
The International Journal of Aviation Psychology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hiap20

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David R. Hunter [a] & John E. Stewart [b]

[a] Independent Counsultant, Fredericksburg, Virginia, USA

[b] U.S. Army Research Institute for the Behavioral and Social Sciences, Fort Rucker, Alabama, USA

Available online: 31 Mar 2011

To cite this article: David R. Hunter & John E. Stewart (2011): Hazardous Events and Accident Involvement by Military and Civilian Pilots, The International Journal of Aviation Psychology, 21:2, 123-134

To link to this article: http://dx.doi.org/10.1080/10508414.2011.556451

THE INTERNATIONAL JOURNAL OF AVIATION PSYCHOLOGY, *21*(2), 123–134

ISSN: 1050-8414 print / 1532-7108 online
DOI: 10.1080/10508414.2011.556451



# Hazardous Events and Accident Involvement by Military and Civilian Pilots

David R. Hunter[1] and John E. Stewart[2]
[1]*Independent Counsultant, Fredericksburg, Virginia*
[2]*U.S. Army Research Institute for the Behavioral and Social Sciences, Fort Rucker, Alabama*

The Hazardous Events Scale (HES), a measure of involvement in potentially dangerous situations in aviation that do not lead to accidents, has been used as a surrogate for actual accident involvement in studies of risk taking and hazardous attitudes. However, no correlation between the HES and actual accident involvement has previously been published. In this research effort we developed an Army-specific version of the HES and administered it, over the course of 4 separate surveys, to a large sample of U.S. Army aviators. We then computed Army-HES scores that we correlated with self-reported accident involvement. We also reanalyzed data from 4 separate civilian studies in which the civilian version of the HES was administered to compute a correlation between HES and self-reported accident involvement. We hypothesized that a positive correlation would be obtained between the HES and accident involvement. That hypothesis was supported by the results. Positive, significant correlations were obtained for the Army sample ($r = .15$), and each of the 4 civilian studies ($r = .23$, $r = .32$, $r = .24$, $r = .30$) between the HES and self-reported accident involvement. The use of the HES as a surrogate measure for accident involvement and indicator of pilot accident risk for both individual pilots and organizations is discussed.

Not every error or hazardous situation leads to an accident. For the most part, errors are caught and hazardous situations are evaded, such that accidents are averted. Indeed, accidents occur very infrequently, even though many errors and hazardous situations can occur. Because of this one-to-many relationship, accidents are sometimes referred to as the tip of an iceberg. Although there are relatively few accidents, there are many incidents and hazardous events that did

Correspondence should be sent to David R. Hunter, 4308 Bridlepath Court, Fredericksburg, VA 22408. E-mail: david.hunter@avhf.com

not result in accidents. In industrial settings, the ratio of incidents to accidents has been estimated to be approximately 600 to 1 (Bird & Germain, 1996, as cited in Phimister, Oktem, Kleindorfer, & Kunreuther, 2003).

In many cases, the difference between an incident and an accident is very slim. For example, the pilot of an overloaded plane might miss clearing a tree on takeoff by only a few feet. However, had the density altitude been slightly higher, or had the aircraft been slightly heavier, then the obstacle might not have been cleared, and an accident would have occurred.

Hazardous events (by which we mean hazardous situations, close calls, and incidents, whether reportable or not) are interesting for two reasons. First, they can be used as indicators of the safety status of a system or individual. In that respect, they can be termed leading indicators (see Grabowski, Ayyalasomayajula, Merrick, Harrald, & Roberts, 2007, for a review of studies that use this terminology) or accident precursors, and they are used in many settings. For example, Sattison (2004) described the Accident Sequence Precursor Program in use in the nuclear power industry, and Tamuz (2004) provided examples of programs designed to identify precursors from the aviation, nuclear power, and health care industries. These users include "government regulatory agencies (e.g., FAA and USNRC), individual organizations (e.g., airlines), hospital systems (e.g., VHA), industry associations (e.g., INPO), professional organizations (e.g., the Institute for Safe Medication Practices), and professional associations (e.g., Airline Pilots Association)" (Tamuz, 2004, p. 75).

Second, hazardous events could be used as surrogates for an ultimate measure of interest. Surrogate measures are used widely in medical research to evaluate the impact of experimental therapies (Burzykowski, Molenberghs, & Buyse, 2005). The use of a surrogate is advantageous because it greatly shortens the time required to complete a study. For example, serum cholesterol level, a risk factor for heart disease, might be used as a surrogate in the evaluation of a new drug designed to prevent heart attacks. Changes in serum cholesterol might be observed fairly quickly after administration of the new drug, although it could take years to observe a sufficient sample of patients to determine whether there was a change in the incidence of heart attacks.

Similarly, in aviation accident research, it has been suggested (Hunter, 1995) that hazardous events could be considered surrogates for the actual measure of interest—accident involvement. The prevalence of hazardous events has been examined both in the United States (Hunter, 1995) and in New Zealand (O'Hare & Chalmers, 1999).

Hunter (1995) conducted a nationwide survey of pilots in the United States that included a set of questions he termed the Hazardous Events Scale (HES). The HES consisted of questions that asked respondents to indicate the number of times they were involved in potentially hazardous events. The questions making up the HES (civilian version) are given in Table 1.

TABLE 1
Hazardous Events Scale (Civilian Version)

| |
|---|
| How many aircraft accidents have you been in (as a flight crew member)? |
| How many times have you run so low on fuel that you were seriously concerned about making it to an airport before you ran out? |
| How many times have you made a precautionary or forced landing at an airport other than your original destination? |
| How many times have you made a precautionary or forced landing away from an airport? |
| How many times have you inadvertently stalled an aircraft? |
| How many times have you become so disoriented that you had to land or call air traffic control for assistance in determining your location? |
| How many times have you had a mechanical failure that jeopardized the safety of your flight? |
| How many times have you had an engine quit because of fuel starvation, either because you ran out of fuel or because of an improper pump or fuel tank selection? |
| How many times have you flown into areas of instrument meteorological conditions, when you were not on an instrument flight plan? |
| How many times have you turned back or diverted to another airport because of bad weather while on a visual flight rules flight? |



In their survey of New Zealand pilots, O'Hare and Chalmers (1999) found that encounters with potentially hazardous events were fairly common. Furthermore, the experiences reported by the New Zealand pilots were remarkably similar to those of the U.S. pilots. For example, the proportions of pilots who had entered instrument meteorological conditions (slightly under 25%) or inadvertently stalled an airplane (about 10%) were almost identical in both samples.

Findings such as these have encouraged researchers to consider the utility of such measures in accident research. Because there are many more incidents than fatal accidents (perhaps as many as two or three orders of magnitude), then using them in lieu of accidents in research alleviates to some degree the problems associated with the prediction of rare events. However, because these are only surrogates for the true criterion of interest, it must be remembered that these results are only suggestive of possible relationships.

In several previous studies in civilian aviation settings (e.g., Hunter, 2002a, 2006) the HES has been used to evaluate new measures of psychological constructs that were hypothesized to be related to accident involvement. However, none of the studies that have included the HES to date has reported a link between HES scores and actual accident involvement. Demonstration of such a relation would support the use of the HES as an accident surrogate in research studies. In addition, finding of a positive relation between hazardous events and accident involvement would also suggest that the HES could serve as an indicator of accident risk status for pilots. Beyond simply informing individual pilots of their risk status, this could be of substantial utility to organizations, such as the U.S. Army, that seek to reduce aviation accident rates.

Our goal in this study was to assess the degree of association between the HES and actual accident involvement. We hypothesized that positive correlations between hazardous events and accident involvement would be observed, supporting the use of the HES as a surrogate endpoint for accident research, and potentially as an indicator of pilot accident risk. To test that hypothesis we developed and administered a hazardous events scale (Army-HES) tailored to the activities of Army rotary-wing aviators. We also reanalyzed data from four studies of civilian pilots. In each of these civilian studies a measure of the pilots' involvement in hazardous events was available, along with self-reported accident involvement; in one of the civilian studies, accident data were also available from the National Transportation Safety Board (NTSB) database.



## METHOD

### Participants

Approximately 670 warrant officers and commissioned officers took part in one of four surveys that included the Army-HES. The instruments were approved by the Army Survey Control Office, and the study protocol was approved by the Army Research Institute Human Use Committee. Participation was voluntary and anonymous. No personally identifying information was collected, and no data were reported at a level that might allow for the identification of individual respondents.

### Procedure

Four surveys of U.S. Army aviators were conducted to evaluate a set of prototype psychological scales (Hunter & Stewart, 2009). These scales included the Army-HES, a Locus of Control Scale, a Safety Attitudes Scale, and a Scenarios Scale, in which several constructs (including locus of control, self-serving bias, and risk perception) were assessed using hypothetical Army aviation scenarios. Only the Army-HES is discussed in this article.

The first survey contained 86 items, each consisting of a short description of a potentially or actually hazardous situation. Participants were instructed to indicate how often they experienced each hazardous situation during the previous 24 months. The response options were *none* (0), *1 time, 2 times, 3 times,* and *4 or more times.* In addition to the hazardous events questions, 21 questions that assessed the participants' military and civilian aviation experience and qualifications, their accident involvement, and other basic demographic information were also administered. Invitations to participate in the survey were sent via e-mail to a random sample of 800 U.S. Army aviators. Of that number, approximately 80 aviators (10%) provided usable data.

TABLE 2
Example Items From Army-Hazardous Events Scale

| |
|---|
| How many times have you been forced to perform an abrupt maneuver to avoid an obstacle? |
| How many times have you lost visual contact with the ground because of dust or snow while landing or taking off (brown-out)? |
| How many times have you experienced a near midair collision? |
| How many times have you narrowly avoided a wire-strike? |
| How many times have you experienced a failure of your night vision device during a critical phase of flight (e.g., while on approach to an LZ or while maneuvering low-level). |

*Note*. LZ = Landing Zone.



Using the data from that administration, items were ranked on the proportion of nonzero responses. Generally, those items were chosen for inclusion in the reduced-length scale for which 20% or more of the respondents had a nonzero response, indicating that they had experienced the indicated event at least once during the previous 24 months. However, a few items were included based on their content; for example, addressing an issue such as crew coordination. This resulted in a final Army-HES consisting of 36 items. The 36-item scale length was arbitrary, and represented a desire to include a broad range of potentially useful items without presenting too burdensome a task to respondents. Examples of items from this scale are given in Table 2.

The 36-item Army-HES was included, along with the common set of demographic items, in the three subsequent surveys in which prototype scales for the other constructs were administered. For each of these surveys, invitations to participate were sent via e-mail to 1,000 warrant officers and 200 commissioned officers. The surveys were administered via a secure Web server operated by the Army Research Institute.

## RESULTS

The respondents for the four surveys were predominantly warrant officers who were slightly more likely to participate than commissioned officers. Because of a clerical error, the distribution of warrant officer and commissioned officer invitations for the first survey was not available. However, for the second, third, and fourth surveys, 15%, 15%, and 11%, respectively, of the respondents were commissioned officers. In comparison, commissioned officers constituted 17% of each of the samples invited to participate.

Whereas the modal position for participants in Survey 1 was standardization pilot (reflecting the somewhat higher experience level of that sample), the modal position for the remaining surveys was unit pilot (approximately 24% of respondents). Table 3 shows the number of respondents for each of the four surveys, and their military and civilian flight experience.

TABLE 3
Military and Civilian Experience

| | *Survey 1 Sample*[a] | | *Survey 2 Sample*[b] | | *Survey 3 Sample*[c] | | *Survey 4 Sample*[d] | |
|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Total military flight hours | 2,602 | 1,981 | 2,019 | 1,377 | 2,104 | 1,493 | 2,013 | 1,378 |
| Recent military flight hours | 479 | 430 | 457 | 318 | 510 | 361 | 462 | 312 |
| Total civilian flight hours | 238 | 893 | 110 | 493 | 122 | 547 | 82 | 392 |
| Recent civilian flight hours | 39 | 187 | 4 | 22 | 4 | 14 | 5 | 24 |
| Years as Army aviator | 14 | 9 | 11 | 7 | 10 | 7 | 10 | 7 |

[a]$N = 78$. [b]$N = 197$. [c]$N = 205$. [d]$N = 236$.

TABLE 4
Comparison of the Four Samples on the Demographic and Experience Variables

| *Source* | *df* | *F* | *p* |
|---|---|---|---|
| Pay grade | 3, 708 | 1.05 | .37 |
| Military accident—Ever | 3, 709 | 0.84 | .48 |
| Military accident—Recent[a] | 3, 708 | 1.36 | .26 |
| Military flight hours—Total | 3, 707 | 3.25 | .02 |
| Military flight hours—Recent[a] | 3, 709 | 1.01 | .39 |
| Civilian flight hours—Total | 3, 707 | 1.64 | .18 |
| Civilian flight hours—Recent[a] | 3, 706 | 6.61 | .01 |

[a]Within the previous 24 months.

A comparison of the four samples on the demographic variables was conducted using analysis of variance. The results of this analysis are shown in Table 4. Significant differences were observed only for recent civilian flight hours, $F(3, 706) = 6.61$, $p = .01$, and total military flight hours, $F(3, 707) = 3.25$, $p = .021$. Post-hoc analyses were conducted using the least-significant-difference test (Winer, 1971). Those follow-up analyses indicated that Sample 1 ($M = 2{,}602$) had significantly more total military flight experience than Sample 2 ($M = 2{,}019$), Sample 3 ($M = 2{,}104$), or Sample 4 ($M = 2{,}013$). In addition, Sample 1 ($M = 39$) had significantly more recent civilian flight experience than Sample 2 ($M = 4$), Sample 3 ($M = 4$), or Sample 4 ($M = 5$)

In view of the similarity of the four samples on other demographic measures, it was decided to combine all four samples to increase the power of the analyses. However, a sensitivity analysis was planned to examine the effects of including Sample 1 in the analyses.

## Hazardous Events and Accident Involvement

An overall Army-HES score was computed by summing the responses for the 36 items. This produced a score with a range of 0 to 94 and $M = 24.98$ ($SD = 18.26$). The coefficient alpha measure of internal consistency for the combined sample ($N = 653$) was .90.

Of the 712 participants, 48 (6.7%) reported having been in an accident during the previous 24 months and 217 (30.4%) reported having been in an accident at some point during their military aviation career.

Using the combined sample, correlations were computed among the Army-HES, the two self-reported accident involvement variables, and the flight time and experiences measures. These correlations are shown in Table 5. Consistent with our hypothesis, the Army-HES was significantly correlated ($r = .15$) with recent accident involvement. The positive correlation between Army-HES and accident involvement indicates that aviators who reported having been in more hazardous events were more likely to have been in an accident over the previous 24 months. However, no such relationship was found for career accident involvement.

It is interesting to note that the number of years that the person has served as an aviator served as a protective factor, as indicated by the significant negative correlation ($r = -.11$) between that variable and recent accident involvement. This could indicate that the more senior aviators have superior aeronautical or decision-making skills acquired over the years; however, it could also reflect the fact that the senior aviators might be serving in roles that do not place them in jeopardy as frequently as more junior aviators. The present data do not, of course, allow us to do more than speculate on that point.

TABLE 5
Intercorrelations of Army-HES, Accident Status, and Experience

| | *Total Military Flight Hours*[a] | *Recent Military Flight Hours*[a] | *Military Accidents—Recent*[a] | *Military Accidents—Ever*[b] | *Army-HES*[c] | *Years as an Army Aviator*[d] |
|---|---|---|---|---|---|---|
| Total military flight hours | — | .22* | −.06 | .23* | .06 | .79* |
| Recent military flight hours | | — | .15* | .01 | .50* | −.10* |
| Military accidents—Recent[e] | | | — | −.38* | .15* | −.11* |
| Military Accidents—Ever[e] | | | | — | .06 | .19* |
| Army-HES | | | | | — | −.15* |
| Years as an Army aviator | | | | | | — |

*Note*. HES =Hazardous Events Scale.
[a]$N$=710. [b]$N = 709$. [c]$N$=645. [d]$N = 707$. [e]Coded as 0 = no accidents; 1 = one or more accidents.
*Correlation is significant at the .01 level (two-tailed).

## Sensitivity Analysis

To examine the effect that including the data from the first survey had on the results, those participants were excluded, and the correlations shown in Table 5 were repeated. The results were essentially unchanged. For example, dropping Sample 1 caused the correlation between the Army-HES and recent military accident to change from $r = .15$ to $r = .14$. Similar, small changes were noted for the other correlations, supporting the decision to include all the data in the analysis.

## Reanalyses of Published Studies

Four studies were identified in which items describing involvement in hazardous events drawn from the original set (Hunter, 1995) were administered to civilian pilots, and in which pilots provided self-report of accident involvement. These studies used an overlapping set of items and asked about hazardous events that occurred during the previous 24 months (Hunter, 2002b, 2003) or during the entire flight career (Hunter, 1995; Lubner, Adams, Hunter, Sindoni, & Hellman, 2003). Data from each of these studies were analyzed to compute an HES score, and a correlation between the HES score and the accident involvement criterion was computed. The four studies are summarized next, along with the results from the reanalyses of their data.

*Civilian study 1.* In the earliest study that included the items comprising the HES, Hunter (1995) conducted a nationwide statistical probability survey of 19,657 pilots to collect information on their aviation qualifications and experiences, their participation in training activities, their involvement in critical aviation incidents, their personal minimums and usual practices when planning and conducting a flight, and their attitudes about flying issues. Approximately 35% of the pilots responded to the survey, and data were available on the hazardous events items for 6,261 respondents.

The original scale contained 12 items that addressed hazardous events, plus 1 item that asked about accident involvement, at any time in their flying career. The response alternatives were 0, 1, 2, 3, 4, 5, and 6 or more. Responses for the nine hazardous events items (excluding accident involvement and items that did not appear in subsequent studies) were summed to produce an HES score ($M = 6.89$, $SD = 5.91$). Accident involvement (taken from the first item) was coded as either 0 (no accidents reported) or 1 (one or more accidents reported). Involvement in one or more accidents was reported by 14.25% of respondents. A correlation was then computed between the HES score and accident involvement variable. For this sample, the HES correlated $r = .23$ ($p < .01$) with self-reported accident involvement. Coefficient alpha for this sample and nine-item scale was .65.

*Civilian study 2.* As part of a Web-based study of risk perception and risk tolerance among pilots, Hunter (2002b) obtained item responses from 394 pilots on the 10-item version of the HES. Pilots visiting a government Web site completed two risk-perception measures, and three risk-tolerance measures. They also provided demographic information and completed the 10-item scale that assessed their involvement in hazardous aviation events. To create an HES score, we excluded the item that asked about accident involvement and computed the sum of the nine remaining items. The resulting HES score had $M = 3.16$ ($SD = 3.42$). Pilots' responses to the first (excluded) item from the10-item scale served as the criterion. As before, that variable was coded as zero (no accident reported) or one (one or more accidents reported). Of the 394 respondents, 18 (4.6%) reported having been in an aviation accident during the previous 24 months. The HES score correlated $r = .32$ ($p < .01$) with this measure of self-reported accident involvement. Coefficient alpha for this sample and nine-item scale was .65.

*Civilian study 3.* Lubner et al. (2003) conducted a retrospective, anonymous, case-control survey of 4,000 active U.S. pilots with a 42% response rate. Cases had a recent accident or incident, whereas controls had no such occurrence up to 5 years prior, according to data obtained from NTSB records. As part of this study, they administered seven items from Hunter's (1995) HES. As before, we computed an HES score by taking the sum of the responses for those seven items. The mean for this HES score was 5.14 ($SD = 4.96$). For this study, two measures of accident involvement were available: self-reported accident involvement and case-control status based on NTSB records. Of the 1,333 pilots, 597 (44.8%) reported having been in an aviation accident at some point during their flying career. The HES score correlated $r = .24$ ($p < .01$) for this self-report measure. Correlating the HES score with case-control status yielded a correlation $r = .26$ ($p < .01$) for a sample of 1,401 pilots. Coefficient alpha for this sample and seven-item scale was .64.

*Civilian study 4.* The 10-item HES was administered as part of a study to develop and evaluate a situational judgment test (SJT) for general aviation pilots (Hunter, 2003). In that study, pilots were presented with descriptions of in-flight situations that required a decision on the part of the pilot and four alternative solutions to the situations. The SJT and the HES were administered to 467 participants over the Internet. Item response data on the HES were available for 446 participants and these data were analyzed, as described earlier, to create an HES score ($M = 3.06$, $SD = 3.39$) based on nine of the items. The item concerning accident involvement was recoded (zero or one) as before. Of the 446 pilots, 24 (5.4%) reported having been in an accident during the previous 24 months. The correlation between HES and the self-reported accident status was $r = .30$ ($p < .01$). Coefficient alpha for this sample and nine-item scale was .65.

## RESULTS AND DISCUSSION

The data from the present military sample and the results from the reanalyses of data from civilian aviation studies are congruent with our hypothesis that involvement in hazardous aviation events, as measured by the HES, is associated with an increased involvement in actual aviation accidents. However, the strength of the relationship is stronger in the civilian samples, which had correlations ranging from .23 to .32, than in the military sample, in which the correlation for recent accidents was .15. Further, the correlation of the Army-HES with career accident involvement was much smaller (.06) and nonsignificant.

Potential explanations for the observed difference in correlations for the civilian and military samples include differences in reliability of the scale and restrictions in the variance of the variables. Differences in reliability can be dismissed as an explanation, as the Army-HES had a larger coefficient alpha (.90) than the civilian samples (roughly .65). Thus, on the basis of reliability, a larger correlation with the criterion would be expected for the Army-HES.

Disregarding the studies by Hunter (1995) and Lubner et al. (2003) in which the criterion was accidents during the entire flying career, the proportion of pilots reporting an accident during the previous 24 months for the remaining two civilian studies was 4.6% and 5.4%. The corresponding proportion of Army aviators who reported having been in an accident during the previous 24 months was 6.7%, which approximates the civilian results. Thus both the civilian and military samples suffer from roughly the same degree of attenuation due to restricted variance of the criterion.

Having eliminated the usual statistical reasons for attenuated validity, the observed difference could be attributed to random variation, or to a substantive difference in the strength of relationships between the civilian and military pilots. Unfortunately, the data here do not allow for further determination of this issue, and we prefer to recommend additional research, rather than speculate in the absence of either data or theory to guide that speculation.

It might be argued that to some extent, the relationship between the HES and accident involvement is confounded by the very nature of the HES. That is, many, if not the majority of accidents will also involve at some point in their evolution one or more of the hazardous events in the HES. However, that relationship is a critical feature of a measure that is used as a surrogate. Indeed, to the extent to which these hazardous events lie in the path to an accident, they approach the ideal of a surrogate measure. For more information on this topic, readers are directed to Burzykowski et al. (2005) for an extensive discussion of the evaluation of surrogate endpoints in the medical community.

## CONCLUSIONS AND APPLICATIONS

Demonstration of a significant relationship between the HES and accident involvement supports its use in two ways. First, it supports the use of the HES as a surrogate for actual accident involvement in research settings. Because accidents are rare events (even among military aviators who spend much of their flying career in hazardous environments), demonstration of a significant statistical relationship between some measure of interest and a criterion of actual accident involvement might require very large samples, for all but the most robust of effects. Substitution of a surrogate measure allows the researcher to evaluate the measures with a much more modest sample, as hazardous events occur much more often than actual accidents. Promising measures found using this process can then be evaluated further using, preferably, long-term longitudinal studies of large samples of pilots.

Second, it supports the use of the HES as a measure of differential risk among aviators. In this role, the HES could be used to build self-awareness of accident risk among aviators. It could also be used by organizations to identify aviators who might need training, counseling, or some other intervention to reduce the number of unsafe acts and consequent hazardous events that they experience.

Within a general aviation organization (e.g., a flying club or flight school) or military unit, HES data might be used to identify pilots who are drifting into unsafe practices. At a collective level, these organizations might use HES data cumulated across all members as an index of their organizational safety level. This use is consistent with current applications of leading indicators and precursors in, for example, the chemical industry (Phimister et al., 2003) or the nuclear power industry (Sattison, 2004). In these and other industries, incident data are used to identify organizations that are drifting toward an unsafe condition. The HES could provide a means for the organization to take proactive steps to improve safety both at the organizational and individual level.

### Limitations to Generalizability

Self-reported accident involvement and involvement in hazardous events are subject to a number of well-known limitations that apply both to the new data collected in this study and to the data from the earlier published studies. In all cases, the samples consist of self-selected pilots who chose to participate in the studies. They are therefore convenience samples and might not be representative of the total population of pilots. Further, all of the data (with the exception of the NTSB data from Lubner et al., 2003) presented are based on self-report and are therefore subject to inaccuracies resulting from respondent forgetfulness, bias, or misinterpretation of the questions.

Arguably, a more serious concern, and one that is less often mentioned, involves the limitations imposed by a cross-sectional study, in which retrospective correlations between events are evaluated (Hunter, 2001). In the instance here, a better test of the relationship between the HES and accident involvement would be a prospective design.

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Manuscript first received: June 2010