Chapter 3 – COUNTERMEASURES: HUMAN MACHINE INTERFACES

3.1 INTRODUCTION

As alluded to in Chapter 2, rotary-wing aircraft pilots are trained to rely primarily on external visual cues to land. Pilots will visually scan the intended or designated landing zone for hazards using ground features as a reference to maintain spatial orientation and adequate control of the aircraft. This becomes particularly important when landing or maneuvering near various obstacles such as trees, poles, buildings, etc. Because rotorcraft are inherently unstable and require constant control inputs, pilots must closely monitor the orientation of aircraft (i.e., attitude; the lateral, vertical, and longitudinal velocity and acceleration) at all times. When operating in Degraded Visual Environments (DVE; i.e., brownout, whiteout), the blowing dust or snow obscures ground features. Hence, pilots must rely on aircraft instruments and displays to safely maneuver (e.g., hover, take-off, landing) in such environments. Traditional displays using symbol sets to depict aircraft orientation provide no information with respect to drift while maneuvering the aircraft. They are mostly incapable of depicting potential obstructions (e.g., rocks, ditches, berms, vehicles) without an accompanying sensor system. By replacing some of the visual cues used for maneuvering with virtual references, one might prevent spatial disorientation during such degraded visual conditions. This section provides an overview of a number of sensory displays that have been investigated to aid the rotary-wing pilot in maintaining orientation while operating in DVE.

3.2 VISUAL DISPLAY

With respect to symbology for landings in DVE, there are two major symbology sets, 2-D low speed symbology and 3-D conformal symbology display system.

3.2.1 2-D Low Speed Symbology – Brownout Symbology System (BOSS)

One of the low speed symbology systems is the Brownout Symbology System (BOSS) developed by the US Army AMRDEC (Aviation and Missile Research Development and Engineering Center). The BOSS symbol set was designed to be nearly identical for both the panel-mounted displays and head-mounted displays (such as NVG-HUD). In the case of panel-mounted displays, the BOSS display is designed to work with terrain imagery in the background from an imaging sensor (such as FLIR) or synthetic terrain imagery. The history, various phases of development, and evaluation of the BOSS symbology set is described in detail in Annex A and C.

The BOSS symbology set is illustrated in Figure 3-1 below. The latest version of BOSS symbology (2011) enables the entire approach to be accomplished on a single display page starting at any speed. The page used is called the Hover-Approach-Take-Off (HAT) page. A logarithmic scale is used for ground speed beyond 10 knots and for landing/hover point position beyond 100 ft. Therefore distracting scale changes, which are common on other 2-D displays, are not necessary with the BOSS symbology. The pitch ladder scale is fixed on the screen enabling the same scale marks to be used for pitch and horizontal speed. Therefore a horizon line and pitch scale are always available, in case of go-around during the approach.

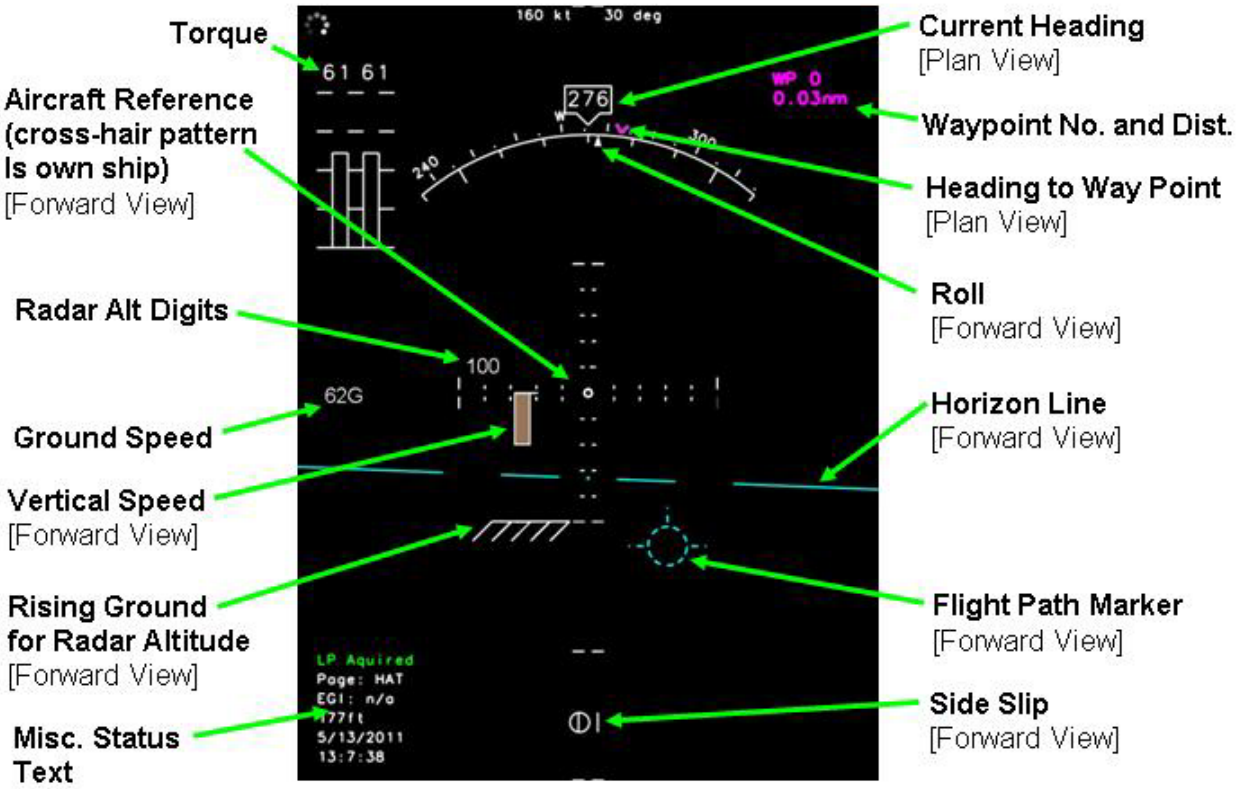


Figure 3-1a: Enroute Page of BOSS Symbology.

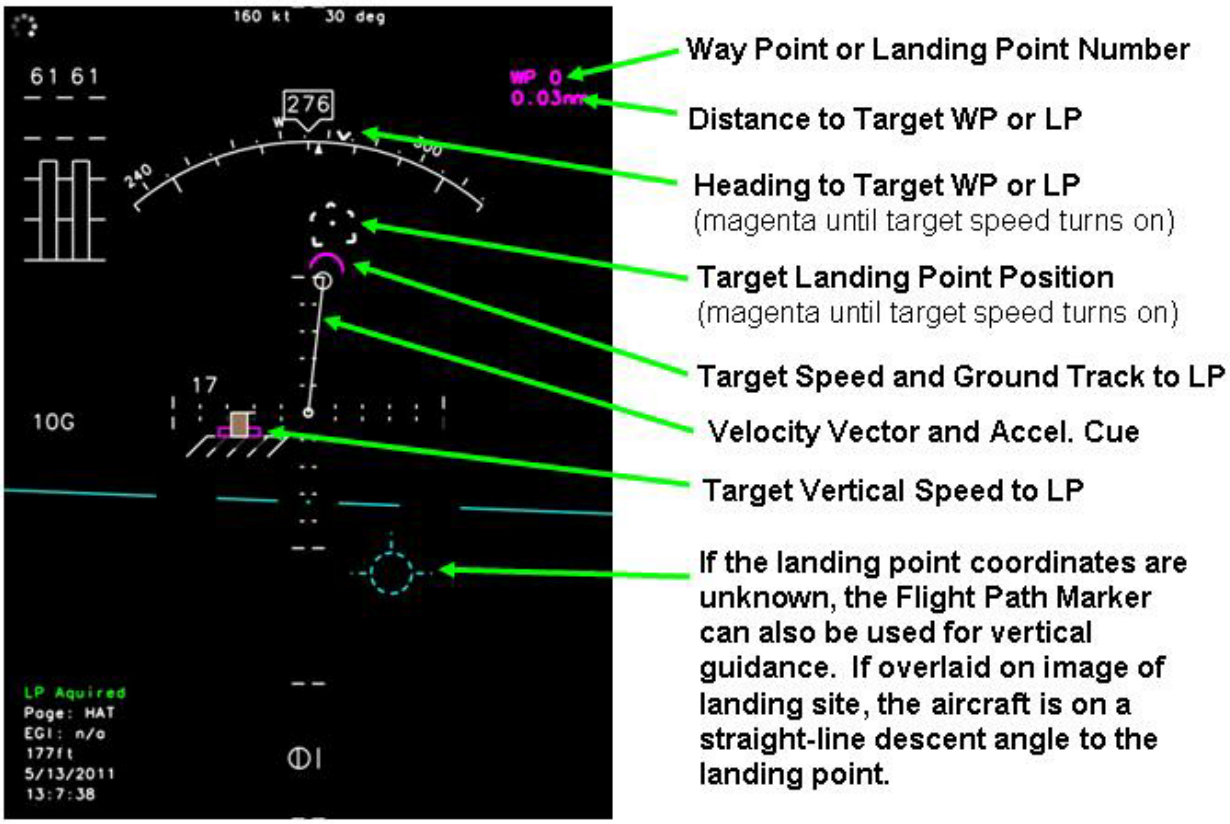


Figure 3-1b: Hover-Approach-Take-Off (HAT) Page of BOSS Symbology.

The aircraft reference symbol in the center of the screen is the plan-view of the own-ship location. Key elements of the hover symbology for BOSS include the velocity vector and acceleration cue symbols. The target speed symbol is scaled in the same manner as the velocity vector. At 0.8 nm the target speed symbol is activated (turned on). The target speed algorithm always starts at the speed of the aircraft when it crosses the 0.8 nm distance boundary. As the aircraft approaches the landing point the horizontal speed guidance algorithm directs the pilot to slower speeds, while the vertical speed guidance algorithm indicates the correct descent rate. In addition to providing the desired speed, the target horizontal speed symbol also rotates about the own-ship symbol to provide target ground tracking to the landing point.

The horizontal speed guidance equations used in earlier simulation tests [1];[2] were determined to be too slow during AFRL (Air Force Research Laboratory) simulations. The linear speed versus distance equations were modified by AFRL to include a constant deceleration portion for most of the distance. At 500 ft, the constant deceleration equations transitioned to a linear speed versus distance guidance algorithm. The reason for keeping the linear speed vs. distance portion was to decrease the deceleration near the landing point, as compared to the constant deceleration algorithm. Therefore, there is a smaller attitude change required near the landing point when close to the ground.

The flight path marker symbol is useful in situations where the elevation of the landing point is not known ahead of time, nor can it be measured with a sensor. The flight path marker shows the current direction of

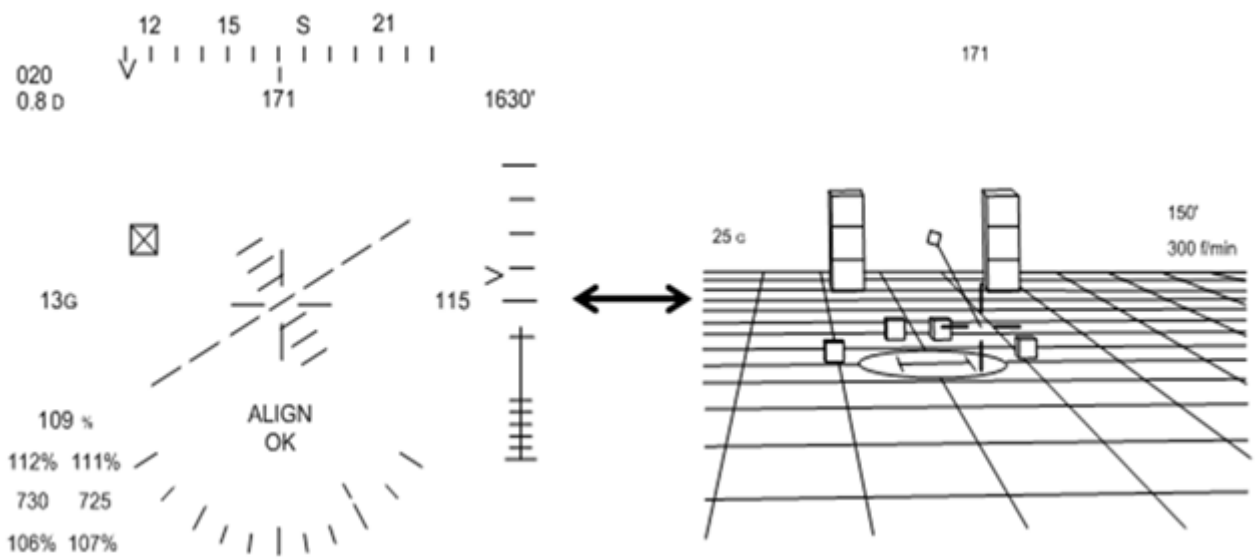
travel with respect to the terrain imagery. The pilot can manipulate the controls to hold the flight path marker over the image of the landing point, indicating that the aircraft is on the correct descent angle to the landing point. The flight path marker is set to change to a “dashed” format below 20 knots ground speed, and to turn off below 10 knots ground speed. On a head-mounted display, the flight path marker symbol requires a head tracker.

Key milestones of the Brownout Symbology System development are described in Annex A of this document.

3.2.2 3-D Conformal Symbology Display System – FTL 3-D Conformal Symbology

One of the biggest challenges for any kind of technology used for DVE landing and take-offs is to provide intuitive displays and keeping the workload low while providing all the necessary cues for the pilots to perform the tasks safely and efficiently.

The generic design of helmet-mounted 3-D conformal symbology is based on the augmented reality principle, whereby symbols are placed accurately on the real world ahead of the aircraft. The concept attempts to mimic a real-world cueing mechanism by providing stationary cues from which relative movements (differential motion parallax) and closure rates and relative height can be extracted by the pilot in the same manner as real-world cues. Figure 3-2 presents the contrast between a traditional 2-D fixed symbology display which presents flight, navigation and helicopter systems data and a 3-D symbology display presents “real world” information such as landing point position, ground references, and pilot line of sight. The virtual reference symbols provide the overall intuitive impression of all necessary cues for landing and take-off such as height (altitude), drift, landing position, rate of closure (rate of decent and ground speed), and attitude. The intention is to provide a natural cueing environment to ensure conventional control by the pilot in DVE by providing the key orientation elements listed above.



2-D Symbology 3-D Symbology

Figure 3-2: A Comparison between 2-D and 3-D Symbology Displays.

A 3-D conformal symbology system is designed to be installed on legacy and new helicopters, with no requirement to have a Digital Automatic Flight Control System (DAFCS) or Fly-By-Wire capability.

More detailed information of the 3-D symbology shows that a few key elements are used to provide an intuitive interpretation of the symbology as shown in the following diagram (Figure 3-3):

- Reference towers – Provide an approximate altitude. Used mainly when it is away from the LZ.
- Reference boxes – Replace the contrast object used for reference in visual hover.
  - Used on final approach stage – near the LZ.
  - Provide both drift and "gentle" altitude perception.
  - Scattered in several locations to allow pilots with different landing "habits" to look at the reference box in the same manner as employed during normal visual flight.
- Landing grid – represents the ground level at the LZ. It provides drift and altitude perception, mainly during approach.
- Landing point – Allows the pilot (along with other cues) to determine the exact landing point. The pilot can look "into the cockpit" to view the landing point as if the cockpit is transparent.
- 2-D flight data are combined with the 3-D symbols (altitude, torque, heading, etc.).

They provide additional data that the 3-D symbols do not provide and allows the pilot to "calibrate" his perception of altitude and speed, etc. – see Figure 3-3 below.

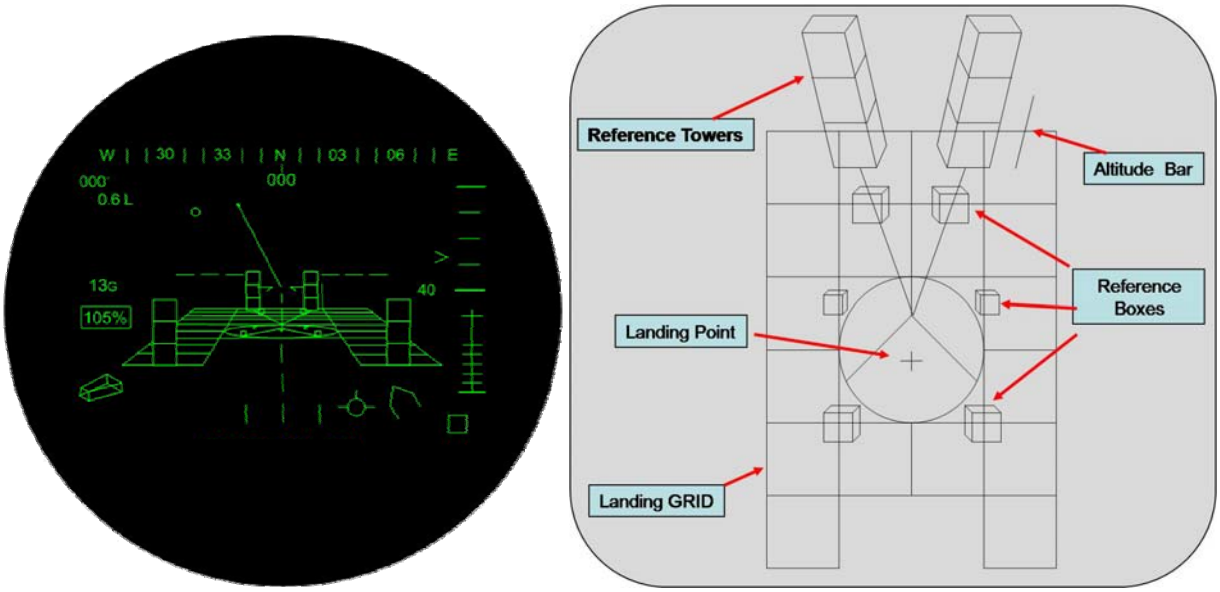


Figure 3-3: 2-D Flight Data are Combined with the 3-D Symbols.

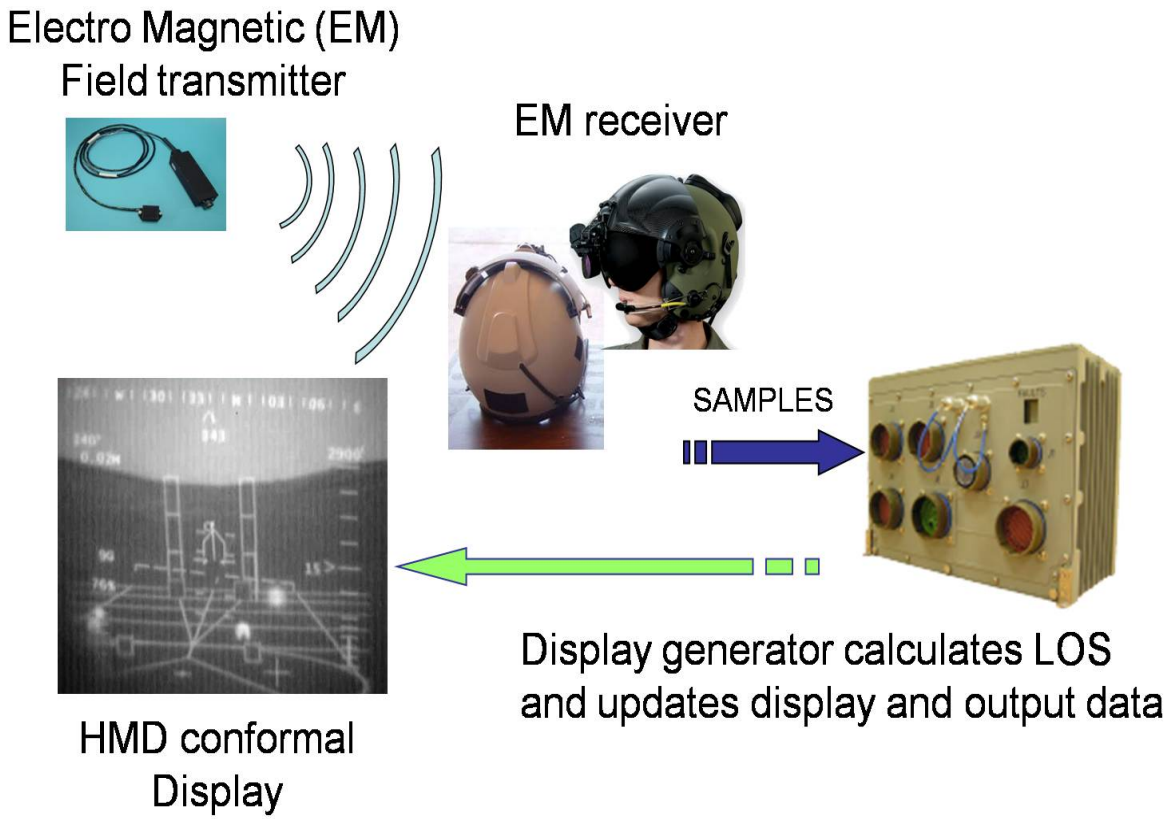


Figure 3-4: Line of Sight Principle.

However, there are a few major requirements in order to generate an efficient 3-D conformal symbology:

- Helicopter sensors – To provide accurate, frequent and reliable data (including precise position, height and a digital terrain database).
- Display generator – Uses data from the helicopter to generate symbology.
- Head tracking and designation – To provide head position (Line of Sight) information to the display generator.
- Helmet-mounted Display HMD) – To present combined symbology to the aircrew.
- Integrated system – Optimizing system performance, in parameters that are crucial to the pilots such as latency (delay between gathering and displaying the information), real-world registration (how is the symbology displayed on the real world) and consistency of elements in the display.
- LOS (Line Of Sight) principles as depicted in the Figure 3-3.

3.2.2.1 Synthetic Vision

Synthetic vision is the construction of a three-dimensional image of the landing zone using a combination of flight dynamics information (position, height above ground, aircraft attitude) and a terrain database. Such systems are being introduced on civil airliners to aid situational awareness in poor weather. Synthetic

vision provides a clear view of the landing zone during approach and landing in brownout and will improve situation awareness of the outside world. The imagery should be relatively intuitive and enable a visual flight control strategy to be maintained. The concept has application to improved Day Night All Environment capability assuming the sensors can gather all the information required and it can be processed and presented in a timely and readily interpretable form to enable safe flight.

3.3 ALTERNATIVE DISPLAYS

Traditionally pilots receive flight related information either visually or aurally. Cockpit instruments, flight displays, head-up displays, etc., present visual information. Auditory information comes from warning signals and from communication with crew-members, other aircraft in the mission and air/ground control. In mission scenarios under operational conditions (e.g., Afghanistan), pilots' visual and auditory senses may be heavily involved, requiring high levels of concentration inducing considerable workload. Workload may be increased further because information is not necessarily presented in the most effective ways. In order to lower pilot workload and increase mission effectiveness, research has explored possibilities to present information in alternative, more intuitive modalities. The main developments include alternative visual displays as described above, 3-D audio, and tactile displays, or a combination thereof. In general, these displays are often referred to as multi-modal displays. Moreover, modern cockpit interfaces may use voice recognition (direct voice input or DVI) and speech synthesis, facilitating hands-off handling of flight parameters. The following section deals with some of these alternative displays.

3.3.1 3-D Audio Displays Overview

Normal binaural hearing allows for 3-D sound localization. Determination of 2-D lateral direction (left or right) is based on the interaural time and differences in sound level. Sound from the left side of the listener reaches the left ear before the right ear, and with higher intensity due to the head shadow effect. Regular stereo audio systems are capable of presenting sound with lateral direction, and provide limited information about the distance of its origin. Discrimination of sounds in the median plane (above, below, front and back), as well as their distance, also depends on direction-selective reflections at the ears, head, shoulders and torso, causing spectral transformations. The 3-D audio systems or spatial audio systems can present 3-D directional sound through headphones. Spatial audio creates a natural sensation of sound as if they arise from the outside world. The technique is based on a set of real-time digital audio filters (HRTF, Head-Related Transfer Function) which recreate the spectral transformations caused by the shape of the ears, head, and torso.

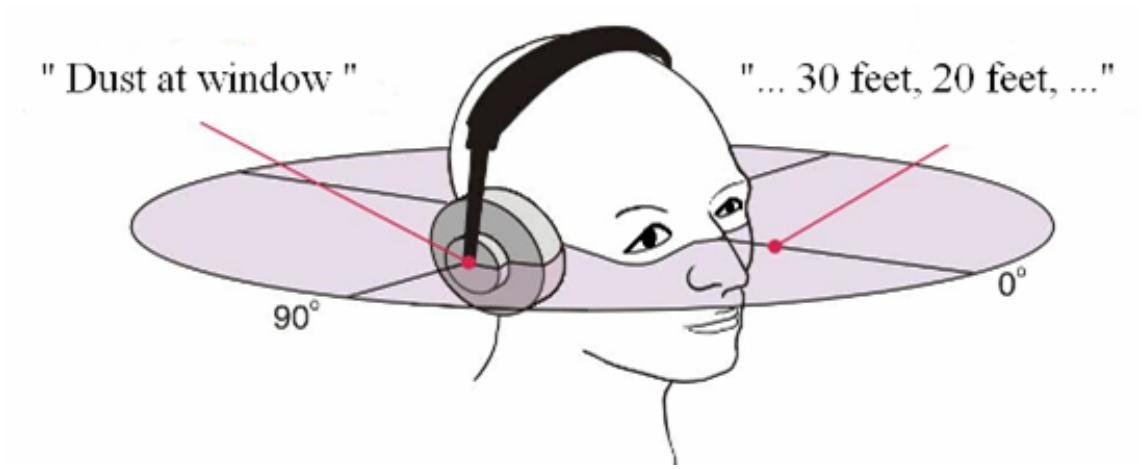


Figure 3-5: 3-D Audio.

To obtain optimal results, the HRTFs should be individualized so that they match the individual direction-sensitive reflections of the listener's head and ears. Use of generic HRTFs increases the risk of mis-localization, in particular front-back reversals inherent to the perceptual ambiguity between sounds in the median plane. This ambiguity can be resolved by making small head movements, which requires head tracking. Nevertheless, generic filters generate directional information that is reasonable for most applications, but it may require training to adapt to these filters [3].

In general, directional sounds are detected and interpreted more easily among other sounds or against background noise. Flight simulator studies showed that fighter pilots can afford to pay more visual attention for additional tasks when warnings are presented on a 3-D audio display [4]. The investigated audio displays include threat warnings and Traffic Alert and Avoidance System (TCAS). With 3-D audio, the overall performance increased, indicating a reduced workload. Another simulator study with fighter pilots showed that 3-D audio may also be useful in communication and situation awareness, for example, presenting the location of the wingman relative to the own ship [11]. The main advantage of this is that directional information is readily available. Presently, 3-D audio systems are commercially available. The Danish Air Force has employed a 3-D audio system in their F-16s as has the US Air Force in their F-35s.

Although 3-D audio systems may be useful for some applications in rotary-wing aircraft, there are some perceptual and operational limitations that could prohibit their use during helicopter landing. These are:

- Possibility of front-back reversals.
- Limited number of different auditory signals that a person can distinguish (no more than three or four).
- As in any auditory communication, virtual sounds or radio communication can mask other environmental sound. (Similarly, virtual sounds can also interfere with speech of team members.)
- The introduction of 3-D audio may require testing individual pilot for accurate binaural hearing.
- Limited spatial resolution; even when the signals are well designed, it is impossible to improve auditory resolution (which, in comparison with the visual system, is quite poor).
- For virtual sound sources, resolution is often worse, especially if the sound source is not compensated for head movements.

- In certain situations it is problematic or even unsuitable to present auditory information such as in noisy environments (the case in many military environments), while in other situations there may be excessive auditory information.

3.3.2 Tactile Displays

Research has shown great potential of tactile displays for navigation and spatial orientation in military environments. Tactile displays make use of vibrating elements ('tactors') to relay information to the skin. A well-known example is the vibrating function of a cell phone or paging devices. The development of (military) tactile displays has been driven by the objective to reduce sensory and cognitive workload. In high-workload situations the pilot's visual and auditory sensory channels are usually occupied by scanning cockpit instruments and communication, respectively. The skin provides an extra sensory channel, which works in parallel with the other sensory channels. The use of tactile displays has been successfully shown in several aviation situations, for instance as a countermeasure for spatial disorientation [5];[12], helicopter hovering [7];[13];[9], and threat intercepts under high G-loads [10]. Hence, a tactile display can be considered a cockpit instrument with the possibility to present orientation information. In other words, it can be used as a multi-function display. The usefulness of tactile displays for military applications has been extensively reviewed in the final report of the RTO TG-122 "Tactile Displays for Orientation, Navigation and Communication in Air, Sea and Land Environments (2008)".

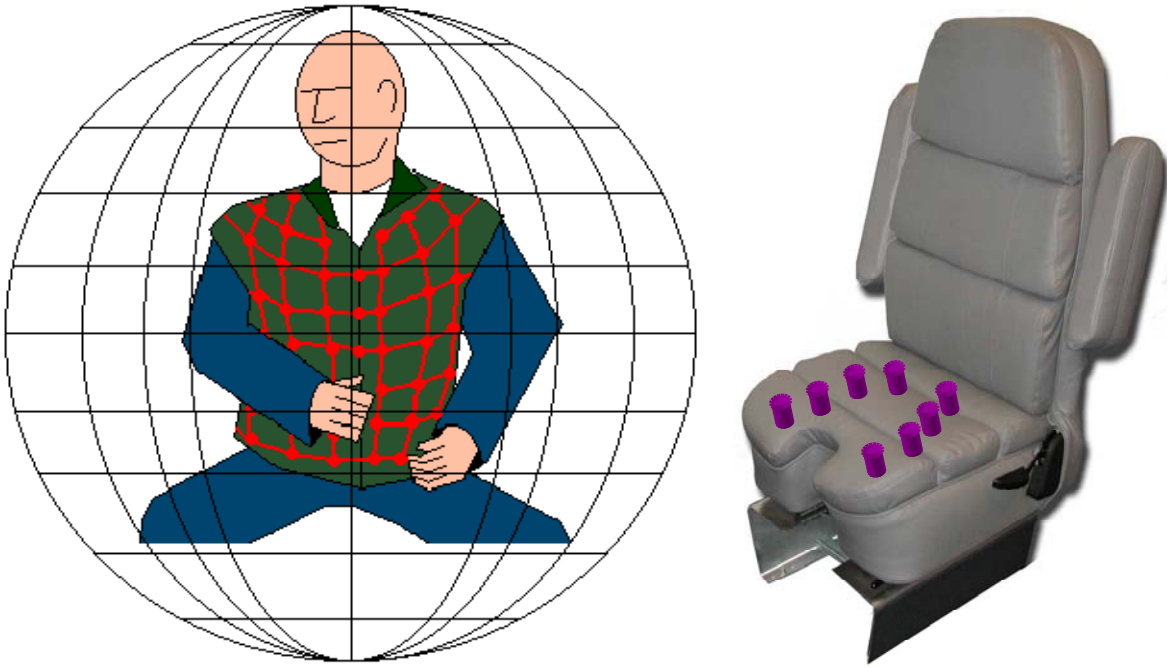


Figure 3-6: Examples of Tactile Cueing Devices; Vest (left); Seat (right).

For several reasons, tactile displays offer a promising support tool for rotary-wing pilots in brownout conditions or DVE in general. The most significant advantage of tactile displays is that they do not require the pilot to look or listen: they are "eyes and hands free". This is especially relevant in the final phase of landing, where pilots need their eyes to maintain visual contact with a reference point in the outside scene and require

their ears to listen to the call-outs from the loadmaster and the non-flying pilot monitoring the descent. When non-visual information about the aircraft's motion is available, the pilot does not need to look inside the cockpit. This advantage may be complementary to modern HUD symbology. However, by presenting aircraft motion in the HUD (e.g., acceleration) will help the pilot to remain head-up, there is still a requirement for him to allocate his visual attention to the HUD, rather than the outside scenery. Under stressful conditions it is questionable whether the pilot can look at the HUD and the outside landing reference at the same time.

Another advantage of a tactile display is that, with appropriate configuration of the tactors, it can provide three-dimensional spatial information in an intuitive manner. Consistent with the "tap-on-the-shoulder" principle, humans can easily externalize the direction of a tactile stimulus. For example, when a pilot feels a tactor on his right flank, he immediately knows that something happens on his right side. This 'something' can be a threat warning, or in case of brownout landing, intentional or unintentional drift. As with visual instruments, the information presented on a tactile display depends on the demands of the application. There have been a number of in-flight studies that have investigated the usefulness of tactile displays for DVE. They are described in Annex B.

3.3.3 Haptic Controls

Haptic controls are sometimes referred to as "active controls". The flight controls of helicopters configured with active controls begin to vibrate when the flying pilot nears an aircraft system or flight limitation (e.g., maximum power available, bank angle). Although not considered a "display" for landings or take-offs in DVE, haptic controls can relieve the pilot from having to visually monitor power settings and landing attitudes, thus, allowing the pilot to maintain his or her visual attention on those instruments critical for landing or on outside visual cues. In effect, its benefit is that it reduces the flying pilot's visual workload in addition to providing non-visual information that will reduce the likelihood of exceeding aircraft operating limitations. The effectiveness of haptic controls has been successfully demonstrated in several simulations and flight campaigns.

3.3.4 Conclusion

There has been intensive research and development in display systems; however, various sensor technologies are required to gather the information in order to create appropriate displays. The following chapter describes the various sensor technologies that are available. A detailed analysis of the various sensor technologies in terms of capability, strengths, limitations, system readiness, human factors and integration issues are described in the following chapter.

3.4 REFERENCES

[1] Szoboszlay Z., Albery, W.B., Turpin, T. and Neiswander, G.M. (2008). Brown-Out Symbology Simulation (BOSS) on the NASA Ames Vertical Motion Simulator, American Helicopter Society 64th Annual Forum.

[2] Szoboszlay Z., McKinley R. and Turpin T. (2009). Symbology for Brown-Out Landings: The First Simulation for the 3D-LZ Program. American Helicopter Society 65th Annual Forum.

[3] Carlander, O. and Eriksson, L. (2006) Uni- and Bimodal Threat Cueing with Vibrotactile and 3D Audio Technologies in a Combat Vehicle. In Proceedings of the HFES 50th Annual Meeting. San Francisco, CA, USA: Human Factors and Ergonomics Society.

[4] Veltman, J.E. and Jansen, C. (2004). The adaptive operator. In: D.A. Vincenzi, M. Mouloua and P.A. Hancock (Eds.), Human Performance, Situation Awareness and Automation Technology (HSPAA II), March 22-25, 2004, Daytona Beach, FL, USA, Vol. II, pp. 7-10.

[5] Raj, A.K., Suri, N., Braithwaite, M.G. and Rupert, A.H. (1998). The tactile situation awareness system in rotary wing aircraft: Flight test results. In: Proceedings of the RTA/HFM Symposium on Current Aeromedical Issues in Rotary Wing Operations, pp. 16-1 – 16-7. Neuilly-sur-Seine, France: RTO NATO.

[6] *Van Erp, J.B.F., Bos, J.E., Groen, E. and Van Veen, H.A.H.C. (2003). A spatial disorientation suit as instrument to counteract spatial disorientation. Report TM-03-A. Soesterberg, the Netherlands: TNO Human Factors.

[7] Raj, A.K., Kass, S.J. and Perry, J.F. (2000). Vibrotactile displays for improving spatial awareness. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Santa Monica, CA, USA: Human Factors and Ergonomics Society.

[8] *Van Erp, J.B.F., Veltman, J.A., Van Veen, H.A.H.C. and Oving, A.B. (2003). Tactile torso display as countermeasure to reduce night vision goggles induced drift. In: Spatial disorientation in military vehicles: causes consequences and cues. RTO Meeting Proceedings 86, pp. 49-1 – 49-8. Neuilly-sur-Seine, France: NATO RTO.

[9] Schultz, K., McGrath, B., Cheung, B., Craig, G., Jennings, S. and Rupert, R. (2009). In flight evaluation of tactile situation awareness system during high hover and simulated shipboard landing. In: Proceeding of American Institute of Aeronautics and Astronautics conference on “Guidance, Navigation and Control”, Chicago, IL, USA. August 2009.

[10] Van Veen, H.A.H.C. and Van Erp, J.B.F. (2001). Tactile information presentation in the cockpit. In: S. Brewster, R. Murray-Smith (Eds.): Haptic Human-Computer Interaction. Lecture Notes in Computer Science, pp. 172-181. Springer Verlag.

[11] Groen, E., Cornelisse, E-J., Jansen C., Van der Hoorn, J. and De Graaf, B. (2009). Personalized intuitive displays enhance pilot performance. RTO-MP-HFM-181/27 presented at the RTO Human Factors and Medicine Panel Symposium, Sofia, Bulgaria, 5-7 October 2009.

[12] Van Erp, J.B.F., Groen, E.L., Bos, J.E., and Van Veen, H.A.H.C. (2006) A tactile cockpit instrument supports the control of self-motion during spatial disorientation. Human Factors 48 (2); 219-228.

[13] Van Erp, J.B.F., Veltman, J.A., Van Veen, H.A.H.C. and Oving, A.B. (2002). Tactile Torso Display as Countermeasure to Reduce Night Vision Goggle Induced Drift. NATO RTO HFM Panel Symposium “Spatial disorientation in military vehicles: causes, consequences and cures”, La Coruna, Spain, 15-19 April 2002.

* Supplemental Material.