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ENHANCING HELICOPTER-PILOT OBSTACLE AVOIDANCE USING A BINOCULAR HEAD-MOUNTED DISPLAY

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Twenty-three helicopter pilots flew a simulated Bell 206 in Helicopter Emergency Medical Service (HEMS) scenarios with obstructions present. In Study 1, the head-mounted display (HMD) showed highway-in-the-sky guidance but not obstructions. Study 2 added obstructions (broadcast towers, power lines) in the HMD. Pilots detected and avoided HMD-depicted obstructions earlier than those only shown out the window. Wire strikes were frequent without HMD depictions of obstructions but were greatly reduced when these objects were shown in the HMD. They were completely eliminated when a red warning fence was overlaid on the power-line graphic at the point it transected the flight path. Pilots indicated that the power-line representation was slightly ambiguous in its meaning, but the red warning fence intent was clear. Pilots preferred power lines without the ground-plane representation and realistic complex green imagery for guy wires, and red/white striped towers with beacons and digital tower elevations.

Helicopter Emergency Medical Services (HEMS) operations, as reported in previous publications (Beringer, Luke, Quate, & Walters, 2009; NTSB, 2006), frequently experience accidents related to obstructions or obstacles to flight that are not as frequently encountered by other types of operations, specifically due to the operation of the aircraft into unimproved and/or confined areas (see Lee, Choi, Choi, & Ujimoto, 2007, and NASDAC, 2002, for accident statistics). As such, parts of the aircraft have been known to strike various structures and both man-made (including other rotorcraft) and naturally occurring objects during the conduct of a flight. One of the major difficulties in these operations, then, is the effective location and avoidance of obstructions; wires of various descriptions are a frequently encountered obstacle. They become particularly problematic in conditions of reduced visibility. Even when visibility is good, descents into confined areas or to unimproved sites are usually very slow requiring multiple crew members to scan the area surrounding the selected touch-down zone for wires and obstructions. That the striking of obstructions by rotorcraft in reduced visibility continues to be a problem is illustrated by the recent fatal crash involving a construction crane atop a high-rise residential complex in London (Topham, 2013).

Means of Detecting Obstructions and Terrain

The use of Helicopter Terrain Awareness and Warning Systems (HTAWS) for rotorcraft engaged in HEMS operations is expected to be mandated soon (Lau, 2013; RTCA, 2008). These systems are anticipated to be coupled with plan-view terrain displays and to provide warnings of approach to terrain and advisories for terrain avoidance (per RTCA DO309 minimum operations performance standards). While this system should allow rotorcraft pilots to detect approaches to terrain and avoid unanticipated terrain contact, it will not necessarily protect against contacting cultural features (human-constructed obstructions).

Some systems that incorporate forward-looking perspective-view displays with some type of terrain representation also include obstruction graphics generated from a database, showing towers and sometimes buildings, usually depicted as some form of vertical lines. However, it may be difficult to ascertain their precise locations in the real world dependent upon the size of and minification in the display. Similarly, obstacles can also appear on plan-view map displays. These systems require the pilot to recognize the location of obstructions by referencing one or more displays and determining a path avoiding the obstacles.

Using head-mounted displays (HMDs) to provide VMC-like visibility of both terrain and cultural features for general aviation applications was outlined in Beringer's (1999a) chapter on this topic. The notion was that one could present terrain, cultural features, and augmented visual information/cues to the pilot to aid in visually guided/referenced maneuvers and piloting in conditions where the prevailing visibility did not allow such with the unaided eye. While the use of head-mounted displays is well established in military combat aircraft, there was not at that time, nor is there now, a certified system that can be used for this type of operation in civil aviation. The existence of efforts to produce a certifiable system for civil aviation made it prudent to evaluate how pilot performance

could be affected by the use of such a system, and to what degree both flight performance and thus the level of safety in this type of rotorcraft operations could be improved with such displays.

We previously reported the results of a preliminary evaluation of the use of a HMD for rotorcraft navigation and approach to a landing site (Beringer, et al., 2009) (Study 1) and discussed pilot ratings of various type of graphics that represented obstructions (Beringer & Holcomb, 2010) and the inherent advantages of the HMD. We used a stereoscopic see-through HMD presenting very simple overlaid synthetic imagery of obstructions (Foyle, Ahumada, Larimer, & Sweet, 1992), rather than a synthetic-vision (SV) representation of obstructions (Hughes, 2005; Rash, Russo, Letowski, & Schmeister). This approach was taken to (1) avoid clutter in the visual field and (2) to allow the outside world to be seen through the guidance-information graphics, allowing the pilot to detect any potential hazards when visibility allowed, rather than having them obscured by HMD-displayed data. That work based upon earlier work in a fixed-wing simulator (Beringer et al., 1999b) demonstrated that pilots could effectively use the HMD to follow highway-in-the-sky (HITS) guidance cues to a synthetic landing pad but that they had difficulty using out-the-window obstacle information, as shown by flying through or under power lines on the final approach (as the debriefing discussion frequently went, “Did you see those power-line towers on your final approach?” “Yeah, but I didn’t see any wires between them.” “Exactly!”) and, from the preference assessment in the later study, that they had a definite preference for simple power-line representations and complex broadcast-tower representations.

As is frequently the case in these kinds of evaluations, several questions arose as to the effective use of a HMD with obstructions (non terrain) shown. First, given that the image was derived from position sensing and a database, what would happen if position sensing were a little off or the database contained an error (object in wrong place or object missing altogether)? Would the pilot be able to see through the presented image sufficiently to pick up obstructions that were improperly rendered, or would there be significant enough cognitive or perceptual capture to prevent that? One must add to the “cognitive-capture” category a belief that the image is correct, regardless of information to the contrary, as we have found in other studies of forward-looking terrain displays and NEXRAD displays. Our colleagues in Aircraft Certification frequently refer to this quality in a display as “compelling.” Second, would the display of the obstructions alone be sufficient, or would some kind of additional warning be required as a cue to the pilot that the flight path should be altered? That is to say, would our previously preferred low-complexity power-line representations be sufficiently unambiguous to promote avoidance behavior, or would there be enough ambiguity about their location relative to the intended flight path that pilots would not use them effectively? We set out, then, to look at these questions in Study 2 in the same type of applied HEMS scenario as we had before, but added additional graphical imagery to the HMD to evaluate a potential spatial-graphical warning.

Method

Equipment and Displays

Participants flew a simulation of a Bell 206 helicopter with the Chelton/Cobham display suite of a forward-looking perspective primary-flight display (PFD) and a plan-view map/terrain multi-function display (MFD) (Figure 1). Engine instrumentation of a conventional, round-dial B-206 was presented to the left of the PFD and MFD. The Chelton displays contained programmed route information to the remote pick-up site and stick-figure representations of towers. A lateral path vector was also shown for any turning flight and an auditory “obstruction, obstruction” warning was triggered when the path vector came into close proximity to a tower contained in the database, with appropriate visual cueing added to the PFD and MFD.



Participants wore a Kaiser (now Rockwell) Optical stereoscopic full-color see-through HMD (640 by 480 resolution; 25% transmissivity; Figure 1). The display was head-position slaved so that obstructions generated in the HMD overlaid obstructions visible in the out-the-window scene.

Figure 1. *HMD and simulator cockpit with PFD/MFD, engine instrumentation, and out-the-window view.*

Design of stimuli

Six configurations (low, medium, high complexity paired with ground plane symbol off or on) of each HMD obstruction image (radio/television broadcast towers and power transmission towers with lines) from the previous study were used. Red beacons were added to the power-line towers and those on the broadcast towers were expanded vertically to be more visible from a distance. A red-and-white striped broadcast tower similar to real-world towers was added for ratings only. Additionally, one set of obstructions was produced with yellow wires for comparison with green (latter perceived as brighter in HMD, but not a color associated with caution/warning), and a red warning fence was added that could be turned on during the final approach to the helipad. Although all images were rated, the most preferred ones from the previous investigations were used for the flights (low-complexity power lines, complex broadcast towers, green wires). The only change to the synthetic helipad was that the LZ marker was relocated to the top of a pole that started at 200 feet AGL (Figure 2).

Table 1. Variations in the obstruction images.

Tower	
Low Complexity (LC)	Vertical line (green), red beacon
Medium Complexity(MC)	Vertical line, guy wires, red beacon
High Complexity (HC)	Vertical rectangles (2)(green), guy wires (green), red beacon; red/white striped version also added
	<i>Ground plane: white circle at radius of guy-wire anchors</i>
Power-line	
Low Complexity (LC)	Vertical line (green), small circle at base (white), line across tops (green), red beacon at top
Medium Complexity (MC)	Vertical lines (2), lines across top (2), red beacon
High Complexity (HC)	Trapezoids (2), splayed, lines across top (2), red beacon
	<i>Ground plane: wire shadows for low and medium; square tower base for high</i>
Overall color	Green guy wires and power lines versus yellow of same
Power line overlay	Red “fence of death” overlaid on power-line segment intersecting intended flight path

In an attempt to conserve space, only the full scene used for the flight trials (Figure 2, left) and the warning graphic for the power line (Figure 2, right) are shown in this paper. See Beringer & Holcomb (2010) for the other variants used during the ratings portion as they were repeated from that study.

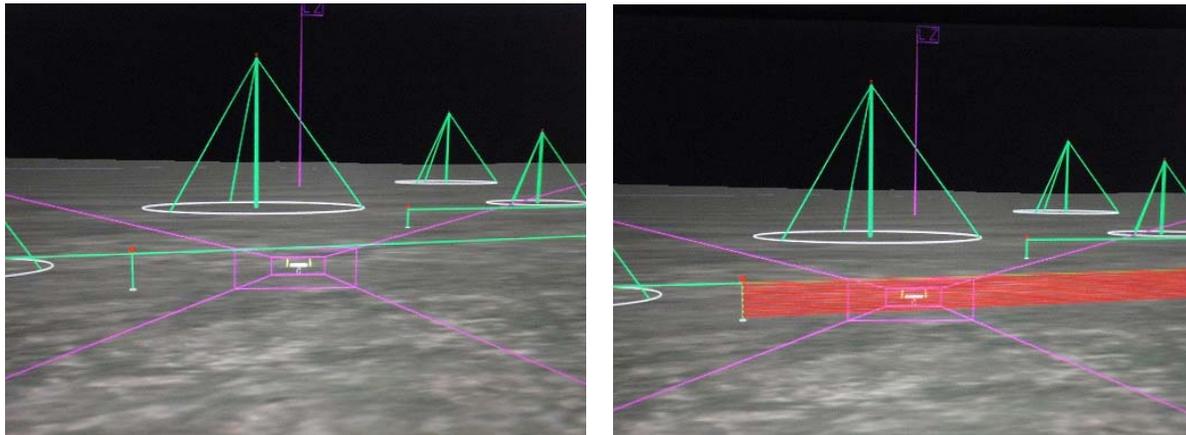


Figure 2. Obstacle field and HITS (left) compared with same view having red power-line warning fence (right).

Participants/Procedure

Seventeen licensed rotorcraft pilots from the greater Oklahoma City area participated in Study 2, with 14 completing all flights. Of these, 6 had ATP/helicopter ratings, 6 were 90-day current, and 8 had logged time in the previous 12 months. Data for six pilots from Study 1 where obstructions did not appear in the HMD were included for comparison with the Study 2 trials in which obstructions were shown.

Each participant first took a familiarization flight in the simulator in the vicinity of KAMA (Amarillo) and the mythical HEMS base. After accomplishing this, each was fitted with the HMD and flew a baseline flight from KAMA direct to the remote pick-up site with obstacles represented in the HMD but without any explicit explanation of what they represented. This course line took them very close to a tall broadcast tower near the destination. Following this segment, the simulator was placed in freeze mode in a position where they could view the various obstruction representations in the HMD. Each viewed a complete subset of stimuli (power lines first, then broadcast towers, then green versus yellow obstacle fields, then 4 with striped broadcast towers) without rating, then viewed

the same subset again while assigning ratings (5 scale points from poor to adequate to very good) and making unstructured comments about each graphic. This was done for each of the subsets until all graphics had been rated.

Following the ratings, the participants flew 3 more flights using the HMD. Flight scenarios followed those in the 2009 study and used the same type of pathway guidance for the later trials (approach to a remote landing site using a highway-in-the-sky 6-degree descent guidance to a synthetic helipad seen in the HMD with out-the-window VMC conditions; 3-mile visibility in haze). The first of these was a familiarization flight with the HITS guidance flying from the HEMS base at KAMA to KTDW (Tradewinds, west of KAMA) and an actual helipad. Pilots used the PFD/MFD to fly a HITS on the PFD to the intersection with the descent to KTDW, where another HITS was depicted in the HMD (consistent with leg 2 of the HITS on the PFD). This was identical in concept to what would come next, as the next flight was from the HEMS base to the pick-up site NW of KAMA in the midst of HMD-presented broadcast towers and power-line runs, using guidance on the PFD and MFD to intersect the final approach course/6-degree descent to the synthetic helipad. Emergency vehicles and an accident vehicle were present at the site in the out-the-window view.

We saw some of the same behavior (flying through or below wires) in the earliest trials, even though the power lines were explicitly depicted. We added the red warning fence at this point for the remainder of the participants so that we could compare an active indication of a hazard with the extant passive representation. This was added as a fourth flight to all of the later sessions and was activated half way along the final descent, a point before which we would have expected to see any flight-path deviation according to our initial performance data.

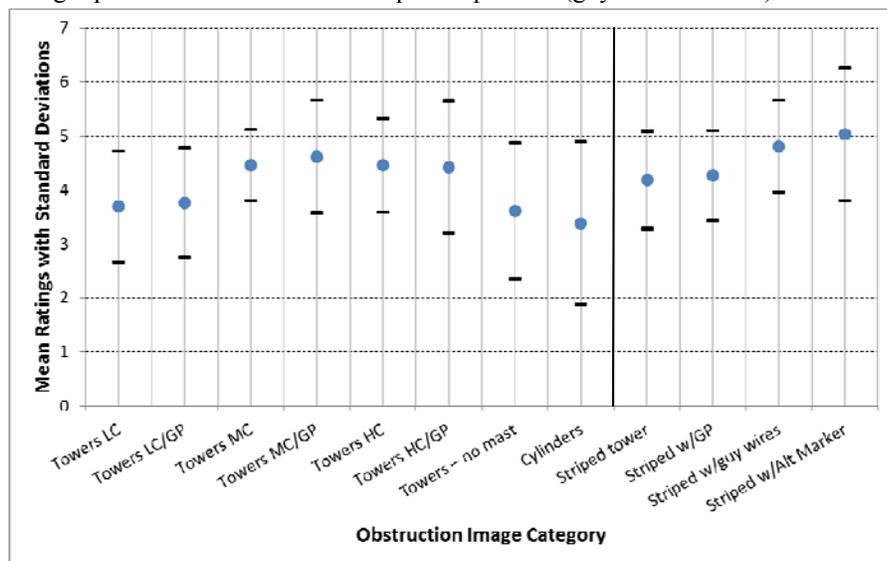
Results & Discussion

Three issues will be addressed in this reporting. First, how did the pilot ratings of graphics compare regarding what this sample found most representative of the obstructions that they were intended to represent, and was there a color preference overall? Second, we wanted to assess to what degree having the obstructions visually represented in the HMD would influence course deviation on flights without overt 3-D path guidance and closeness of approach to the obstructions (here we report only the nearest approach to first and tallest tower). Third, we wanted to determine how effective the power-line warning graphic was at causing pilots to appropriately alter their flight path.

Pilot Ratings of Graphics

Rating data for 13 of the pilots were found complete enough to be usable. Participants assigned a score of 1 to 6 to each graphic, 1 representing “very poor” and 6 representing “very good.” Figure 3 shows mean pilot ratings for tower depictions and 1 standard deviation above and below the mean.

Presence of the ground-plane indicator did not greatly affect ratings within any level of complexity, but there was a slight preference for the more complex depictions (guy wires favored). Removing the tower mast was seen as



negative, and the threat cylinders were not seen favorably at all. Comparing the most preferred format, striped tower masts having guy wires, ground circles, and digital altitude markers, with the cylinders indicated that the distributions of ratings did differ significantly [$t(12) = -4.15$, $p < .05$], consistent with the negative comments about the cylinders provided by the raters. One can also see a small but consistent increase in ratings of the masts as each additional feature was added (ground-plane circle, guy wires, and digital altitude).

Figure 3. Means and standard deviations for pilot ratings of broadcast towers.

Regarding the power-line representations, the differences were not significant excepting between the lowest-rated one (LC with a ground-shadow line) and the first high-complexity tower (HC, no ground plane indicator) that had dual lines on top of paired trapezoids [$t(12) = -2.54, p < .05$]. There was uniform agreement that anything producing what looked like a ribbon or chain of boxes looked too much like command guidance information (HITS) and was confusing. Thus, adding the ground-plane was not as advantageous as keeping the depiction simple, particularly as this was only a factor when close to 120 feet AGL. Although a verbal preference for green wires was often expressed, ratings for green and yellow did not differ significantly despite a slightly higher mean for green.

Approach to Tower

Figure 4 shows a plot of the closest approach, on the initial flight to the NW field of obstacles, by participants from both Study 1 and Study 2. Note that points indicated by arrows in Figure 4 were those individuals in Study 1 having no HMD-presented obstructions but having the destination synthetic helipad visible (obstacles only visible in the out-the-window view with towers but no wires).

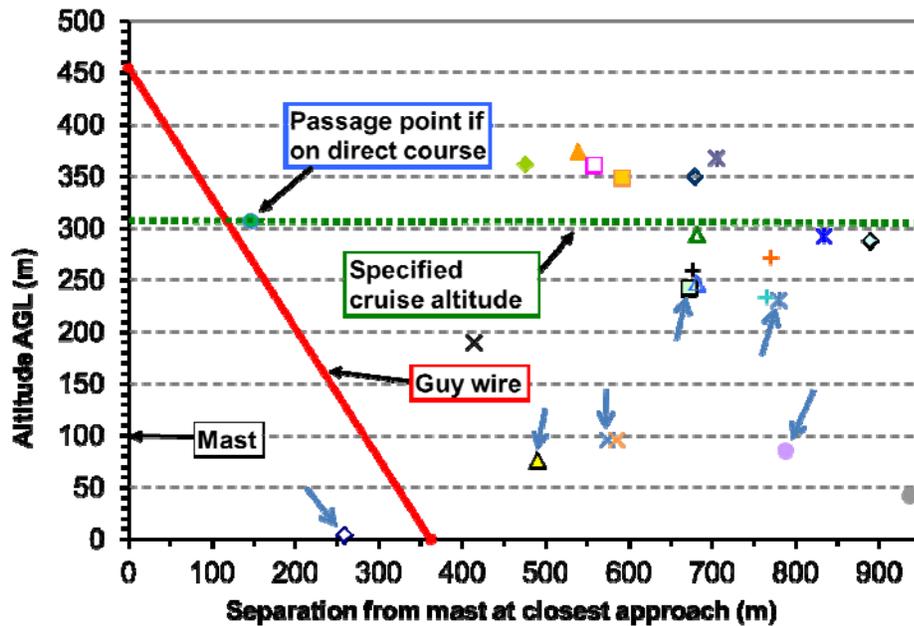


Figure 4. Altitude and lateral separation from tower mast/guy wire at closest approach.

Point of Course Deflection & Power Line Avoidance

Space constraints prohibit a detailed discussion herein of the course-deflection findings, which will be reported in the technical report version of this paper. However, to roughly summarize, pilots with the obstructions depicted in the HMD (1) reported the obstructions as a potential hazard earlier, (2) appeared to make intentional course deviations away from the direct course earlier, and (3) maintained altitude longer before descending to the destination.

Of the 14 pilots who completed the third and fourth flights using the HITS, 5 flew through power lines on the final approach to the pick-up site on the third flight, replicating our earlier findings to some degree, although with a slightly reduced frequency of occurrence. There was no discussion of the pilots' performances between the third and fourth flights, and they were told only that they would see something different on their displays and that the approach would be slightly different. On the final flight, **none** of the pilots flew through the power lines, with the minimum clearance over the lines being 69 feet at crossing (mean without warning fence, 144 feet; mean with warning fence, 306 feet). We hypothesized that the warning would allow pilots to analyze that the HITS would take them through the lines and thus arrest their descent earlier and allow better vertical separation from the lines (Paired-samples t , one-tailed: $t(13) = -1.851207, p < .05$). Pilots indicated, in the post-flight debriefing, that they would like an integrated system in which the MFD, PFD, and HMD indications were all correlated and synchronized so that all warnings regarding obstructions appeared at the same time and in related representations on all 3 forms of display, as well as in the auditory obstruction warnings generated for towers by the MFD/PFD equipment.

the out-the-window view with towers but no wires).

The remainder had GPS guidance via the MFD/PFD and obstacles with wires shown in the HMD but no synthetic helipad/destination. From the distribution by groups, it is evident that those without HMD obstructions and with line-of-sight HMD visibility of the destination tended to descend earlier and thus place themselves in potentially a greater hazard regarding tower guy wires.

Conclusions

Preferences for HMD graphics, as seen in previous assessments, tended towards power-line graphics without the ground-plane shadow but towards the more literal representation (HC) for broadcast towers because the graphic looked like a tower with guy wires. Flight-performance results demonstrated that obstruction imagery in a head-mounted display could be useful in aiding rotorcraft pilots engaged in an HEMS-like activity to avoid obstacles, both strategically and tactically. This was particularly true in a case that simulated a misprogrammed navigation system that would take the descent path through a known obstruction, in which case the inferred conflict (passive obstacle representation) was successful in preventing a collision only 64% of the time. However, the addition of an active graphical warning overlaying the hazard was completely (100%) effective in preventing power-line strikes during the final descent. The possibility of using HMDs for both navigation and obstacle avoidance in operations near the surface of the terrain appears to be supported by the cumulative results to date.

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