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**Attentional Tunneling
and Task Management**

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**Technical Report
AHFD-05-23/NASA-05-10**

December 2005

Prepared for

**NASA Ames Research Center
Moffett Field, CA**

Contract NASA NAG 2-1535

Abstract

This paper discusses attentional tunneling as one cause of breakdowns in task management. The phenomenon is defined, and empirical evidence is then reviewed to show the conditions in which the phenomenon is created by head up display location, compelling 3D displays, fault management, and automation induced complacency. Statistical and methodological issues are reviewed regarding the generalization of the phenomenon in the laboratory to real world mishaps.

Introduction

Breakdowns in task management and task prioritization have been well documented to cause mishaps in aviation (Funk, 1991; Chou, Madhavan, & Funk, 1996). A classic accident here is the crash of the Eastern Airlines L1011 into the Everglades, when pilots failed to manage their descending altitude while addressing an apparent landing gear failure. While such breakdowns have diverse psychological causes (Dismukes, 2001), our specific interest in this paper is focused on a collection of related phenomena that are known variously by names of “attentional tunneling”, “attentional fixation” or “cognitive tunneling”. Note that in this context, “attention” and “cognition” can be used nearly interchangeably, if it is assumed that attention can be directed both inward to cognition, as well as outward toward particular channels and events in the environment.

We can offer a rough definition of attentional tunneling as the **allocation of attention to a particular channel of information, diagnostic hypothesis or task goal, for a duration that is longer than optimal, given the expected cost of neglecting events on other channels, failing to consider other hypotheses, or failing to perform other tasks**. Thus note that the definition must include both the forces that “lock the tunnel” to its current channel, as well as a definition of a channel of neglect.

Such a definition can account for more specific mishaps in a wide variety of circumstances. For example automobile accidents while on the cell phone can be attributed to undesirable “engagement” in the process of generating and understanding conversations (Strayer & Johnston, 2001; Horrey & Wickens, in press). Analysis of the Three Mile Island nuclear power accident associated the crisis with operators’ excessive tunneling on one (incorrect) hypothesis as to the nature of the obvious failure, and this hypothesis led them to fail to attend to contraindicating visual cues. The Air Force has identified attentional tunneling as being a major cause of F16 mishaps, and indeed a case can be made that nearly all CFIT accidents (Shappell & Wiegmann, 2003) can be associated with attentional tunneling away from important altitude information.

While salient mishap data clearly indicates that the tunneling problem exists, such data often provide little usable evidence about its precise causes, because of the invariable absence of control that such data contain when they are used retrospectively to infer causality. Thus a complementary approach is to turn to more controlled flight simulation experimental data to both reveal the prevalence of the phenomenon in the general population, as well as the causal factors that amplify the likelihood of tunneling. Below we describe empirical data that bear on proposed causes of attentional tunneling to examine how the literature supports the degree of influence of each. We focus explicitly on four different factors that have been postulated to induce such

tunneling: head up display location, the compellingness of 3D displays, fault management, and automation. We conclude with discussion of some of the methodological and statistical issues involved in relating tunneling to flight safety.

Display location: HUD-induced tunneling. The now classic experiment of Fischer, Haines and Price (1980) revealed that pilots flying with a HUD were less likely to detect an unexpected runway incursion than those flying with conventional head down instruments, despite the fact that the HUD generally preserved the runway within foveal vision, where the incursion could be seen. While their observation of this phenomenon was not based upon a sufficiently large sample of pilots to reveal statistical trends, the phenomenon has been sufficiently replicated in both low fidelity (Wickens & Long, 1995) and high fidelity (Fadden, Ververs & Wickens, 2001; Hofer, Braune, Boucek, & Pfaff, 2000) simulations to establish it as real. Something about the HUD appears to attract attention to its image, and therefore lead attention away from important, but unexpected events within the visual field (see Wickens, Ververs & Fadden, 2004 for a summary). Such HUD costs appear to be restricted to noticing totally unexpected events, since HUD benefits are generally found for most other visual tasks, including the detection of low frequency (but not truly surprising) events (Fadden et al., 2001).

3D Immersion Compellingness. The gradual appearance of 3D displays in the cockpit, such as the SVS guidance system (Prinzel et al., 2004; Schnell et al., 2004), has led to some concern that the highly realistic ego-referenced perspective of such a system can alter pilots' scan patterns so that they look extensively at the display (attentional tunneling), and fail to adequately sample the outside world. Such behavior can compromise safety to the extent that critical events, unknown to the data-generation sensors and software that drive the display, may be present as hazards in the outside world (e.g., the "rogue airplane" with an inoperable transponder; Wickens et al., 2002). Earlier research by Olmos Wickens and Chudy (2000) revealed such a trend exhibited in a 3D display in fighter aircraft in a low fidelity simulation. Four recent experiments in our laboratory described below, all using a high fidelity light aircraft Frasca simulator, clearly document the phenomenon.

Fadden, Ververs and Wickens (2001), compared a 3D "pathway-in-the-sky" display in a HUD location with a conventional HUD presenting ILS information in an approach and landing simulation. While we observed superior overall performance with the 3D display we did observe that the pathway induced a marginally significant 4 second delay in pilots' response to an unexpected runway incursion on a single (last) landing trial of the experiment.

Wickens, Alexander, Horrey, Nunes, and Hardy (2004; Thomas & Wickens, 2004), examined the guidance offered by a photo-realistic SVS display coupled with a 3D flight path pathway display in a long curved step down approach through a terrain challenged environment. Guidance and traffic detection performance with the 3D pathway was compared with that supported by less compelling (but equally accurate) instruments presenting the same flight path information. While flight path performance was much better supported by the integrated pathway, the detection of two unexpected or "off-normal" events was not. These included a blimp, located in the airspace on the flight path, but not visible in any head down display (Figure 1), and a runway offset, whereby the positioning of the SVS pathway and the synthetic runway on the display brought the pilots on an approach parallel to but offsetting the true runway (a disparity only detectable by looking outside).



Figure 1. Off-normal outside-world traffic.

We observed that 4 of the 8 pilots flying with the pathway failed to detect the blimp, whereas only 1 of 6 pilots flying without the pathway missed this critical off-normal event. Furthermore, while the runway offset was only imposed on those landing with the 3D pathway (and hence data could not be compared with those flying with the conventional instruments), 5 of the 12 pilots landing with the 3D pathway failed to detect the offset until very late in the landing phase. Furthermore, analysis of visual scanning revealed that the breakdowns in detection were associated with pilots who spent relatively more time looking head down at the instruments, rather than scanning outside. To some extent this head down scanning was “encouraged” by the rich and precise guidance offered by the pathway, and by the runway depiction on the head down terrain display lying on the SVS panel.

In a third study, Alexander, Wickens and Hardy (in press) also examined SVS-induced tunneling, although they did not compare their off-normal event detection with a control non SVS condition. On the final approach in their simulation, during the final trial of the experiment, a truly surprising runway incursion was present. This incursion did not itself form the basis of the unexpected event, since the tunnel guidance was designed to automatically reconfigure to form a missed approach path, and guide the pilot away from the runway obstacle (Figure 2). However the missed approach path was designed to put the flight trajectory squarely in the path of a blimp, visible only in the outside world, as in the first off-normal event examined by Wickens, Alexander, Horrey, Nunes, and Hardy (2004). Importantly, 14 of the 17 pilots in the experiment failed to detect the blimp, flying a flight path directly through it.

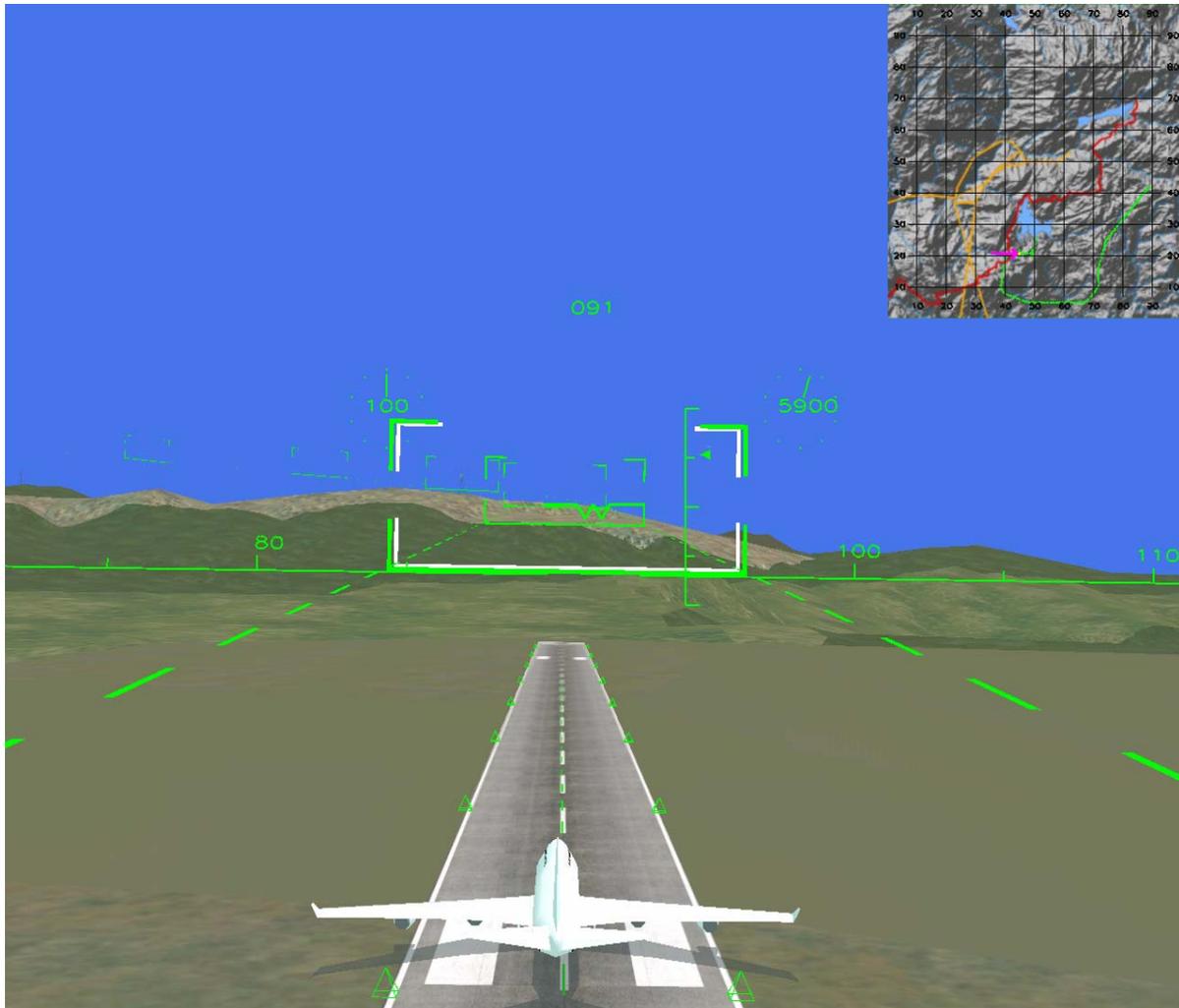


Figure 2. Hits configured for missed approach around runway incursion. The tunnel leads through an obstacle (blimp) visible only in the outside world.

In a fourth study, Johnson, Wiegmann, and Wickens (2005) observed that pilots flying a simulated cross country flight with a 3D SVS/HITS suite were more likely to fly into bad weather (VFR into IMC) than those flying without such display support.

While the above findings suggest that the 3D pathway (and its associated SVS background) can inhibit the detection of truly surprising events, it is important to highlight two findings that failed to indicate “pathway induced tunneling”. First, Wickens, Alexander, Horrey, Nunes, and Hardy (2004) examined a third off-normal event, a radio tower constructed so that it protruded into the pathway-defined flight path, but **was visible on the SVS display**. Here all pilots appeared to detect the tower adequately, as inferred from their flight path maneuvering.

The second example of “3D pathway success” was an experiment by Iani and Wickens (2004), using the same flight simulation as above, in which pilots’ response to unexpected weather

changes on a head down electronic weather map designed to influence the choice of an optimal safe flight path, were used to infer tunneling. Under these circumstances, those pilots flying with the 3D pathway display, which we hypothesized might induce tunneling, were actually **more** likely to notice the weather changes, than those flying with the separated instruments. This result, in seeming contradiction to the 3D pathway costs described above, were accounted for by two factors: (1) the weather changes, while unexpected, were not truly surprising, in that a well trained pilot, flying through areas where bad weather may exist, can be expected to be reasonably vigilant for unexpected changes in those weather patterns; (2) the 3D pathway was so much easier to fly (lower workload) than the separated display, that pilots were inferred to have a much greater amount of available attention with which to monitor the surrounding displays.

The collective results of 3D immersive display tunneling effects are shown in Table 1. In summarizing these effects of immersed 3D display compellingness, we argue that some components of both a 3D SVS terrain background and a 3D pathway (or tunnel) hosted within, may contribute to a large allocation of visual attention to this location, an allocation which can leave a pilot vulnerable to missing **truly surprising** events that can only be seen elsewhere (i.e., the outside world). Not all pilots demonstrate this, but those that do, tend to scan outside less than those that don't.

Table 1.

3D Data			
<u>Miss Rate of Off-Normal Events When Flying with SVS</u>			
<u>STUDY</u>	<u>EVENT</u>	<u>HITS</u> (Tunnel)	<u>No HITS</u>
<u>Attention Tunneling Evidence</u>			
SVS 3	Blimp	4/8	1/6
SVS 3	Runway offset	5/12	
SVS 2	Missed approach blimp	14/17	
SVS 5	Tower	10/24	
		Miss rate = 50%	
SVS 8 (Johnson)	Bad weather	12/20	1/10
<hr/>			
<u>Uncertain</u>			
SVS 6	Blimp	3/24	
<hr/>			
<u>No Tunneling</u>			
SVS 2	SVS Tower	0/8	
SVS 7 (Iani)	ND WX change	4/20	8/20

Importantly, one variable that appears to amplify this tunneling effect is the existence of a system failure. It is, for example, a failure of the overall SVS system that leads its guidance to a runway offset approach. Also, the one circumstance where the tunneling was most dramatically documented (over 80% of the pilots) was the finding of the blimp collision by Alexander et al. (in press), in what could be classified as a “double failure”. That is, there was a runway incursion (failure of the air traffic management system), coupled with a failure of the SVS sensors to note the mid-air blimp following the missed approach path configuration. Thus we now discuss the contributions of failure management to attentional tunneling.

Failure Management. We noted above that attentional tunneling was amplified during the missed approach incident coupled with the sensor failure. Indeed there is a long history of research documenting the problems of failure and fault management inducing some sort of cognitive lockout, as true with the Eastern Airlines Everglades crash, and as demonstrated in other domains such as process control (Moray & Rotenberg, 1989). Dismukes (2001) has highlighted fault management as one of the “red flags” that pilots need to consider, as they remember to sample other non-fault-related instruments in the cockpit. The extent to which this results from the stress-induced cognitive narrowing brought on by the danger of the failure state (Hockey, 1986), or simply the high importance of the fault management task (which **should** optimally command a good deal of attention, even if not all of it) cannot be fully discriminated. Probably some of both factors are involved.

Automation Failure and Complacency. A final phenomenon, with great relevance to the cockpit, is that of automation induced “complacency” whereby a pilot, depending on automation which has always functioned safely in the past, fails to notice the unexpected failure (Parasuraman, Molloy & Singh, 1993; Parasuraman & Riley, 1997). This phenomenon is closely related to the “automation bias” reported by Mosier et al. (1998) whereby automation-based diagnosis is blindly followed by the pilot, in spite of evidence to the contrary. In a sense this phenomenon does not describe the capture of and “lock on” of attention (by the salient or compelling entity), so much as it describes the neglect of attention (to the channel characterizing the automated processing where events – failures -- are **not** expected to occur). Importantly, this phenomenon shares with other examples of tunneling described above, the property that its manifestations occur most notably when automation failures are extremely unexpected (e.g., truly surprising). These are what we describe as the “first failure effects” (Wickens, 2000, Yeh et al., 2003). Subsequent failures of automation now known by the supervisor to be imperfect appear to lead to less dramatic forms of attentional neglect of the automated process.

Statistical and Methodological Issues. The investigation of attentional tunneling is challenged by certain statistical issues. Most importantly, because it is an effect generally manifest with unexpected/surprising events, it is a phenomenon that by definition can be effectively produced only one or two times per experiment (or per flight simulation). If the event used to document attentional tunneling occurs more frequently than this, it will by definition, no longer be surprising. One consequence of this fact is that pilot response to the event will be subject to high variability (since variability decreases with sample size, and the sample size will be small); as a consequence, the effects will be of relatively low statistical power, and researchers should be willing to accept a greater likelihood of committing a type 2 statistical error by raising their alpha level for significance above the 0.05 level (Wickens, 1996, 2001) when examining such responses to rare events.

(We note here the advantages of measuring visual scanning (Thomas & Wickens, 2004), a technique with relatively high statistical power, since it can be continuously measured, that can be a direct measure of attentional tunneling; thus a channel that is not looked at for a long period of time, can be inferred to produce neglect of important events that occur along that channel, should those events ever occur).

A methodological criticism that is sometimes directed toward the research typical of that above, which has documented attentional tunneling in flight simulation experiments, is that this is somewhat of an artificial phenomenon of the simulation laboratory, and that pilots flying in the “real world” would be more vigilant of such unexpected events, because of the higher stakes involved, and/or because of a greater expectancy that “anything can happen”. On the one hand, there is some merit to this concern over generalizability. For example Fadden, Ververs and Wickens (2001) found that HUD-induced attentional tunneling was manifest for those pilots who had not participated in a flight simulation involving the off-normal runway incursion, but that the phenomenon was not shown by those who had previous experience. Thus it is possible that experience may mitigate the tunneling effect.

In response, however, two counterarguments can be given. First, the phenomenon has been demonstrated in very high fidelity simulations, by well qualified commercial pilots (Hofer et al., 2000). Second, higher levels of training may, ironically, make pilots **less**, rather than more likely to “expect the unexpected”, if the unexpected event has never occurred within their many years of flight. A driving analogy is appropriate here. Most people drive on an expressway with a headway that is well less than the minimum to avoid a rear end collision should the leading driver suddenly come to a halt. This tendency is, in part, the result of never having experienced such an event.

Going beyond the issue of statistical and methodological issues, a strong case can be made that the safety implications of attentional tunneling may simply not be amenable to conventional statistical techniques that focus on “the statistics of the mean”. This is because accidents, the target of generalization from our research, are **not** typical, and are probably not caused by human error of the “average” pilot flying in typical circumstances (Wickens, 2000, 2001). Rather, we might expect them to be caused by the poorly trained pilot, in high workload environments, perhaps, as noted above, dealing with a failure management scenario. Thus while only a small number of pilots may demonstrate the phenomenon of interest in the simulation laboratory, so also only a small number of pilots may demonstrate unsafe neglect and attentional tunneling in the sky in such a way as to lead to a mishap. Given that such accidents are well documented, any identification of factors that may invite greater tunneling, are worthy of empirical investigation. We hope that the factors discussed above contribute to that investigation.

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