Pilot Decision Making in Weather-Related Night Fatal Helicopter Emergency Medical Service Accidents

Bryan B. Aherne; Chrystal Zhang; Won Sun Chen; David G. Newman

INTRODUCTION: In the United States, between 1995 and 2013, night-time visual flight rules (VFR) Helicopter Emergency Medical Service (HEMS) fatal accidents mostly encountered adverse weather, and pilots with <6 yr of HEMS experience showed higher likelihood of a night operational accident. One adverse weather indicator is cloud-ceiling likelihood indicated by temperature dew point spread (TDPS). This study investigated the relationship between TDPS and HEMS pilot years of experience. It was hypothesized pilots with <6 yr HEMS experience were associated with fatal outcomes encountered at lower TDPS.

METHODS: Between 1995 and 2013, 32 single pilot night VFR HEMS fatal accidents occurring in the United States, caused by controlled flight into terrain or loss of control, were analyzed. Using Federal Aviation Administration weather guidance, the 0–4°C TDPS was selected as an indicator of cloud ceiling. Each flight's TDPS was analyzed with pilots' HEMS domain task experience.

RESULTS: There were 27 flights which entered the 0–4°C TDPS range; 20 (74%) were significantly associated with adverse weather. A significant negative linear relationship was found between TDPS of each mission and years of pilot HEMS experience ($r = -0.423$, $P = 0.028$). Pilots with <6 yr of experience were significantly associated with fatal outcomes ($P = 0.049$).

CONCLUSION: Pilots' incremental years of HEMS experience were associated with a TDPS decrement. Fatal outcomes were over nine times higher for pilots with <6 yr of HEMS experience in night VFR operational accidents in those conditions. Interventions for <6-yr pilots are recommended during experience building to prevent likelihood of operational accidents.

KEYWORDS: air medical, instrument proficiency, risk, expert, darkness, nighttime visual flight rules.

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At night, flights over featureless terrain devoid of man-made lighting, and/or the presence of cloud or fog, represent a hazardous operational condition (HOC) for visual flight rules (VFR) Helicopter Emergency Medical Service (HEMS) missions.[1] Weather has been reported as the greatest hazard encountered by HEMS pilots.[23] Before every flight, HEMS pilots must examine weather data and ultimately make the final decision to reject, accept, continue, or delay a mission following that evaluation.[1] That decision is a critical preventative risk control to avoid encountering nonvisual meteorological conditions (non-VMC) so pilots can maintain visual spatial orientation, required under VFR.[1,11] Night flying under VFR with reduced visibility, where no visual cues or horizon is visible, presents ideal conditions for spatial disorientation.[17]

Distinguishing VFR and non-VFR criteria is difficult in darkness,[17] where the lack of visual cues inhibit the pilot's ability to easily discriminate adverse or marginal weather. This poses a significant hazard to night VFR HEMS operations, as they regularly operate in environmental conditions not representative of other night helicopter operations.[7] Adverse weather, terrain, and obstacles that may not be seen at night must be planned for. In darkness, it is essential that the pilot determines an altitude and position for the helicopter to remain clear of cloud and above a minimum terrain protection height and safe horizontal distance from obstacles.[1] Without careful evaluation

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and planning, inhibited nighttime visual cues leave VFR helicopter operations susceptible to inadvertent entry into instrument meteorological conditions (IMC).[7]

The limited time available during mission evaluation and planning compounds this high cognitive workload and the mission task itself has implicit pressures.[1] HEMS pilots have reported pressure as an issue, but it was unable to be measured.[23] Experienced pilots reported concerns that inexperienced pilots may allow knowledge of patient condition to influence the risk assessment process.[23] However, some life-threatening HEMS mission tasks result in over-triage. Research of U.S. HEMS trauma patients flown between 1983 and 2004 demonstrated the majority had non-life-threatening injuries, with >25% discharged within 24 h after arrival at the hospital.[4] Moreover, anxiety and stress were reported to influence all HEMS pilots' assessment of mission task risk when weather conditions were marginal or questionable, and job security could potentially be affected if they took too much time to assess the risks.[23]

Where a HEMS pilot assesses increased likelihood of/or encounters HOC, the correct risk treatment is to reject or execute safe recovery action and delay or terminate the mission.[1] However, if the mission continues into HOC, the higher cognitive demand increases mission task workload, which can cause working memory to become saturated.[1] One practice by HEMS pilots to remain VFR in marginal weather conditions is known as 'scud running,' where the helicopter decreases altitude under lowering cloud.[24,25] However, this can obstruct the sight path, essential for visual spatial orientation. In this scenario at night, where a decision to abort is delayed, reducing height and recovery space options could mean avoidance maneuvering to evade non-VMC, might be too late, encounter IMC, or induce disorientation, leading to an accident.[1,18,24,25] The combination of limited environmental nighttime cues like man-made lighting, deteriorating weather, and any increased cognitive requirement all contribute to likelihood of spatial disorientation.[12,18] Therefore, correct evaluation to avoid adverse weather and any HOC is critical to operational safety.[1]

Adverse weather featured in the majority (66%) of HOC for 32 fatal night VFR HEMS accidents in the United States between 1995 and 2013, where loss of control (LCTRL) and controlled flight into terrain (CFIT) were found to be the cause.[1] Previous research used pilot years of HEMS domain experience to identify why an increased likelihood of a subgroup of pilots was seen in nighttime VFR LCTRL and CFIT accident data.[1] Using domain task experience (DTE), the application of expertise within the Recognition Primed Model of the decision making process introduced characteristics of HEMS pilots who were under and overrepresented in operational night accident data.[1,10,14] Pilots with <2 and <4 yr of HEMS DTE demonstrated significantly higher likelihood of involvement in nighttime VFR HEMS operational accidents; they were more likely to make operational decision-based errors than pilots with >10 yr DTE.[1] The lower levels of weather-related cue acquisition and utilization were, in part, a function of lower DTE.[1] HEMS pilots with ≥6 yr DTE (high DTE) were found to have domain expertise consistent with higher levels of weather-related cue utilization, which facilitated more accurate diagnostic or weather situation assessment skills.[1]

From 2014, U.S. Federal Aviation Regulation (FAR) Part 135.609 specified VFR HEMS require a night 1000-ft cloud ceiling, which increases in mountainous areas to 1500 ft, and adds 'local' (3-mi visibility) and 'nonlocal' (5-mi visibility).[1] One weather cue or feature event object which can be used to determine likelihood of cloud ceiling and reduced visibility is air temperature and its dew point. This, among other weather data, is available to pilots for weather evaluation. When the temperature of air reduces to its dew point, where air is completely saturated, it is highly likely that moisture will condense out in the form of fog, low clouds, and rain. The difference between temperature and dew point is known as the temperature dew point spread (TDPS). Using U.S. Federal Aviation Administration (FAA) guidance, each 1°C decrease in TDPS will highly likely lower the cloud ceiling by approximately 400 ft above ground level (AGL).[11]

Using that guidance and regulation requirements, flights conducted in a 3.7°C and 2.5°C TDPS would represent a cloud ceiling of 1500 ft and 1000 ft AGL, respectively. In most cases, pilots can determine probability of poor visual conditions en route and at the destination knowing the TDPS. As TDPS is reported in 1°C intervals, the 0 to 4°C TDPS range captures the likelihood of cloud-ceiling height in accordance with Part 135.609 requirements. As a weather-related feature/event object, TDPS provides useful cues for operational safety risk when assessing HOC.

Although HEMS operations during the 1995–2013 study operated under earlier less restrictive regulations,[1] useful comparisons for future operational safety under stricter regulations can be made. As age and total flying hours were found to be unrelated to fatal night HEMS accidents,[1] this investigation sought to determine if a relationship between pilots' years in HEMS and potential cloud-ceiling conditions measured by TDPS existed in night VFR operations accidents. Given their increased likelihood of night VFR operations accidents,[1] it was hypothesized that fatal outcomes in the 0°C to 4°C TDPS range would be most associated with low-DTE pilots.

METHODS

A search of the U.S. National Transportation Safety Board (NTSB) database identified 189 accident reports under rotorcraft for key words 'EMS', 'HEMS', 'aeromedical', 'ambulance', and 'medevac'. Selected for the study were 32 single-pilot night VFR fatal HEMS accidents in the U.S. between 1995 and 2013 that suffered loss of control or controlled flight into terrain.

The study used proportional data[2,8] between pilot groups for the analysis. While the lack of denominator data[2,6,8] precludes accident rate analysis, proportional data accident analysis has previously identified preventative interventions where denominator data does not exist or lacks meaningful specificity.[6,22]

Data relating to number of fatalities and survivors, DTE, TDPS, pilot instrument proficiency, and causal factors were

collated using a PC-based spreadsheet (Microsoft® Excel 2007). Statistical analyses were conducted using statistical software SPSS Statistics (version 24, IBM Corp, New York, NY). Fisher's exact test of independence was chosen to analyze association between categorical variables. A *P*-value of less than 0.05 (two-tailed) was deemed to be statistically significant. Linear regression analysis was chosen to examine any relationship using TDPS as the dependent continuous variable and years of HEMS experience as a continuous independent (predictor) variable. Due to small sample size and violation of the normality assumption, the bootstrapping technique using 10,000 iterations with the bias-corrected and accelerated method was used in computing more reliable 95% confidence intervals (CI).[13]

Relative risk [using percent relative effect (RR-1)] and odds ratios[3] were calculated to assess the likelihood of: 1) non-VMC flight outcomes when exposed in the 0–4°C TDPS range compared to the 5°C+ TDPS range; 2) fatal outcomes when exposed in the 0–4°C TDPS range compared to the 5°C+ TDPS range; and 3) flights wholly within the 0–4°C TDPS range for fatal outcomes compared between low-DTE and high-DTE pilots.

Odds ratios determine effect size (small, large, or very large effect) and inform the practical meaning of a variable by the magnitude of the underlying odds in the ratio.[16] The coefficient of determination (r^2) in the regression analysis determines amount of shared variance between both variables (effect size).[16]

One assumption for TDPS was made within this study. The NTSB reported a TDPS of 12°C in one accident, obtained from a manually transcribed weather station readout from a facility over 1 nmi from the accident location. Despite the NTSB querying the third party about method for data capture, it was reported as 12°C. An international airport weather station near the departure location 18 min prior to accident and another airport weather station located beyond the intended destination both indicated a TDPS within the 0–4°C TDPS range. It is unlikely that the actual weather conditions at the weather station used in the report differed so strikingly, so a 0–4°C TDPS was assumed.

The accident site and basic weather of two accidents were not recorded in the respective factual reports and accident briefs. The first accident reported a 0-ft cloud ceiling, finding a low cloud ceiling and fog were causal to an overwater CFIT. The second accident reported a pilot LCTRL following inadvertent entry into IMC while maneuvering to avoid obstacles below a 1200-ft cloud ceiling.

Two accidents reported visual conditions at the accident site and basic weather, however, the NTSB reported probable cause as a pilot who encountered weather (fog) on takeoff, found inadequate weather evaluation at night in fog conditions, and reported three other HEMS operators refused the mission, one in flight, due to fog. The second accident reported probable cause as LCTRL after the pilot encountered IMC at 1000 ft above water in weather below VFR minima in a low cloud ceiling. Therefore, this investigation determined non-VMC was encountered during those accident sequences.

RESULTS

There were 32 HEMS accidents that were identified which resulted in CFIT (15) or LCTRL (17) at night. Linear regression analysis demonstrated a significant negative relationship between HEMS DTE and the 0–4°C TDPS range, showing reduction in TDPS was associated with increment in pilot DTE ($r = -0.423$, $r^2 = 0.18$, $P = 0.028$). HEMS DTE was found to be a significant predictor in estimating the 0–4°C TDPS range (variable HEMS DTE coefficient β, −0.072, 95% CI −0.136 to −0.039, $P = 0.028$; variable constant coefficient β, 1.785, 95% CI 1.306–2.310, $P < 0.001$). Overall, DTE accounted for 18% of the variation in TDPS.

There were 27 flights (84%) which operated within the 0–4°C TDPS range and 23 (85%) within 0–2°C. Of the flights, 21 (66%) encountered non-VMC and 20 were statistically significant in the 0–4°C TDPS range ($P = 0.037$; outcome 1 in **Table I**). The 0–4°C TDPS range was significantly associated with fatal outcomes (outcome 2, Table I) compared with the 5°C+ TDPS range ($P = 0.025$). Only 8 occupants (7%) out of a total of 108 survived the accidents. Low-DTE pilots were significantly associated with fatal outcomes in the 0–4°C TDPS range compared to high-DTE pilots ($P = 0.049$) (outcome 3, Table I). **Fig. 1** shows the frequency of fatalities and survivors in

Table I. Results of Fishers Exact Test of Independence, Odds Ratios, and Relative Risk.

OUTCOME VARIABLE	EXPOSURE (ODDS)	ODDS RATIO (95% CI)	RELATIVE RISK (95% CI)	*P*-VALUE
1. Non-VMC* Frequency	5°C+ TDPS (0.25) (reference)	11.43¶	--	$P = 0.037$
	0–4°C TDPS (2.86)	(1.31–38.03)		
2. Fatal Outcomes*	5°C+ TDPS (3.5) (reference)	6.14§ (1.11–36.75)	‡	$P = 0.025$
	0–4°C TDPS (21.5)			
3. Fatal Outcomes*	High-DTE pilots in 0–4°C TDPS (6.66) (reference)	9.9§ (1.35–25.00)	‡	$P = 0.049$
	Low-DTE pilots in 0–4°C TDPS (66.0)			
4. Fatal Outcomes*	High-DTE pilots in 0–3°C TDPS (Reference)	†	1.15 (1.042–1.40)	$P = 0.020$
	Low-DTE pilots in 0–3°C TDPS			
5. Fatal Outcomes*	High-DTE pilots in 0–2°C TDPS (reference)	†	1.15 (1.042–1.40)	$P = 0.026$
	Low-DTE pilots in 0–2°C TDPS			
6. High-DTE pilots* Frequency	1–17°C TDPS (0.13) (reference)	15.33¶	--	$P = 0.012$
	0°C TDPS (2.00)	(3.00-69.00)		

* $P < 0.05$; †unable to calculate OR due to no survivors and noninteger decimal values unable to be used in the bootstrapping software; ‡RR unable to be calculated due to low survivor frequency; §Large effect size; ¶Very large effect size.

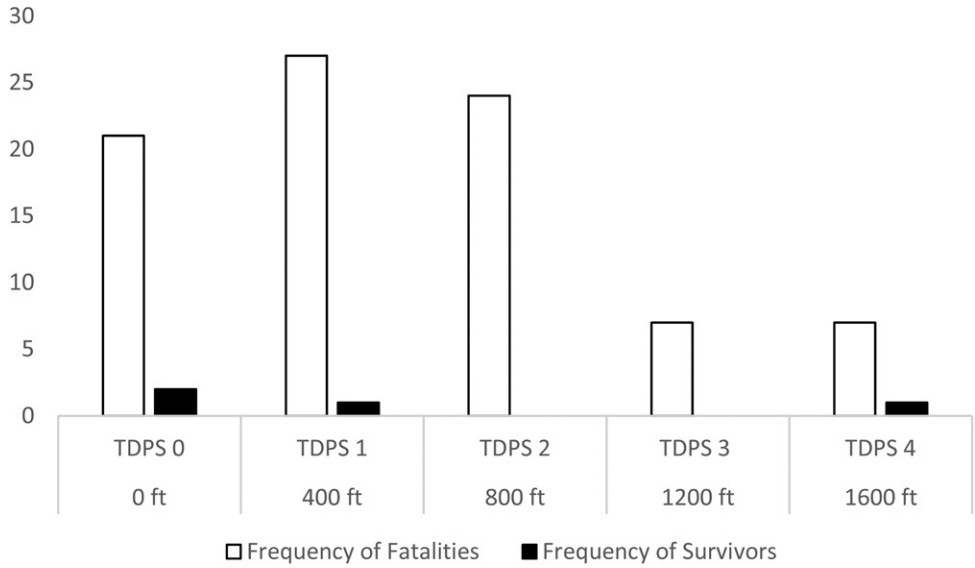

Fig. 1. Frequency of fatalities and survivors in each temperature dew point spread (TDPS) 0–4°C and highly likely cloud ceiling (using FAA pilot handbook guidance).

the 0–4°C TDPS range, showing most (84%) occurred in 0–2°C. Fig. 1, **Fig. 2, and Fig. 3** show potential cloud ceiling in feet for each TDPS, based on FAA guidance.

The frequency of high-DTE pilots ($N = 4$) was statistically significant in the six 0°C TDPS flights (outcome 6, Table I), in which all crashed in non-VMC, compared to the 1–17°C TDPS range ($P = 0.012$). Fig. 2 shows all seven high-DTE pilots flew within the 0–2°C TDPS range.

Pilots with ≤2 yr ($N = 14$) occupied more than half (52%) of the 0–4°C TDPS range missions and less than half (45%) non-VMC flights. A strong negative correlation ($r = -0.79$) between the number of fatalities within each TDPS in the 0–4°C TDPS range was seen. Fig. 3 shows the frequency of each flight and frequency that encountered non-VMC.

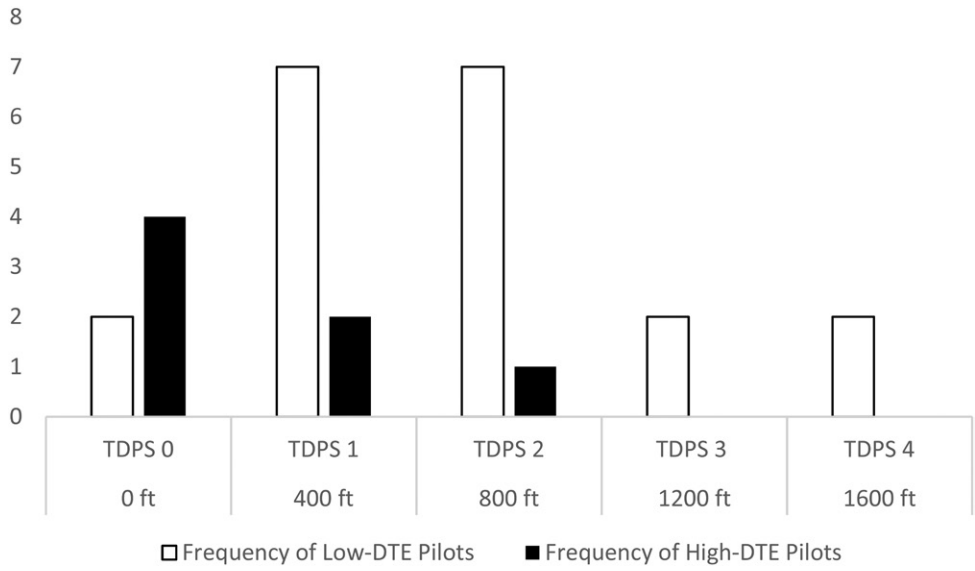

Fig. 2. Frequency of low-DTE and high-DTE pilots in each temperature dew point spread (TDPS) 0–4°C and highly likely cloud ceiling (using FAA pilot handbook guidance).

Fig. 4 shows the majority (84%) of 32 pilots held nonproficient helicopter instrument ratings,[1] 22 in the 0–4°C TDPS range. Pilot instrument proficiency is required to operate in non-VMC in an instrument equipped and certified helicopter under instrument flight rules (IFR)[1] procedures.[24] All the 0–4°C TDPS inadvertent IMC findings ($N = 8$) occurred within 1–4°C TDPS (high DTE: 1°C $N = 1$, 2°C $N = 1$; low DTE: 1°C $N = 1$, 2°C $N = 3$, 3°C $N = 1$, 4°C $N = 1$).

DISCUSSION

The results from regression analysis revealed DTE to be a significant predictor in estimating the 0–4°C TDPS range. As pilot experience increased, the TDPS of the mission reduced. The resulting effect of potential lower cloud ceiling and visibility, i.e., non-VMC, was found to be significant; it estimated a 10-yr HEMS pilot in this study would encounter approximately 260-ft lower cloud ceiling AGL compared to a 1-yr pilot. Missions in the 0–4°C TDPS range were 11 times more likely to encounter adverse weather, and 6 times more likely to be fatal compared to those in the 5°C+ TDPS range, respectively.

Of the 27 missions which crashed in the 0–4°C TDPS range, those flown by low-DTE pilots were over nine times more likely to be fatal than those with ≥6 yr HEMS experience. Missions in the 0°C TDPS, which were all non-VMC, were 15 times more likely flown by a high-DTE pilot. This result was surprising given their experience.[1] Increasing DTE as an estimate of higher operational safety risk was not expected.

The low-DTE pilots' large effect size with fatal outcomes demonstrates limited effectiveness for assessing all possibilities for safe and justifiable operational decisions.[1] Their significantly increased risk over high-DTE pilots in the very low TDPS range is consistent with higher likelihood of night VFR operational accident.[1] Their limited effectiveness and higher likelihood of encountering HOC is consistent with the interrelationship between reduced risk control effectiveness and increased likelihood of catastrophic consequence.[15] Low-DTE pilots, particularly

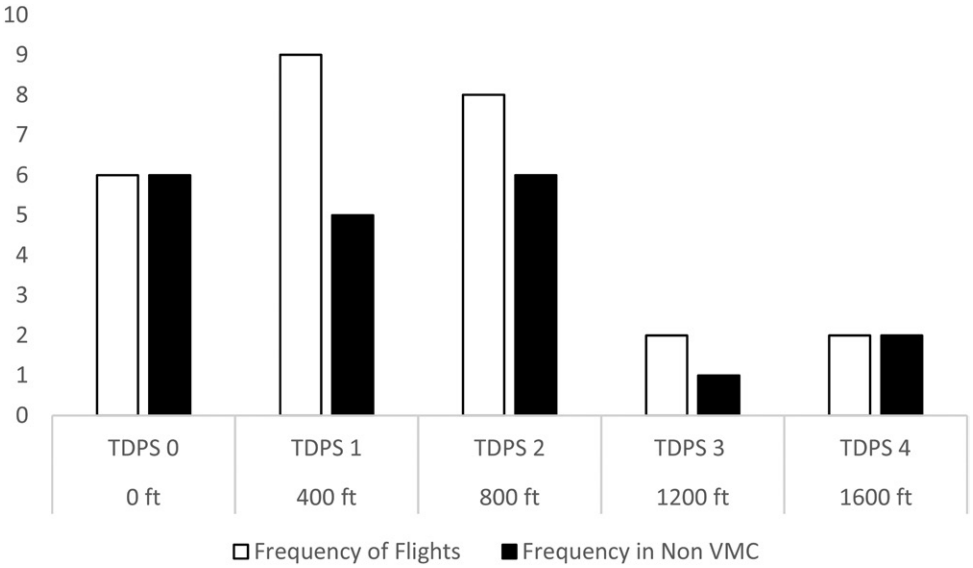

Fig. 3. Frequency of flights and accidents recorded as non-VMC in each temperature dew point spread (TDPS) 0–4°C and highly likely cloud ceiling (using FAA pilot handbook guidance).

≤2-yr pilots (novices) increased risk, appears indicative of a performance with reduced, or very little deliberate practice in the night HEMS domain.[1] Any apparent lack of understanding of operational weather cues, such as TDPS, demonstrates the imprecise association of features which is seen by learners,[9] particularly during the skill acquisition period.[20] This likely explains, in part, why the <2-yr HEMS pilots made up 56% of night operational accident data.[1]

The low-DTE pilots reduced task performance, particularly interpreting night VFR weather cues, likely affected their assessment of risk.[29] Without daytime visual cues as a redundancy to rapidly discern VMC, night VFR visual assessment is problematic.[17] For night HEMS missions to unsurveyed locations,[1,23] the association of weather cues from multiple sources with successful (VMC) and unsuccessful (non-VMC) scenes accumulates with deliberate practice,[1] essential to obtaining higher domain performance.[10] Helicopter pilots updating their position without knowing it were effectively acting as 'Bayesian agents'.[5] That is, their subjective beliefs were being updated by additional evidence to stay on course,[5] like Bayes' theorem of conditional probability. Similarly, just as helicopter pilots were unaware they were refining overland route position,[5] HEMS pilots are unaware,[5,21] through deliberate practice,[10] that repeating patterns of relationships with domain objects and feature-event associations are stored as cues in long-term memory (LTM),[1] refining operational decision estimations. Updating TDPS via additional evidence[5] [such as feature-event association with successful (VMC) or unsuccessful scene assessment] acquired by nighttime deliberate practice calibrates decision estimate accuracy, resulting in higher domain task performance.[1]

A high-DTE pilots' greater capacity to conduct more accurate/realistic probability and consequence assessments for various flight profiles, likely explains why industry peer >10-yr pilots were not prominent in these accidents.[1] Their knowledge of practices and conditions which increase risk, like 'scud running', and of historical night accidents, is consistent with the availability heuristic,[27] in that pattern recognition,[19`] stored as cues in LTM,[14] provided reference points to establish subjective probabilities[5] with salient outcomes.[26] A high-DTE pilot's repository of diagnostic operational cues enables rapid assessment of safety risks, such as likelihood of HOC with lowering TDPS, consequences of CFIT or LCTRL, and development of alternative courses of action to minimize those risks.

In terms of risk perception within these missions, it is assumed pilots intended to follow regulations which allowed HEMS operations to be conducted in less restrictive weather criteria.[1] However, in rapidly deteriorating conditions, margins can reduce quickly. For example, a 3°C TDPS (an approximate 1200-ft cloud ceiling) decreasing to 2°C potentially reduces cloud ceiling to 800 ft AGL. Therefore, low-DTE pilots' likely perception of increased risk in some cases was not likely aligned with the reality[26] of expected marginal conditions, which more experienced pilots[26] would have perceived.

The high-DTE pilots' association with the lowest TDPS suggests risk may have been calculated in a way which considered a very high likelihood of entering HOC. Their large aggregation of years and decades of domain acquired knowledge[1] meant they possessed a repertoire of highly refined and diagnostic feature-event relationships or cues. They may have considered their capabilities ruled out an accident or assessed their chance of LCTRL or suffering CFIT as minimal. Any overconfidence during subjective assessment of outcome likelihood, not only increases susceptibility to spatial disorientation,[18] but may have influenced their decision to attempt a mission task in highly likely nonvisual conditions.

Pilots with high cue application were found to make definitive decisions to either reject or commence flights into HOC using scenario based research of available preflight weather data as feature-event object associations.[29] In-flight decisions demonstrated those pilots were also more likely to continue the flight in that scenario.[29] This may partly explain why pilots with higher levels of cue acquisition and utilization, like the ≥6-yr DTE pilots, commenced or continued the flight, consistent with the findings of Wiggins et al.[29] Previous successful decisions in the HEMS domain may have given them overconfidence in their ability to perform in HOC.

Helicopter pilots accepting higher risk was seen from survey results in military aviation.[26] It found, as flying hours increased, experience seemed to guide choices toward risky alternatives.[26] It was suggested overconfidence from improved task performance

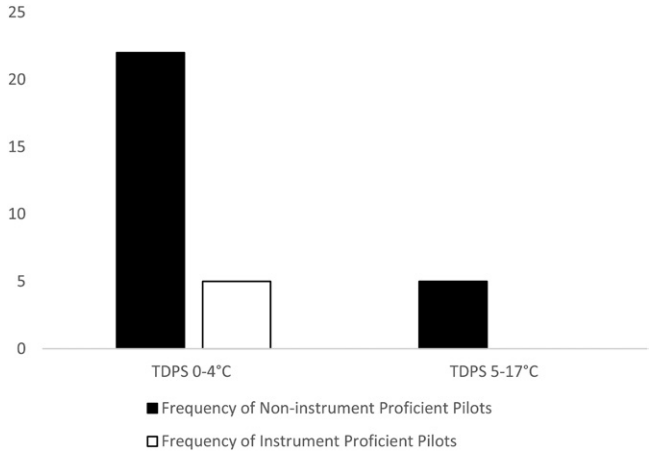

Fig. 4. Flights in temperature dew point spread (TDPS) and pilot instrument proficiency.

may play a role in risk taking.[26] While this was not seen with TDPS in this study, a positive relationship between pilots' flying hours and HEMS DTE was seen in previous research.[1] Therefore, a similar effect with increased DTE may result, much the same way as a flying hours increase was suggested by Thomson, et al.,[26] albeit between different experience parameters. Findings from both studies suggest more research is required in this area.

It is beyond the research aim of this study to understand what exact cues or feature-event objects were seen preflight or seen/obtained in flight by pilots in these accidents. This is arguably the main reason why good preflight decisions remain critical in preventing entry into IMC for a night VFR operation. It is possible low-DTE pilots had difficulty in the preflight phase to make good decisions and avoid HOC. If a mission proceeds in degraded visual conditions, the workload of the pilot increases with the cognitive demands of correct aircraft control. In those conditions, working memory of low-DTE pilots, particularly novices with limited pattern recognition, would be under higher demand with previously unseen or infrequently seen features during the mission.[1] This could have presented an overwhelming situation and likely incorrect, late, or absent recovery response.[1] Even in atmospheric conditions where cloud ceiling and visibility meet VMC criteria, dark-night conditions without man-made lighting,[1,18] under a visually inhibiting cloud ceiling, increases the chance of encountering HOC. Six low-DTE pilots suffered accidents in VMC where no man-made lighting or sparsely lit terrain could provide orientation cues.[1,18]

It may be that TDPS results seen here are an indicator of other weather feature/event objects that low-DTE pilots did not associate as weather cues. It is possible another feature-event object was missed, as an undetected nuance which might have otherwise caused them to discontinue the mission.[29] Any ineffective association of weather cues could mean novice pilots may be particularly vulnerable when evaluating night VFR in those conditions. Any inaccurate assessment of risk, together with any apparent desire to reach a destination,[29] suggests a motive which could influence an inexperienced HEMS pilot's decision, such as the task itself.[1] It is likely the pilots experienced some pressure[1,23] when assessing their flights and patient condition,[23] which could provide motive to accept or continue the mission. It is likely some degree of anxiety and stress was experienced during evaluation, or during an encounter with adverse weather;[23] anxiety and stress can increase the likelihood of, incorrect recognition of, and/or recovery from spatial disorientation.[18]

Adverse weather and nighttime helicopter operations have been shown to be a lethal combination.[7] The brittle relationship of night VFR HEMS and HOC is highlighted in Fig. 1 and Fig. 3, where a majority of fatalities in the 0–2°C TDPS occurred. Of those missions, 74% entered non-VMC. The loss of visual cues following entry into IMC increases the chance for both recognized (Type II) and unrecognized (Type I) spatial disorientation,[18,28] particularly for noninstrument proficient pilots.[7,18] The CFIT accidents demonstrate that, despite control being maintained, pilot instrument skill atrophy[18] likely delayed or did not detect instrument cues, like radio-height AGL, airspeed, turn and descent rates, and/or navigation position references. CFIT is a form of unrecognized spatial disorientation.[28]

It is possible that low-DTE pilots' increased likelihood of night LCTRL/CFIT accidents resulted from implicit pressures from the mission task,[1] like patient condition,[23] real or perceived,[1] as one motive to continue to destination.[29] Or it is possible they assessed the risk and weather cues incorrectly[29] for the route with HOC,[1] which is more likely during the skill acquisition and learning period.[20] It may be a combination of both. As they made up 10% more of inadvertent IMC findings, preflight evaluation of weather cues by those pilots was less effective compared to the high-DTE pilots.[1] The higher demand on their working memory likely contributed to task saturation and ultimately LCTRL or CFIT.[1] The high-DTE pilot's expected increased cue application, their significance in the 0°C TDPS, and regression analysis suggest their experience likely considered a very high chance of encountering HOC.[1] No findings of inadvertent IMC were made in the 0°C TDPS.

A limitation of this study is the retrospective nature of accident analysis and absence of denominator data to calculate accident rates of each DTE group. Given HEMS pilots had fixed day and night shift rotations,[23] it would be unlikely that one group was exposed to more night-shift than the other over the study period; however, this cannot be ruled out. This research is like other aviation accident analysis without denominator data.[2,8,22] It has a narrow and specific focus[2] to identify risk factors in two specific types of night VFR fatal operational accidents,[1] not all HEMS accidents.

In severe consequence environments, error-based learning of weather-related decision making can have significant outcomes.[29] The low-DTE pilots' finding is consistent with that observation. It is only through further domain exposure where inadequate association of feature-event objects can be established and refinements identified that previously unsuccessful associations can be addressed.[29] Night VFR HEMS is a domain in which error-based learning through deliberate practice is necessary to obtain the higher performance of expertise.

The flights featured in this study found TDPS was significant as a non-VMC feature-event object weather cue. The results

demonstrate as TDPS reduced, it correlated with an increase in HEMS years of experience. Therefore, the potential lower cloud ceiling commensurate with increasing experience cannot rule out that experience resulted in an over-confidence, guiding some pilots toward riskier options,[26] or that some pilots intentionally persevered in deteriorating weather. Such total risk to all occupants may be higher than the patients' medical condition risk.[4] HEMS operators' procedures and aviation regulations define practices which should constrain HEMS operations to levels of acceptable risk. A pilot's personal increased risk tolerance beyond those levels imposes higher risk to all occupants.

In this study, low-DTE pilots demonstrated higher likelihood for fatal outcomes in night LCTRL/CFIT accidents. More research is required to identify further risk factors and preventative interventions to reduce likelihood of fatal outcomes associated with these accidents.[1] The study shows missions flown by low-DTE pilots were more likely to have fatal outcomes in those conditions. While low-DTE pilots obtain deliberate practice, preventative constraints suggested for them and effective recovery control interventions[1] are recommended. Any poor assessment of HOC will place flight crew and occupants at higher risk of an operational accident during night VFR HEMS operations.

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