significant differences in mean PDTs between groups for scans to the SVS display ( $F(2,27)=40.5, p<0.01$ ) and the outside world ( $F(2,27)=29.9, p<0.01$ ). Planned comparisons between groups revealed significant differences between both SVS conditions and the control condition ( $p<0.05$ ) but not between the SVS/MM and SVS conditions. Note then that the small amount of scanning to the MM weather display (about 6%) for pilots in this group, did not significantly lower either outside world or SVS panel scanning.

Analysis of eye movement data of pilots from only the two SVS groups reveals further differences in scanning behavior. Figure 5 compares the PDTs to the SVS display and Outside-World during the 7-minute encounter with the deteriorating weather of the eight pilots who avoided and the twelve pilots who continued flight into the clouds.



**Figure 5. PDTs to AOIs during weather encounter, grouped by decision, for pilots in the two SVS groups.**

The difference in visual scanning behavior between the two pilot decision groups is readily apparent. Of particular interest is the fact that pilots who avoided the weather spent 19.8% of their time scanning the outside world, compared to a figure of only 6.7% of the time by those pilots who continued into the clouds.

A two way ANOVA (between subjects: decision; within subjects: AOI) revealed a significant interaction between the two factors ( $F(1,18) = 13.2, p < 0.01$ ) indicating that the weather avoiders looked more at the OW and less at the SVS than did the penetrators.

A comparison between the amount of time spent looking at the moving map display for those pilots who avoided the weather and those who continued into the clouds in the SVS/MM group revealed no difference in percent dwell time to that AOI ( $t(8)=0.09, p > 0.10$ ).

## DISCUSSION

Both SVS display conditions generated the behavior of flying VFR into IMC and penetrating into the clouds, in a way that pilots in the control condition did not: pilots flying with SVS displays were six times more likely to penetrate the clouds than pilots in flying with traditional instruments. Furthermore, this behavior appears to be tied fairly directly to “attentional tunneling” in that pilots in the control condition looked outside approximately four times as much as those with the SVS displays, a region that occupied around 80% of their visual attention. This linking between the “compelling” nature of the SVS and HITS, and attentional neglect of the outside world (and its important events and information) is certainly consistent with the pattern of attentional

tunneling revealed in other SVS studies, using non-weather hazards, summarized in Wickens (2005). The current results are important in extending this conclusion to weather monitoring.

Clearly, the visual scanning behavior of pilots with SVS displays exhibited in this study was far from ideal. These pilots typically allocated only 10% of their visual attention to the outside world, compared to the recommended 67% to 75% (FAR/AIM, 2003; AOPA, 1993).

Interestingly, while the tendency toward tunneling, operationally defined by penetration of the clouds, was slightly mitigated by the presence of the moving map weather display inside the cockpit, this effect was very modest. Specifically, only two pilots used the map display *strategically* and descended prior to encountering the deteriorating weather.

Mitigation of the observed costs of attentional tunneling could take two generic forms. First, it is possible that enhanced representation of in-cockpit weather deterioration could be effective. This might take the form of more salient representation on the Moving Map display, or even some form of alerting on the SVS display itself. The second approach, and not mutually exclusive of the first, is to focus on training the scan patterns associated with SVS displays, and to try to establish some minimum outside-world scan percentage. The advantage of this approach is that, naturally, it will address all problems of cognitive tunneling and neglect of the outside world including those related to issues such as runway offsets, and traffic and terrain not reflected on the SVS database.

The results of this study also lend some support to the claim that SVS displays can be effective in preventing low visibility loss of control GA accidents (Hughes & Takallu, 2002). All twelve of the non-instrument rated pilots who flew into the clouds with the SVS display managed to fly the aircraft safely to the destination airport and land uneventfully.

## ACKNOWLEDGMENT

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