Chapter 4 – TECHNOLOGY: SENSORS AND DATA PROCESSING

4.1 INTRODUCTION

This chapter investigates the application of technology to improve safety during landing in brownout. Our first objective is to define various assumptions that will shape the requirements for specific technology. A second objective is to provide a review of relevant generic technologies identified from both government and industry programmes that will provide potential brownout solutions. For each technology, key capabilities, strengths, limitations, system maturity level, system integration requirements, required sub-systems and human factors issues will be reviewed. This is followed by a discussion which will aim to identify the most realistic technologies that are suitable for short term or immediate brownout solutions and future technologies that could provide enhanced capability over a longer timescale, together with technical approaches which may have been abandoned by some countries. The discussion will also illustrate the impact of different platform capabilities and scenarios on technology selection. The section will close with recommendations on immediate and future technology strategies for DVE landing risk mitigation.

4.2 TECHNOLOGY ASSUMPTIONS

The requirement for additional technology to aid brownout landings is dependent on the capability of the helicopter type, its avionics and the way it is operated, together with the operational scenario which dictates the visual environment and the level of preparation at the intended landing zone. Furthermore, a minimal set of "pilotage information" is required by the aircrew to complete the landing task safely. Failure to provide different parts of the information set may contribute to different types of brownout accident.

4.2.1 The Helicopter

For the purpose of our discussion, we will consider a generic, legacy helicopter operated by a Handling Pilot (HP), Non-Handling Pilot (NHP) and rear crewman. This generic platform will have a basic flight and navigation capability, for example, head-down primary flight instruments, simple GPS (Global Positioning System), Barometric and Radar Altitude, and a conventional rate command flight control system (essentially analogue avionics) to transit from level flight to the intended landing zone. A generic approach and landing procedure is also assumed that will cover helicopters of all configurations, i.e., skids/wheels/single/double main rotor. It should be noted that helicopters with digital avionics, may have been equipped with some advanced technologies which may provide additional information beyond the minimal requirement.

4.2.2 Mission Scenario

The scenario in which the mission is conducted will affect the level of information available from the outside world and hence the onboard brownout capability required to support the crew during the landing. For the purpose of the scenario, no dust suppression techniques are employed and brownout is assumed to occur over all terrains during every landing. Our discussion is also limited to the brownout landing phase and does not include the navigation phase. Three scenarios have been defined as follows:

1) Day Scenario: Operations in day light only to a Landing Zone (LZ) of known characteristics (e.g., ATP49 – prepared by ground forces), secured, cleared of Improvised Explosive Devices (IEDs), provided with detailed pre-recce information of the LZ together with generous planning time. In addition, there are no hostile forces present and multiple landing attempts are possible;

2) Night Scenario: As above but including night operations with adequate illumination; and

3) Worst Case Scenario: Operations to an unprepared LZ of unknown characteristics, unsecured, with short planning time and no detailed pre-recce information (such as slope, surface, surrounds, size, shape, etc.). In addition, it is a hostile, combat environment where multiple landing attempts and go-arounds are highly undesirable. This applies to both day and night operations with low illumination and a high possibility of heavy brownout, for example, during Combat Search And Rescue (CSAR), Quick-Reaction Force (QRF) infill/exfill at night or Immediate Response Team (IRT).

4.2.3 Minimal Information Required for Safe Landing

For each of the above scenarios, the minimal SA information required for safe landing can be broadly divided into:

1) Aircraft State Awareness:

   - Drift (longitudinal and lateral speed below GPS velocity detection limit or visual sub-threshold detection level, down to 1 m/minute resolution and a 10 Hz update rate);
   - Height Above Ground Level (AGL) and Rate Of Descent (ROD);
   - Groundspeed (40 Knots Indicated Airspeed (KIAS) down to minimum velocity detection (note most aircraft have pitot tube systems which are only reliably down to 40 KIAS); and
   - Attitude indication (must be available prior the onset of re-circulated particulates, and exceeding the pitch/roll limits of the aircraft).

2) LZ situation awareness:

   - Size, shape, surface, slope, surrounds, obstacles and hazards.

In each scenario, the information requirement can be contributed from different sources, for example, from the HP's unaided eye view or sensor view through NVG, "patter" from the NHP using head-down instruments or "talk down" from the rear crewman with awareness of the encroaching brownout cloud and ground surface. More complex presentations of the "outside world" can be generated from multiple sensors and databases, for example, synthetic vision. These different technological approaches offer different levels of capability and currently exist at different levels of technical maturity.

4.2.4 Types of Brownout Accident

The causes of accidents have been described in earlier chapters and provide a focus for the application and prioritisation of potential technology solutions. In general terms, helicopter landing accidents in re-circulated dust can be divided into the following causes:

1) Spatial disorientation (lack of aircraft state awareness); and

2) Collision with surface hazards (lack of LZ situation awareness).

Different technologies may be used onboard to address each accident cause. Furthermore, off-board technology may be used to minimise the magnitude of re-circulated dust, for example, landing zone preparation techniques.

4.3 TECHNOLOGIES

4.3.1 Onboard Systems

A range of technologies with different capabilities have been proposed to be of potential benefit in brownout landings. However, it is highly likely that any brownout solution intended to improve the pilot's Situation Awareness (SA) will at minimum make use of a sensing component and a display component and therefore comprise a system. A modular systems approach has been employed to identify and categorize technologies as follows:

1) Sensors:
   - Radar;
   - Laser; and
   - Passive Electro Optical.

2) Human Machine Interface (Displays):
   - Symbology;
   - Head-mounted Display;
   - Synthetic Vision;
   - Tactile; and
   - Haptic.

3) Flight Control:
   - Automatic Flight Control System with advanced flight control laws.

A minimal system will gather and present information effectively to provide the pilot with adequate SA, for example, relayed information from NHP or crewman. Systems which provide SA to the pilot directly may be more complex, for example, providing aircraft state cues in real time to allow safe stabilisation and control of the helicopter. The system may provide critical flight information and the eventual certification must be considered at all system levels as this will directly impact the release to service recommendations.

The accuracy with which the sensed, integrated and presented information represents the outside world, and the efficiency with which it is communicated to the designated crew-member (e.g., pilot or rear crewman), will depend on the capabilities of the different technologies within the system and how effectively they are integrated together. Some systems will be quite simple, for example, Low Light level TV (LLLTV) cameras mounted under the fuselage to give landing point surface information may be fed directly to a display for the NHP or crewman. Systems intended for the HP will need to at least provide the minimal information set described earlier and are likely to use a variety of sources combined together, forming an inherently more complex solution. It should be noted that on-going research and development in camera systems (e.g., IR cameras) will provide additional enhancement of the visual environment in the future.

Where a visual representation of the outside world is used for the HP, key system requirements will include the spatial and contrast resolution of the sensor, for example, the ability to detect and recognise fine features, surface texture, slope and obstacles in all light levels and through dust. The sensed data must then be processed into a readily interpretable picture and presented to the aircrew in a timely fashion without

excessive latency, for example, such that the picture responds correctly with aircraft movement. The display technology should at least match the sensor in terms of spatial and contrast resolution, field of view and dynamic response to minimise the loss of information in the presentation process. The human factors of the information presentation are critical to enable intuitive interpretation and prevent excessive workload, particularly in high stress environments.

4.4 ANALYSIS OF SENSOR SUB-SYSTEMS

4.4.1 Radar

Current Terrain Following (TF) / Terrain Avoidance (TA) radar that has been used on helicopters for weather penetration capability operating at approximately 15 GHz does not see through dust. Research programmes have shown that radars operating at high frequencies (35 to 94 GHz) provide precise dust penetrating height and descent rate information or obstacle warning capability for enhanced situation awareness.

4.4.1.1 Active MMW Radar Altimeter Sensor

4.4.1.1.1 Capability

Active millimetre wave radar altimeters operating in the 77 GHz and 94 GHz frequency bands provide a see through dust capability with greater accuracy and consistency than conventional RadAlts (which typically operate in the 4 GHz frequency band). Specifically, they provide improved height above ground measurement for the final approach and landing phase.

4.4.1.1.2 Strengths

Active millimetre wave RadAlts are small in size and weight with compact, integrated antennas which is advantageous when integrating on an airframe. They offer centimetric resolution and more consistent operation over a range of different terrain surfaces. Testing at 77 GHz and 94 GHz has shown minimal attenuation due to dust. They have a low power consumption and use small transmission power (~10 mW) with low probability if intercept.

4.4.1.1.3 Limitations

Such RadAlts have short range capability at about 100 m.

4.4.1.1.4 System Maturity

Systems have been developed for Unmanned Air Vehicle applications and are being adapted to meet the release to service/flight certification requirements for manned helicopters. Technology has also been exploited from commercial, automotive cruise control radars. There are systems developed specifically for helicopters which are being implemented as part of the German brownout solution.

4.4.1.1.5 System Integration Issues

The reduced weight, size and power consumption ease the integration issues with helicopter airframes and give the potential to mount them in potentially unconventional and multiple locations on the airframe.

4.4.1.1.6 Required Sub-Systems

Power and interfacing to aircraft avionics.

4.4.1.1.7 Human Factors

No issues directly – radar altimeters are considered to be important sub-systems to provide accurate height above ground in the final approach and landing phase and will be used to support improved symbology.

4.4.1.2 MMW Electronic Bumper Sensor

4.4.1.2.1 Capability

Electronic bumper sensors are based on small active millimetre wave radars which provide obstacle detection (moving or static) and proximity warning to the pilot. Their see through dust capability promises improved situation awareness within the brownout cloud during landing and take-off. For example, the sensors could be used to pick up dynamic obstacles such as vehicles or people, which have moved into the landing zone during brownout.

4.4.1.2.2 Strengths

Small and light, multiple sensors can provide a wide field of regard around the airframe. Alternatively, the radar sensor can be mechanically scanned to provide 360 degree coverage. The radar sensors can be derived from commercial automotive applications, e.g., cruise control radar, and are cost effective.

4.4.1.2.3 Limitations

The sensors are generally short range, <300 m, and rely on returned signal strength (i.e., radar cross-section which may be independent of obstacle size) to detect obstacles. The capability may not allow obstacle recognition so an avoidance strategy may be based on incomplete information.

4.4.1.2.4 System Maturity

Electronic bumpers are being developed in different research programmes worldwide. Some have been flight tested on target platforms and sensor technology is between TRL 5 and 7 (Table 4-1). The system technology, i.e., sensor combined with processing and displays is less mature.

Table 4-1: Technology Readiness Levels.

TRL Level	Original NASA (1989)	NASA Modified (1995)	NATO
0	N/A	N/A	Basic research with future military capability in mind
1	Basic principles observed and reported	Basic principles observed and reported	Basic principles observed and reported in context of a military capability shortfall
2	Potential application validated	Technology concept and/or application formulated	Technology concept and/or application formulated
3	Proof of concept demonstrated, analytically and/or experimentally	Analytical and experimental critical function and/or characteristic proof-of-concept	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard laboratory validated	Component and/or breadboard validation in laboratory	Component and/or “breadboard” validation in laboratory/field (e.g., ocean) environment
5	Component and/or breadboard validated in simulated or real-space environment	Component and/or breadboard validation in relevant environment	Component and/or “breadboard” validation in a relevant (operating) environment
6	System adequacy validated in simulated environment	System/sub-system model or prototype demonstration in a relevant environment (ground or space)	System/sub-system model or prototype demonstration in a realistic (operating) environment or context
7	System adequacy validated in space	System prototype demonstration in a space environment	System prototype demonstration in an operational environment or context (e.g., exercise)
8	N/A	Actual system completed and “flight qualified” through test and demonstration (ground or space)	Actual system completed and qualified through test and demonstration
9	N/A	Actual system “flight proven” through successful mission operations	Actual system operationally proven through successful mission operations

4.4.1.2.5 System Integration Issues

The radar requires a display system to convey proximity warning information to the pilot. This may be achieved through a dedicated additional display (requiring integration into the cockpit) or integration with existing head-down displays or head-mounted displays. Alternatively, a display could be provided to the rear crewman. Distributed sensors require suitable locations on the airframe, whereas a scanned sensor may consist of a single, but larger unit mounted underneath the airframe where there insufficient ground clearance. Integration with the aircraft navigation system may be required for aircraft attitude reference and geo-location.

4.4.1.2.6 Required Sub-Systems

Power and suitable display sub-systems.

4.4.1.2.7 Human Factors

Two human factors issues have been identified; how the information is displayed and how it is being used. A head-mounted display is desirable to reduce attention away from the outside world view and some symbology display concepts have been developed which integrate proximity warning with flight symbology. The second issue concerns the concept of operation whereby once a warning is received, what action should be taken.

4.4.1.3 Scanning Active Millimetre Wave (MMW) Radar Sensor

4.4.1.3.1 Capability

Active millimetre wave radar operating at the 77 GHz to 94 GHz range that has a “see through” dust capability and when combined with mechanical or electronic/phased array scanning promises the ability to survey a landing zone both before and during brownout. Radar technology has been researched for this role and adapted from existing applications such as missile seekers. The radar is capable of building up a 3-dimensional description of the surveyed terrain using time of flight ranging and angular measurements to objects which reflect the radar energy. The radar data can be used to update a terrain database, however, the data must be processed and displayed to the pilot in a suitable form and this area of technology is currently immature. It is however under development for synthetic vision systems (see later).

4.4.1.3.2 Strengths

Millimetre wave radars operating at around 94 GHz have been demonstrated to have negligible attenuation in dust. Radars derived from missile seekers can be small, lightweight with a compact antenna aperture which reduces the integration issues associated with mounting on the airframe. Mechanical scanning enables an area to be surveyed ahead of the aircraft. Range resolution is sub-metre whereas angular resolution may depend on the mode of operation. For example, a search mode could provide detections within the scanned beam without quantifying the elevation or azimuth angles to the target, whereas a track mode could measure the angular position of the radar beam. The angular resolution is determined by the beamwidth of the radar. To determine the target position within the beam a monopulse capability can be used which provides increased angular resolution to locate targets more precisely. Doppler tracking can also be used to locate targets more accurately. Trials have shown that millimetre wave radars are capable of detecting the majority of obstacles and features likely to be encountered during landing.

4.4.1.3.3 Limitations

A number of system trade-offs exist which limit the ability for current Commercial Military Off-The-Shelf (CMOTS) millimetric wave radars to completely fulfil the brownout landing recce requirement. The radar should have a scan pattern which enables the complete LZ to be covered throughout the approach and have sufficient scan rate to provide real-time data for display. The apparent increase in the angular width of LZ as range reduces causes an increase in the area to be scanned. The resolution of the radar is limited by the beam width. The beam width can be reduced by increasing the aperture but this also reduces the scan time or the dwell time on target which reduces detection capability. Current beam widths may prevent detection of fine features such as poles and wires and wire detection at oblique angles can be very problematic. Improved resolution may require a mono pulse capability for both azimuth and elevation angles. The radar cross-section of the target is independent of physical size; hence, an apparently large detection may result from an object of unimportant size (e.g., metallic corner reflector) and vice versa. Radars are usually designed to detect manmade features by removing radar clutter caused by reflections from the ground, however, for brownout landing surface recce, many of the features of interest, for example, ditches, rocks and berns may fall within the ground clutter. Effective techniques to process radar data to extract relevant, naturally occurring features will be required. A major current limitation is the generation of a suitable pilot display from the gathered radar data. Pure imagery from radars is unsuitable and a 3-D reconstruction of the terrain will be required to support synthetic vision.

4.4.1.3.4 System Maturity

Millimetre wave radars developed for existing applications such as missile seekers are mature, in-service and potentially available as CMOTS. However, their ability to meet the brownout landing requirements in terms of detection and scan capability is likely to be limited and require further development. Electronic scanning using phased array antennae is currently immature for this application. The Human Machine Interface (HMI) for radar derived pilotage displays is immature hence the sensor/display system TRL is low. Safety case arguments for radar derived synthetic vision systems are immature.

4.4.1.3.5 System Integration Issues

The radar sensor may require turret mounting/gimballing if the mechanical scan cannot cover the LZ adequately or accommodate aircraft attitude changes during landing, e.g., pitch. A wider field of regard may be required for “see-through” hazard detection around the aircraft during or after landing the aircraft. Alternatively, the sensor may be hard mounted on the airframe in a fixed orientation. The radar data will be complemented by precise aircraft position and height to enable a 3-D perspective, synthetic view of the outside world to generated and stabilised with aircraft motion. Sensor controls will need to be integrated into the cockpit together with suitable displays if not already fitted. The radar sensor should provide data which complements existing sensor capability, for example, some level of integration between radar image and Forward-Looking Infrared (FLIR) image could be anticipated.

4.4.1.3.6 Required Sub-Systems

Precision navigation system (e.g., an embedded GPS / Inertial Measurement Unit) together with precise height above ground level, display systems, head down or head up depending on CONOPS and certification level. The radar processor could be integrated within the sensor housing or a separate Line Replaceable Unit.

4.4.1.3.7 Human Factors

The key human factors issue is the generation of a suitable display from the radar and terrain database which is readily interpretable and provides adequate situational awareness to the aircrew to complete the brownout

landing safely. Features should be readily recognisable and classified, for example, terrain surface, wires, poles, hazards. The display could be used primarily by the NHP or presented directly to the HP. HOCAS control of the sensor should be provided. In addition, it provides crucial information for synthetic vision system.

4.4.2 Laser

4.4.2.1 LADAR Sensor System

4.4.2.1.1 Capability

A 3-D LADAR sensor system (sometimes also called LIDAR instead of LADAR) is capable of measuring the 3-D space in front of the helicopter in real time. This is done by time of flight measurements of single laser pulses which are typically scanned over the field of view of the sensor[1] . Each laser pulse results in a single distance measurement associated with the two scanning angles at that time. The rate for a complete scan over the field of view for typical systems is between 2 and 3 Hz. Therefore a highly accurate measurement of the landing zone and the elevated objects on the ground can be updated with a rate of 3 complete measurements per second. Due to the scanning nature, the short laser pulses, the enhanced beam aperture size and the selected wave length (typically 1.5 µm) most 3-D LADAR sensors are eye safe[2]. Typical detection ranges on real targets (like ground surface, houses, trees, etc.) are above 1000 m, typical detection ranges on wires (5 mm diameter as a reference) are above 600 m.

4.4.2.1.2 Strengths

3-D LADAR sensor systems have their strengths in generating a precise 3-D data set of the landing zone and the objects elevated above ground. This can be achieved by emitting a very well-defined focussed measurement beam. Beam divergence of typical systems is in the order of 1 mrad. In contrast to radar systems beam divergence can be altered by adapting the optical lenses without having a disadvantage in size or weight.

Accuracy of each distance measurement is typically between 10 cm and 60 cm. The limiting design factors are counter frequency for the time of flight measurement and beam divergence. The latter results in a finite footprint of the measuring spot which causes a blur of distance measurements on an inclined surface or object. The effect of beam divergence decreases the useful accuracy for targets further away and becomes the driving factor for a slanted measurement which is the case for a landing approach. 3-D LADAR sensors are currently the only available sensors which are capable to reliably detect wires in flight or in the landing zone. Due to the wavelength of the emitted electromagnetic energy (typically 1.5 µm) the backscatter from most objects including wires is mostly diffuse. Although detection range is reduced with reduced angle of incidence existing LADAR systems can detect wires down to almost parallel angles of incidents. Therefore the main advantage of 3-D LADAR systems is to serve as obstacle warning systems in flight phase while being in addition an accurate landing zone measuring device during final approach. Typical LADAR systems can reconstruct the ground surface in such a way that elevated objects like rocks can be reliably detected down to a size of 30 cm to 50 cm. The reconstructed ground surface has a very high accuracy in terms of inclination and local slope (better than 1°).

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[1] There are some upcoming systems which do all measurements at once using a single area qui laser pulse (flash) but they still do have issues with detection range and eye safety and are therefore left out in this evaluation.

[2] If a not completely eye safe LADAR is selected additional effort during integration and testing and for all maintenance tasks has to be taken into account.

Due to the scanning nature and the small beam divergence 3-D LADAR systems have a low probability of detection and a negligible probability of interception. A typical LADAR system may trigger a distant laser warner statistically approx. every 8 seconds on a direct hit. The distance could be up to several kilometres. Due to this statistical nature of scanning and short pulse hits there is no known technology being able to lock onto this signal for interception purposes. LADAR performance in rain as well as in snow fall is only slightly reduced, mainly by effects of atmospheric absorption.

4.4.2.1.3 Limitations

Being optical systems 3-D LADAR systems have a limited performance in fog, clouds, dust and snow. There are two effects which have to be overcome by an operationally useful LADAR system: first it has to overcome effects of self blinding; second it has to have the capability to detect targets within a cloud of obscurant. The first effect can be overcome by design (optical design and receiver management). The second effect typically needs the capability to trigger at least two but better multiple reflexes by one laser pulse. This allows for a limited look through capability through fog or dust. Typical values for the maximum detection range in an obscured medium are twice the optical visibility. That is to say at optical visibilities of 20 m a LADAR can detect objects up to approximately 40 m apart. Operational LADAR systems have to be hardened against effects of direct solar illumination. An operationally useful LADAR system needs to have algorithms to suppress solar images as well as solar reflections on snow or on water. Each LADAR system has several specific design parameters which result in a very complex interdependency on the desired effect. Therefore the parameters and the resulting requirements combination as a whole have to be considered for each specific application. For example, requiring a high detection range on a certain target without a specified detection probability is leading to the desired result. Therefore the optimal combination of system parameters for the specific task is essential.

4.4.2.1.4 System Maturity

There are LADAR systems on the market which serve as obstacle warning sensors for civilian and police forces. The next generation of LADAR systems with higher scan rates, increased field of view and field of regard is currently in the final stages of formal flight testing and will be available as series products by the end of 2010. These systems are foreseen for the European NH90 helicopters or as test systems for US SOCOM. They combine a LADAR sensor with complete data processing in one housing. Their intended use is currently obstacle warning and CFIT warning but the sensor as well as the implemented algorithms can also be used for situation awareness systems. Several prototype systems have been developed to a certain stage with the main focus on situation awareness in brownout.

4.4.2.1.5 System Integration Issues

Typical LADARs are comparatively large (bigger than 30 cm by 30 cm cross-section) and heavy (> 20 kg) sensors that have to be fitted in the nose of the helicopter or under the fuselage. LADARs need a free field of view in flight direction.

The typical power consumption is above 250 W if the data processing is included in the sensor. For the integration of LADAR systems it has to be taken into account that they require a certain stiffness of helicopter mounting points to avoid erroneous measurements. For the usage of a LADAR system a navigation system which is aligned to the LADAR is also needed. Command and control is typically performed via a control panel and/or via helicopter input pages. Output media for processed LADAR data are MFDs and/or helmet-mounted sights.

4.4.2.1.6 Required Sub-Systems

A LADAR system requires a medium or better high end navigation unit (e.g., EGI) with errors of the helicopter axes below 0.2° in each axis and velocity accuracies of 20 cm/s.

4.4.2.1.7 Human Factors

When used as a source for landing zone and obstacle visualization great care has to be taken on the generation of synthetic views. The LADARs as such give data points with a specific spacing that are rather crude and therefore are not suitable to be used for direct visualization of the complete scenery. Therefore the ground surface, i.e., the landing zone should be visualized as a rendered closed surface. Objects elevated above the ground should be classified to reduce the amount of data points shown. These classified obstacles can then, e.g., be visualized as conformal obstacle symbols. Objects elevated above the ground which do not fit to an existing obstacle class can then be visualized as data voxels in the synthetic view.

4.4.3 Passive Electro-Optical

For improved situational awareness in very low light, continuous low visibility and transient very low visibility such as brownout, imaging technology is driven towards longer wavelengths which are less attenuated by atmospheric obscurants. Further considerations are affordability of sensor technology and the necessity of a larger aperture size to achieve a useful spatial resolution. The size of the sensor together with the mounting system (e.g., turret) will impact the ability to mount it on the airframe in a suitable location.

All current imaging sensor technologies offer reduced resolution in comparison to the naked eye and this limits the ability to detect and recognise cues necessary for pilotage. Magnification optics can improve the ability to resolve fine features but results in reduced field of view, necessitating a steerable sensor system. The following passive electro-optic sensor systems are investigated:

- Visible Waveband or Low Light Camera sensor;
- Thermal Imaging sensor; and
- Passive MMW Imaging sensor.

4.4.3.1 Visible Waveband or Low Light Level TV Cameras

4.4.3.1.1 Capability

Visible waveband sensors cannot see through significant brownout but have been applied to look underneath the helicopter during the final stages of landing and touchdown. The dust is less dense here, giving the ability to detect hazards at the touchdown point and drift. Imagery from the cameras can be interpreted by a rear crewman and critical information relayed by voice to the aircrew.

4.4.3.1.2 Strengths

The system negates the requirement for a crewman to manually look under the fuselage during landing and improves safety. Visible wave band cameras are cost effective, small, lightweight, low power and straightforward to install. The imagery requires no additional processing to provide a readily interpretable image and does not create additional workload for the handling and non-handling pilot. The cameras view the aircraft undercarriage together with ground immediately below and enable the perception of drift and hazards such as rocks and ditches.

4.4.3.1.3 Limitations

The cameras cannot see through significant brownout and rely on a "doughnut effect" of downwash whereby dust is blown away from the aircraft leaving the area immediately below the fuselage relatively clear. This effect will be platform dependent. The cameras have limited resolution and ambient dust may reduce contrast such that fine details and micro texture are not easily detected. The look ahead angle of the camera provides a limited ability to recce ahead of the aircraft during approach, and its main use is for last segment of descent with minimal ground speed.

4.4.3.1.4 System Maturity

The technologies used in this system are very mature and available as Commercial Military Off-The-Shelf (CMOTS) and are being integrated as part of brownout solution (Germany).

4.4.3.1.5 System Integration Issues

The key integration issues are mounting the camera to the airframe with suitable power supply, and mounting a suitable NVG compatible display in the cockpit for the NHP or the rear cabin for operation by the rear crewman. In the latter case the display could be portable via umbilical cable.

4.4.3.1.6 Required Sub-Systems

A cockpit display sub-system is desirable to host the imagery for the NHP and avoid the mounting of additional displays in the cockpit. Power is also required.

4.4.3.1.7 Human Factors

The main issues are to ensure the NHP or rear crewman can operate and interpret the display system in all ambient light levels and communicate critical information to the pilot effectively.

4.4.3.2 Passive MMW Imaging Sensor

4.4.3.2.1 Capability

Passive Millimetre Wave (PMMW) imaging is a form of thermal imaging but operating at longer wavelengths, giving the ability to see through atmospheric obscurants such as cloud, fog and dust without active emission. Current technology operates at 94 GHz and exploits naturally reflected and emissive radiation to provide a readily interpretable image for the pilot, day or night.

4.4.3.2.2 Strengths

A PMMW camera can be combined with a simple display to provide a see through capability with imagery which can be easily interpreted and understood. The main source of contrast in a PMMW image is the sky, which has a very low radiometric temperature. Objects in the scene reflect this "cold sky" illumination to different extents, depending on their material composition and orientation. For example, fields, hedgerows, trees and manmade features are visible due to their different reflectivities in the MMW part of the spectrum. Grass tends to diffusely reflect the cold sky radiation, appearing cooler than ambient temperatures. Trees and hedgerows appear radiometrically warmer. Manmade features, particularly metallic objects such as vehicles, poles and cables have high contrast due to "cold sky" reflections.

4.4.3.2.3 Limitations

The wavelength of radiation at 94 GHz is 3.2 mm and this is orders of magnitude longer than used by infra-red (10 µm) or visible camera (0.5 µm) systems. The consequence of this is that, for a given camera size, the resolution of a PMMW sensor will be much lower than the resolution of an infra-red or visible camera. Increasing the optical aperture will increase the range at which an object can be detected by sharpening the beam width of the sensor. The limiting factor on this approach is typically the difficulty of deploying a large sensor. An aperture of 50 cm, gives an angular resolution is 0.45 degrees. In other words, at a range of 1 km, the spatial resolution of a sensor with a 50 cm aperture is approximately 8 metres; alternatively, the spatial resolution is approx 30 cm at 40 m range. Objects smaller than the spatial resolution can be detected if they have sufficient radiometric contrast with the background, however, they will appear as a single point, unless they have significant linear extent, for example cables. The large optical aperture results in a camera which cannot be integrated into existing turret systems and would require a bespoke mounting to the airframe.

4.4.3.2.4 System Maturity

Mechanically scanned PMMW systems have been flight demonstrated in a research and development environment and attained TRL 6. Significant further development would be required to improve the thermal sensitivity, spatial resolution and camera packaging to provide an exploitable system. In the longer term, the ultimate performance would probably offered by a staring array system, as with thermal imagers, or electronic scanning. In each case there are trade-offs in terms of cost and associated complexity.

4.4.3.2.5 System Integration Issues

The physical size of existing PMMW sensor systems presents an integration challenge on the airframe. The sensor could be hard mounted, assuming the field of view is large enough to preserve an adequate view of the ground during changes in aircraft attitude. Alternatively, the sensor could be mounted in a steerable turret. In both cases, there could be issues with nose mounting and ground clearance. The sensor packaging could be improved but a trade-off with aperture size and spatial resolution will remain. Integration with a cockpit displays systems and turret controls will be required, together with navigation systems if geo-pointing is required. The sensor requires an image processor unit which may be a separate LRU or integrated within the sensor itself.

4.4.3.2.6 Required Sub-Systems

A turreted PMMW camera system requires a suitable display sub-system and potentially information from a navigation sub-system.

4.4.3.2.7 Human Factors

A turreted PMMW system would be operated by the non-handling pilot who would conduct the recce and advise the pilot accordingly. Current imagery enables the interpretation of macro scale features with low workload, however, the limited spatial resolution makes it difficult to see fine features and micro scale surface texture. Greater workload is required to extract the detail need for landing, which may only be interpretable at very short range, if at all. Further sensor development is required to improve the clarity and fidelity of the imagery. The sensor has a large dynamic range which exceeds the dynamic range of most display systems. The imagery can be manipulated by the non-handling pilot to present the most readily interpretable form. The imagery could be displayed in a location visible by the handling pilot, however, any slew angle or magnification may make correlation with the outside world view (direct or via NVG) difficult and distracting.

4.4.3.3 Thermal Imaging Sensor

4.4.3.3.1 Capability

Thermal imaging sensors operating in the 3 – 5 µm and 8 – 12 µm Infra-red wavebands have effectively no see through dust capability. Some see through capability has been claimed in the very far IR (~ 20 µm) but only at very short range. The primary benefit of such sensors in brownout landings is to survey the intended landing zone during approach, prior to brownout, to ensure it is free of hazards and suitable for landing. Thermal imaging video cameras are commonly integrated within a turret system which can provide stabilisation and geo-pointing, together with switched optics or zoom magnification. Multiple sensors may also be distributed to provide a wide field of regard, fixed magnification for pilotage (Distributed Aperture System (DAS)). Sensor spatial resolution is improving with "High Definition" capability becoming commercially available. Turret imagery can be displayed on a head-down display and interpreted and manipulated by the non-handling pilot. DAS imagery would be displayed to the aircrew using Helmet-Mounted Displays (HMD).

4.4.3.3.2 Strengths

A turreted, high resolution, Gen 3 cooled IR video camera with magnification promises an improved day/night capability (compared to unaided eye and NVG) to survey an LZ before brownout occurs and before committing to land. DAS systems provide common IR imagery to both HP and NHP using lower performance but less expensive un-cooled technology.

4.4.3.3.3 Limitations

A turreted IR camera system requires a suitable mounting point, ideally on the nose of the airframe and integration with a suitable display and controls. Basic symbology is required to reduce the potential for disorientation at high magnifications. High resolution, turreted systems are expensive to procure and integrate. The concept of allowing the handling pilot to land from a head-down display will have certification/release to service issues. LWIR and MWIR cameras provide a "see-and-remember" capability and cannot detect dynamic hazards on the LZ. DAS systems cannot currently match the resolution of NVGs for night vision and rely on a complex visually coupled system with an integrated HMD. Furthermore, Thermal imaging is also limited by atmospheric moisture and performance can be severely limited by rain, cloud and damp terrain with little thermal contrast.

4.4.3.3.4 System Maturity

Turreted systems with high resolution IR cameras are available as CMOTS at TRL9. DAS systems are still in development and not available as CMOTS.

4.4.3.3.5 System Integration Issues

A turreted IR camera system requires integration with the airframe and a suitable display in the cockpit. Turret controls (e.g., pan, tilt, magnification, gain and offset) are also required. The turret may require integration with onboard navigation systems for stabilisation and geo-pointing, and with display systems if additional symbology overlays are required. The display system should be matched in terms of resolution, contrast and area to optimise the presentation of high resolution imagery. DAS requires a powerful image processor together with an integrated HMD and head tracker. An array of sensors, usually three, is hard mounted on the nose of the aircraft.

4.4.3.3.6 Required Sub-Systems

A turreted IR camera system requires a suitable display sub-system and potentially information from a navigation sub-system.

4.4.3.3.7 Human Factors

A turreted IR camera system would be operated by the non-handling pilot who would conduct the recce and advise the pilot accordingly. The imagery could be displayed in a location visible by the handling pilot, however, any slew angle or magnification may make correlation with the outside world view (direct or via NVG) difficult and distracting. Boresighting the camera with a fixed field of view close to 1:1 scaling would enable the display to be used by the pilot more easily. DAS systems using HMD provide a more immersive environment in which additional flight symbology is essential to reduce the likelihood of spatial disorientation.

4.5 HUMAN MACHINE INTERFACE/DISPLAY SUB-SYSTEMS

4.5.1 Head-Mounted Display

4.5.1.1 Capability

Head-mounted displays enable information to be presented in front of the pilot's eyes, reducing the need to look down at cockpit displays. HMDs can be modular, mounted to a conventional pilot's helmet, or fully integrated into a bespoke helmet system. It should be noted that there are existing helmets in use (e.g., NH90, Tiger) that have an advanced flight symbology system in place as well as some of the perquisite sensor system and have the potential to accommodate symbology system that are specific for brownout landing.

Unlike a fixed Head-Up Display (HUD) which is mounted in the cockpit, a head-mounted display enables information to be seen over a wide field of regard, which is important for maintaining all round situation awareness in helicopter flight. The addition of a head tracker enables further functionality, for example, a head-steered weapon sight, gun, recce sight, or earth referenced symbolic displays (conformal symbology).

4.5.1.2 Strengths

The major benefit is the availability of flight information whilst maintaining visual contact with the outside world, especially during critical manoeuvres close to the ground such as landing. The requirement to divert attention to head-down instruments is reduced significantly and as a result SA is improved. Modular HMDs provide a simple, lightweight, monocular, daylight readable display mechanism usually attached to a conventional flight helmet using the NVG bracket and projecting across and down in front of the pilot's eye. Night capability is provided by a different display module which is integrated with conventional NVG, producing the Display Night Vision Goggle (DNVG). This replaces the Day display module. The displays are monochrome with a field of view of approximately 25 degrees and enables flight instrument information to be presented head up using symbology similar to the fixed-wing HUD format. Integrated HMDs promise a wider field of view, colour and bi-occular or binocular capability using folded optics or visor projection optics integrated with a specialised helmet. For both types of HMD, different pages of symbology can be selected which are optimised to different tasks, for example, navigation, transit and low speed. Symbology is referenced to the head, i.e., it always appears in front of the pilot, wherever he/she looks. The addition of a head tracker which provides head-pointing angles and displacements allows symbology to be referenced to the aircraft and to the outside world. For example, aircraft referenced symbology could mimic a fixed HUD and

would only be visible when the pilot looked straight ahead. World referenced symbology allows symbols to be placed on the ground over a location of interest and would only be visible when the pilot looked in the direction of the feature. This opens up the possibility of increased SA of ground-based features, for example, friendly and enemy force locations, tactical exclusion zones and landing zones. A line of sight function also allows the HP and NHP to know in which direction the other is looking and aids crew communication.

4.5.1.3 Limitations

Modular HMDs provide separate day and night capabilities rather than a seamless day into night capability. The displays have to be manually changed over and performance may be sub-optimal during dawn/dusk transition periods. The narrow field of view and pixel resolution impact the quality and legibility of the symbology. Regular brightness adjustment is required to maintain contrast between the symbology and the outside world view. Current night display modules clip onto the objective lens of the NVG and symbology is projected through the image intensifier and viewed on the phosphor screen. This can be detrimental to the performance and longevity of the intensifier tube. The night display module adds about 60 g to the end of the NVG furthest from the head and requires additional counterbalance mass to maintain comfort and fit. Integrated HMDs can be expensive, heavy and require precise fitting to the head to maintain the exit pupil consistently and precisely. Night capability can be compromised compared to NVG due to inadequate display/sensor resolution and integration issues. For example, night vision capability has been provided on Integrated HMDs by using image intensifier tubes attached to the sides of the helmet with the imagery relayed optically or electronically to the display surface. However, the extended tube separation compared to inter-pupilliary distance causes hyperstereopsis which impairs judgement of height and distance. Head-up symbology can clutter the outside world view and obscure critical features, for example, wires or ditches. Poorly designed symbology can require excessive workload to interpret.

4.5.1.4 System Maturity

Modular HMDs are mature technology and currently in-service and deployed across many platforms operated by different Nations. One unique modular concept is still in development and uses holographic wave guide technology to provide a light weight day display with physical packaging that may enable NVG to be used in combination. This promises a single, colour display which provides a day into night capability, compatible with conventional aircrew helmets. Integrated HMDs continue to be developed. Some early versions are in-service but the capability is being transformed by the emerging availability of miniature, high resolution, flat panel displays and LED backlighting. Composite materials also enable weight reduction without compromising impact protection. Physical issues remain with the integration of image intensifiers although alternative night vision capability is becoming possible using imagery from aircraft-mounted sensors, for example, turreted or distributed aperture Infra Red or Low Light Level Cameras. In the past, display and sensor resolution were unable to match NVG but recent developments in High Definition sensors and displays promise significant improvements in image quality making it suitable for low altitude night flying and landing.

4.5.1.5 System Integration Issues

Head-mounted displays require integration with the helmet and sufficient mechanical adjustment to achieve alignment with the eye and exit pupil. A separate display processor is used to generate the symbology and must be integrated with aircraft systems to provide, for example, barometric height, radar height, heading, airspeed, ground speed, torque and sideslip. Low speed symbology will require drift information which may not be available from legacy aircraft avionics. In this case additional sensors, such as an Inertial Measurement Unit (IMU) will be needed. Symbology will be continually manipulated by the pilot, for example, symbology

pages, de-clutter and brightness, which requires Hands On Collective and Stick (HOCAS) control. Additional controls such as built in test may be console mounted. Head-mounted displays will be provided to both aircrew and require quick release connectors in the cabling to enable rapid egress in emergencies. The current most mature head-tracker technology uses alternating electromagnetic fields and requires a detailed survey and mapping of the cockpit environment. A Boresight Reticule Unit (BRU) is mounted in the cockpit (usually on the combing or window frame) and used by the pilot to align the head tracker. Low speed symbology such as the velocity vector, indicating aircraft drift, are only as good as the data the sensor provides. Doppler velocity has been found to be inherently latent and cannot provide sufficient update rate to enable a usable velocity vector for landing. Data from an IMU should be used for low speed symbology where possible. The usability of conformal symbology is highly dependent on a precise navigation solution (horizontal position and height) and optimal integration to reduce system latency.

4.5.1.6 Required Sub-Systems

HMDs require a display processor, HOCAS and console controls together with integration with aircraft sub-systems to provide the information to be displayed. These may include the navigation system, airdata computer, Radar Altimeter, engine management system and IMU. On helicopters with modern avionics much of this information will be available on a data bus.

4.5.1.7 Human Factors

Mechanical adjustment of the head-mounted display is essential to ensure correct alignment with the eye. The head-mounted display should not cause excessive head-borne mass and when integrated with the helmet should not impair the balance, comfort and fit. Symbology should be carefully designed to minimise workload associated with its interpretation. Due to the cognitive effort and instrument scan required by some symbology designs, an instrument flying control strategy can be induced which draws attention to the symbols at the expense of the outside world leading to reduced situational awareness. Conformal symbology attempts to put the symbols in the outside world and encourage the pilot to use natural and artificial cues together to preserve a visual flying control strategy.

4.5.2 Symbology

Symbology for approach to landing, hover, and take-off can be presented on a panel-mounted or head-mounted display and provides additional information which may help to reduce spatial disorientation during zero speed landings. The symbology can be divided into 3 different formats:

- **2-Dimensional Low Speed Symbology:** Graphical information provided in plan view with a central aircraft reference, a dynamic velocity vector giving explicit fore/aft and lateral drift velocity, acceleration ball and a dog house symbol indicating the intended landing point on the ground. The velocity vector/acceleration cue is of primary interest for LVL as it provides ground speed and drift information.
- **3-Dimensional Conformal Landing Symbology:** Perspective graphical symbology provides conformal (earth referenced) cues for the landing position together with the ability to extract aircraft fore/aft, lateral and vertical closure rate from the differential motion between the cues. This cueing mechanism is analogous to the use of real-world features to judge relative position and motion of the helicopter. 3-D symbology is presented on a HMD and requires a head-tracking system to allow the symbology to be drawn in the correct location on the earth and hence de-coupled from the pilots viewing direction. An additional conformal symbol is the Flight Path Marker (or Vector) which provides a look ahead of the aircraft's future position against the outside world view based on an

instantaneous extrapolation of aircraft state. Conformal symbology can provide an explicit landing point reference, on the ground, to aid navigation and approach path.

- Combination of 2-Dimensional and 3-Dimensional Symbology.

4.5.2.1 Two-Dimensional Symbology

4.5.2.1.1 Capability

Low speed symbology has been specifically developed to aid helicopter landing and consists of additional 2-D graphical elements which provide scaled indication of acceleration, drift, ground speed, rate of descent and rate of closure towards a pre-planned landing point. The symbols, which may include the velocity vector, acceleration cue, vertical speed indicator, "rising deck" height above ground and landing point are added to the conventional flight symbology and tailored to the dynamic handling qualities of the platform. For a visual approach a frequent switch between head-out and head-in must be avoided and multiple simulator trials have shown the most effective presentation from a flight safety perspective is through a head-mounted display to the handling pilot. Therefore a head-mounted display, for example using a Display Night Vision Goggle or Helmet-Mounted Day display module is the preferred solution. (Newer helicopters may be equipped with more sophisticated integrated helmet-mounted displays which only require the addition of the low speed symbology, e.g., TopOwl helmet or JedEye Helmet). The head-mounted display enables the symbology to be used continuously during the final approach whilst maintaining visual contact with the landing point on the ground and allows any available visual outside world cues to be used when the brownout envelopes the aircraft. Note that if the outside world becomes obscured this leads to an Instrument Flight Rules (IFR) landing which is not the preferred procedure with 2-D symbology.

4.5.2.1.2 Strengths

Low speed symbology can be implemented by enhancing existing flight symbology that is already in service on several helicopters in several Nations[3] on both head-down and HMDs. The symbology has minimal additional processing demands and consists primarily of rescaled existing symbols with few additional, new symbols. Improved aircraft data sources may be required, for example, an IMU. A number of research programmes have investigated the adaptation of flight symbology to the low speed landing task and demonstrated the resulting capability in simulator and flight trials in DVE.

4.5.2.1.3 Limitations

The low speed horizontal acceleration cue symbol is used as a predictor for the horizontal velocity vector symbology. The acceleration cue symbol requires careful scaling to the platform flight dynamics and control system. In other words, how much the symbol moves on the screen per unit of horizontal acceleration must be tailored to each type airframe. Vibration noise on the acceleration signals must also be filter out, without over-filtering and causing excessive delay. Flight control damping or augmentation will improve pilot performance and decrease workload when using 2-D low speed symbology. However, when such symbology is implemented on legacy helicopters with conventional flight control systems, the 2-D velocity vector/ acceleration cue symbology requires additional training[4], induces increased workload and limited task precision until the pilots are fully accustomed with it. Current low speed symbology may cause "cognitive

[3] For example, the AH-64, MK-41.

[4] Most Nations give their pilots 8 to 15 hours for the primary training then about 15 additional hours to fully acclimate.

capture" where attention is drawn away from the background because the instrument scan necessitates significant interpretation. There is also the possibility of "coning of attention" where the pilot becomes concentrated on one specific indicator to the detriment of other symbols and general SA. This may also lead to a modified control strategy similar to instrument flying.

4.5.2.1.4 System Maturity

The maturity of 2-D low speed symbology is high with one configuration already in service, for example, Pilot Night Vision System (PNVS) and DNVG on AH 64D. Low speed symbology optimised for legacy platforms is less mature and currently the subject of several research programmes.

4.5.2.1.5 System Integration Issues

The symbology requires a minimum update rate and accuracy to work well; implementations of the velocity vector using Doppler velocity have proven to be ineffective due to a long latency/update delay. Symbology driven from GPS/IMU is preferred where possible. Modern cockpit displays, such as MFDs, with primary flight symbology may be modified to accommodate low speed symbology. If the cockpit is based on analogue avionic an additional head-down, digital display will be required. Preferably, the symbology is presented head up through a HMD. The low speed symbology system uses different modes or "pages" which can be manipulated by the pilot to adapt the symbology to the level of visual degradation, for example, de-clutter. The method of switching between different modes should minimise any possible distractions and the need to remove the hands from the control levers. The velocity vector and acceleration cue symbology should be harmonised with the aircraft flight dynamics to provide a usable response without the risk of Pilot-Induced-Oscillation (PIO). The minimum requirement of using low speed symbology system in the helicopter is a flight control systems with a good rate damping. However, flight control systems with high levels of augmentation such as attitude command/attitude hold together with height, heading and position holds are additionally preferred.

4.5.2.1.6 Required Sub-Systems

Low speed symbology can be driven from conventional avionics (if digital data are available – often legacy aircraft provide only analogue data), for example, air data, gyros, barometric height, radar height, Doppler velocity can be presented on existing head-down or head-up displays. However, the usability of the symbology may be compromised by slow update rates and excessive latency as mentioned earlier. These limitations can be resolved by sourcing data, particularly for the velocity vector and acceleration cue, from a GPS/IMU, and precision navigation system.

4.5.2.1.7 Human Factors

The use of low speed symbology for landing requires introductory training to develop an effective **instrument scan**. This is because key elements such as horizontal position/velocity and vertical position/velocity are separate entities on the display and must be interpreted together with the view of the outside world. It may require a great deal of attention and workload to visualize and interpret the symbology, particularly if the helicopter has no additional stability augmentation. For example, controlling the horizontal position/velocity may leave insufficient resources to attend to the vertical position/velocity leading to loss of situation awareness and task precision. The potential for loss of SA can be lessened when the symbology is presented using a head-up display controlled with HOCAS. Low speed symbology often results in an instrument flying style of control strategy.

4.5.2.2 Conformal Landing Symbology

4.5.2.2.1 Capability

Conformal, or earth referenced symbology consists of three-Dimensional graphical symbols which provide perspective cues, anchored over the outside world view and presented on a head-tracked, head-mounted display. The concept attempts to mimic 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.

4.5.2.2.2 Strengths

Conformal symbology allows the pilot to retain a conventional, visual flight, control strategy. Such a system provides an intuitive cueing mechanism. In one study in the UK the conformal symbology and has been demonstrated to reduce workload and increase task consistency as compared to low speed, 2-D symbology displays (comparing Ferranti-LVL to the AVS-7 symbol set). However in another study in the US, the opposite was recorded (comparing BOSS to the BAE-LVL). The concept may be more suitable for legacy platforms with conventional flight control systems. The symbology can be utilized continuously when brownout appears.

4.5.2.2.3 Limitations

The usefulness of the symbology is dependent on the accuracy and consistency of the registration against the real world. For example, symbols representing the ground versus real-world ground must be congruent if you have to land on a heightened LZ in order not to have multiple lines and misleading information. This demands a minimum performance and optimal integration of specific, additional avionics systems including GPS/INS, head-tracker and precision radar altimeter. For landing, the use of conformal symbology may change the conventional instrument scanning strategy as the symbology is displayed virtually, ahead of the aircraft. The concept of operation for conformal symbology is relatively immature. As the symbology will be relied upon during brownout it is likely to require certification as a primary flight display or shown to have a risk benefit ratio analysis based on As Low As Reasonably Practical (ALARP) with acceptable operational benefit. Controllability of the aircraft as compared to a modern (non-AVS-7) two dimensional low speed symbology set remains to be tested. In the case of the pure conformal symbology set, the pilot must see multiple frames of video to perceive horizontal or vertical velocity adding delay compared to 2-D symbols which present the information in each video frame. Horizontal acceleration information is difficult to perceive directly from viewing multiple frames of video of conformal symbology, whereas it is shown directly in each video frame on modern 2-D symbol sets (such as AH-64 and BOSS, and missing on AVS-7). The conformal symbology position information is therefore two derivatives behind the acceleration information directly viewed with 2-D symbology. However, the comparison is more complex. The brain interprets the rate of change of position information in the conformal set quickly and more naturally compared to 2-D symbology. In addition, aircraft attitude seen in each frame of the conformal symbology set is a rough predictor of horizontal acceleration. Controllability of symbology sets is a complex issue that must be further tested. Another issue with conformal symbology is that the layout of the conformal symbology must be done with care. If important symbols appear behind the instrument panel or other aircraft structure, the direction of view of the conformal symbols may drive the pilot to look inside the cockpit more often than with 2-D, non-conformal symbology. A further issue is what occurs with conformal symbology when the aircraft makes a hover-turn maneuver, for example to point the nose into the prevailing wind. Conformal symbols that were once in front on the aircraft may end up off to one side, or even behind the aircraft.

4.5.2.2.4 System Maturity

Based on recent research activities the technology readiness level of the conformal symbology system has been demonstrated in flight and simulation at about TRL 7. Additional risk reduction will be required to integrate the system with target platform avionics, for example, the head tracker requires mapping into each platform type.

4.5.2.2.5 System Integration Issues

Conformal symbology is more complex to generate and requires optimal integration between the display generator, head-tracker, display module, precision navigation system and dust penetrating radar altimeter to minimise system latency. Although the data may be available on existing aircraft data buses, the update rate may be insufficient and discrete, high speed serial data links (e.g., Arinc 429) may be required for effective data transport. The conformal symbology system latency is the delay between movement of the aircraft or pilot's head and the corresponding movement of the symbology to maintain it on the ground correctly. Excessive latency can manifest as unwanted movement in the symbology, for example, symbols being dragged across the ground rendering them unusable. Conformal symbology system flight trials and previous research has determined a preliminary key system requirement for acceptable system latency. Excessive mis-registration of the symbology due to position or height errors will reduce confidence in the system and also render it unusable. A boresight reticule unit is required to enable alignment of the head tracker with the aircraft axis and navigation system reference frames. The effects of aircraft and head vibration must be managed to allow the symbology to be displayed clearly without jitter. Conformal symbology should be presented to both HP and NHP to enable effective crew communication.

4.5.2.2.6 Required Sub-Systems

A conformal symbology system makes use of a head-tracker, helmet-mounted display (e.g., DNVG or day display module or an integrated helmet system), display generator (with terrain database), precision, dust penetrating radar altimeter (e.g., millimetric wave) and precision navigation system such as GPS/INS. A bore sight reticule unit is required to align the display system. A precision height sensor is required for the latter stages of final approach. HOCAS is preferred in order for the pilot to alternate between the display modes, declutter and adjust the symbology brightness with minimal distraction.

4.5.2.2.7 Human Factors

Recent flight and simulator trials have proven the viability of the concept and indicated conformal symbology appears to be relatively easy to learn, could be intuitive to use, provides increased task performance and consistency with reduced workload compared to 2-D low speed symbology. The format of the conformal symbology is key to providing sufficient cueing throughout the approach and landing without cluttering the display. The ability to dim the symbology is also important to reduce the potential obscuration of real-world cues.

4.5.2.3 Synthetic Vision

4.5.2.3.1 Capability

Synthetic vision is the construction of a 3-D 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. Terrain databases are inherently

inaccurate and incomplete, hence, SV systems are not reliable for low altitude operations such as landing. To overcome this deficiency, research programmes have investigated the use of sensor information to update the database in real time and enable a more accurate 3-D image to be generated. Active ranging sensors such as millimetric wave radar or LADAR can provide a higher resolution terrain surface, features and hazards which when combined with the underlying terrain database may be used to generate a 3-D scene with sufficient fidelity and accuracy to be used for landing. If non-dust penetrating sensors are used the capability will be "see and remember" with no new data being added once brownout envelopes the helicopter. The 3-D scene will continue to reflect aircraft movement but will be based on historical data and not include, for example, dynamic hazards. If dust penetrating sensors are used the capability will be "see through" and the 3-D scene continually updated during brownout. Two concepts of operation have been proposed for SV assisted brownout landings; the 3-D scene is presented on a head-down display to the NHP who relays information to the HP; the 3-D scene is presented directly to the HP using a HMD.

Infra Red still cameras have also been used to generate SV (Photographic Landing Augmentation System for Helicopters (PhLASH)) whereby multiple auto-focus high resolution cameras are situated around the platform and the outputs processed to produce a 3-D perspective image of the scene which is updated using aircraft position. The scene is continually updated until brownout obscures the camera view, whereupon the last good scene is adjusted for aircraft movement and used by handling pilot to land the aircraft. The scene was presented on a head-down display.

4.5.2.3.2 Strengths

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.

The still IR camera technique promises the production of an image which provides sufficient pilotage cues to land the aircraft in brownout.

4.5.2.3.3 Limitations

Synthetic vision systems are formed from the integration of sensors, database and display generator and the capability of each technology will determine the overall effectiveness of the system. Millimetre wave radar (77 – 94 GHz) has a "see through" capability but limited resolution and is unlikely to detect fine features such as poles and wires. Furthermore, extracting some features such as ditches from general radar clutter from the ground may be problematic. LADAR has much greater resolution and mapping performance but cannot penetrate dust reliably, hence, provides a "see and remember" capability. Data from either sensor must be combined with the terrain database and processed to provide a 3-D scene which can be rendered by the display generator with minimal latency. Updates from the sensors should provide a smooth transition into the 3-D scene without unpredictable jumps which reduce pilot confidence. The render must provide a readily interpretable image with cues such as texture which support visual flying. Sensing, processing and presenting suitable imagery with sufficient update rate to support pilotage may be challenging with current technology. Certification of SV technology as an aid or as a primary flight system has not yet been investigated.

The still camera approach requires the scene to be observed from a number of directions (e.g., to circle the landing point) prior to the onset of the brownout, before attempting the landing. The technology is currently novel and in the development phase.

4.5.2.3.4 System Maturity

Simple SV systems based solely on a terrain database are mature technology as SA aids for civil aviation but are unable to support low altitude and landing tasks in austere environments. SV systems using active sensors are in the development stage with some sub-systems having been flight tested. Radar and LADAR technology has been adapted from existing applications, for example, missile seekers or obstacle warning systems in order to investigate the ground mapping/recce capability required by an SV system. An SV system capable of aiding brownout landing is considered to be at least 3 – 5 years away.

The still IR camera approach has been demonstrated in a flight trial, but there remain significant tactical issues with this concept. The concept has been assessed as being TRL 5 but is no longer being pursued by the US government.

4.5.2.3.5 System Integration Issues

The main integration issue is how to extract and manipulate active ranging sensor data into a form that is readily understood by a pilot in a high workload environment. System latency, for example, the delay between detecting a feature and its subsequent display to the pilot will be a key challenge. A greater latency may be acceptable for a NHP display than a HP display. The SV system will require a precision navigation solution including accurate height above ground; the data may be accessible on a standard data bus but in order to guarantee an acceptable update rate may require high speed serial data links. It is unlikely the 3-D scene will provide all the cues required by the pilot for the landing task and should be compatible with low speed or conformal symbology. The forward looking radar or LADAR sensors should be mounted on the nose of the airframe and may compete with other sensors such as turreted FLIR. Depending on the field of view the sensor may need to be gimballed to allow the entirety of the LZ to be surveyed and to accommodate changes in helicopter pitch attitude during landing. If the 3-D scene is presented to the HP on an HMD, the imagery will need to be stabilised and de-coupled from head movement, necessitating a head tracker. The SV system should also be compatible with existing head-borne equipment such as NVG unless the 3-D scene is of sufficient quality and integrity to meet all night vision requirements currently met by NVG.

A still IR camera system requires multiple cameras to be mounted around the airframe and connected to a central processor which generates the 3-D scene. The processor will be integrated with a cockpit display system, which provides a suitable display and controls to the handling pilot. The processor is also integrated with the aircraft navigation system and will require data with specific update rates, accuracy and resolution to ensure the 3-D scene moves smoothly with aircraft movement.

4.5.2.3.6 Required Sub-Systems

A SV system will require a powerful display generator for image rendering, precision navigation system including RadAlt and terrain database, together with display sub-systems including head-down or HMDs. SV control will require HOCAS. If the system is to be relied upon then dual or triple redundant systems may be required. A still IR camera system requires support from a precision navigation system (e.g., Embedded GPS/Inertial system (EGI)).

4.5.2.3.7 Human Factors

The key HF issue is the interpretability of the synthetic image presented to the aircrew. In simple terms, the synthetic image should replicate the characteristics of the naked eye or imaging sensor view of the outside world already familiar to aircrew, i.e., readily interpretable and intuitive. The dynamics of the display should

reflect aircraft motion smoothly and accurately but be insensitive to sensor noise or sporadic detections. The display may have to accommodate late detection of obstacles which are only resolved by the sensor at close range. The closure rate to the terrain and obstacles should appear realistic, believable and predictable. The render used to cover the terrain database should include texture cueing to provide attitude and closure rate cues with levels of detail increasing as range reduces, such that rate of descent and drift can be easily perceived and understood. The SV image should be compatible with existing night vision equipment.

During brownout the still IR camera techniques will present frozen imagery of the LZ corrected for aircraft movement and is unlikely to be perceived as real imagery. The image manipulation may reduce the spatial resolution and degrade the cues available for pilotage.

4.5.3 Tactile

4.5.3.1 Capability

Tactile displays make use of vibrating elements ('tactors') to relay information to the skin (a well-known example is the vibrating function of a mobile phone). The development of (military) tactile displays has aimed 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 to the other channels. Research has been undertaken primarily by the Unites States Army Aeromedical Research Laboratory (USAARL) and TNO Netherlands to investigate the use of tactile displays as a countermeasure for spatial disorientation and to aid drift awareness during landings in DVE.

4.5.3.2 Strengths

The technology is "eyes and hands free" and requires negligible workload to interpret. Recent research has explored the use of tactile displays to aid approach to hover in DVE with encouraging results: flight trials have shown significantly less drift errors during the hover together with subjective improvements in perception of drift, situational awareness and mental stress. Approach to hover tasks in DVE were achieved quicker and with improved handling qualities ratings when using tactile cueing compared to using flight instruments. Actual landings (touch down) and zero speed landings were not completed.

4.5.3.3 Limitations

Tactile cueing provides no indication of the outside world or explicit indication of the landing point hence additional visual cues may still be necessary. Tactile cueing technology is limited primarily by system maturity, system integration and human factors issues. Tactors are typically implemented in a vest or additional layer of clothing the pilot wears which can add to their heat load in arid climates. This additional heat load outweighs the benefit of the tactors and some pilots prefer a cooler ensemble to additional SA.

4.5.3.4 System Maturity

Several systems have been developed primarily for research purposes. US AAFRL, Ft Rucker have developed a tactile vest, TSAS (Tactile Situation Awareness System) which has been simplified to form TSAS Lite, consisting of a single belt which provides simple drift cues to the pilot. The system has been evaluated in a UH-60 simulator and on a UH-60 flight trial. The ruggedized trials fit is not considered production ready. TNO Netherlands have independently developed a tactile torso display vest and a simplified version called

"Flytact" which uses a single belt and single vertical line of tactors up the back. The Flytact system currently remains in prototype form.

4.5.3.5 System Integration Issues

Further research is required to understand how tactors should be integrated into (existing) flight suits and/or the pilot's seat, and how it should be consistently aligned to the aircraft axis. Potential discomfort induced by additional tactile clothing, for example heat stress, requires further investigation. Tactile cues rely on accurate drift and height information from suitable sensors which it is assumed the aircraft is already equipped with. Additional avionics, for example a dust penetrating RadAlt and Inertial Measurement Unit may be required.

4.5.3.6 Required Sub-Systems

The tactile display uses data from aircraft systems, for example, RadAlt, Doppler Velocity or Inertial velocity.

4.5.3.7 Human Factors

Further research is required to understand how well pilots perceive tactile cues under heat stress, helicopter vibrations (whole body vibration), severe workload or stress and over long periods of flight time (desensitisation). The optimal configuration (numbers, spacing, frequency, amplitude) of tactile cues for landings requires further development. The training burden is not well understood and the complementary use of tactile displays with existing aircraft visual and audio displays requires further investigation.

4.6 FLIGHT CONTROL

4.6.1 Automatic Flight Control Systems (AFCS) with Advanced Flight Control Laws

4.6.1.1 Capability

Most legacy helicopters are equipped with analogue AFCS with conventional flight control laws based on rate command or attitude command/hold, both of which rely on the pilot's ability to perceive and use visual cues to stabilise and control the aircraft. AFCS with advanced control laws provide additional handling qualities, compared to visual landing aids, which improve the precision and ease of control of the aircraft by the pilot. This releases attentional resources which may enable more effective interpretation of visual displays and available visual cues, thereby increasing situational awareness. Improved aircraft handling results from improved flight control laws implemented in a digital architecture, for example, attitude command attitude hold, translational rate command, hold functions for heading, height, speed and hover together with the ability to "beep trim" height reductions slowly in the hover down to landing. Ultimately, advanced control laws coupled to a precision navigation system and suitable sensors, may provide a "hands free" automatic transition to hover and landing capability.

4.6.1.2 Strengths

Advanced control laws may reduce the likelihood of the aircraft entering into a brownout situation by providing increased control and ability to consistently achieve the approach gate parameters and execute an accurate zero speed landing, staying ahead of the dust cloud until touch-down. The potential for spatial disorientation may be reduced through greater platform stability; the aircraft should not drift significantly and attitude maintained more easily.

4.6.1.3 Limitations

Unless coupled to a navigation and display system, advanced control laws do not improve the guidance cueing so the pilot still needs to see where the aircraft is going, i.e., the LZ and LP. Once in brownout, a pilot could still succumb to spatial disorientation. Advanced control law functionality may support landings from a high hover using the height trim. However, a descending hover in sustained brownout will reduce situation awareness and increase erosion of airframe and engines. The functionality is also dependent on the accurate and reliable function of key sensors such as radar altitude and may not be certified for operations in sustained brownout. There is currently insufficient evidence to quantify the operational benefit of advanced control laws during brownout landings.

4.6.1.4 System Maturity

Advanced flight control laws are entering service in a digital implementation of the AFCS on the Chinook CH-47F and are therefore available for new buy platforms. Upgrading legacy platforms is more challenging due to complex system integration issues.

4.6.1.5 System Integration Issues

Advanced flight control laws form part of the primary flighty control system and are designed to safety critical software standards, are platform specific, and are deeply integrated into the rotorcraft AFCS. Full authority systems may require modification of the control actuators and will be integrated with the cockpit display system to enable monitoring and control of the AFCS functionality. Further integration with a precision navigation system provides coupled capability, for example, to automatically fly to pre-planned waypoints. Upgrading legacy aircraft with advanced flight control laws is therefore a significant integration task; a new buy of platforms may be a more cost effective and timely method of achieving this capability, for example, Chinook Ch-47F Digital AFCS (DAFCS).

4.6.1.6 Required Sub-Systems

Advanced control laws will be integrated with the AFCS processor, mechanical flight control systems, precision navigation system including height, cockpit display systems and HOCAS.

4.6.1.7 Human Factors

Advanced flight control laws provide additional stability to the platform and reduce the reliance on visual cues by the pilot to maintain stability and control of the helicopter. Workload should therefore be reduced. Advanced flight control laws provide different modes of operations and an additional training burden will be required to ensure the pilot is familiar with the functionality of the system. HOCAS should be used to manipulate the system together with visual displays to confirm mode entry. The functionality does not increase situational awareness directly but may reduce the workload associated with aircraft control sufficiently to allow greater attention on the interpretation of the displays and visual cues available. A method of identifying the LZ and LP.

4.6.2 Haptic Cueing with Active Sidesticks for Helicopter Operation

Today's state-of-the-art pilot assistance systems in helicopters are a combination of advanced visual information provided through head-down and helmet-mounted displays with intelligent flight control augmentation up to autopilot functions, and limited oral warnings. The advanced active flight controls, made

possible by full authority fly-by-wire technology, allow tuning the helicopter handling characteristics according to the pilot's needs and abilities in the specific operational situation. Complex display symbology enhances situational awareness and guides the pilot when outside references are insufficient.

This classical approach can be extended to the haptic information channel by the use of active inceptors. While the visual channel is loaded with information to the maximum, and experience has shown that oral warnings are the first information to be ignored by the pilot in high stress situation, it has been observed that information provided through the haptic channel is easily detected by the pilot, even in high stress situations. In addition a great advantage is that the pilot can keep his head up to look out of the cockpit. The force-displacement characteristics of active inceptors can be dynamically varied, allowing the optimization of the flight control mechanical characteristics depending on the underlying response-type (Rate Command, Attitude Command, etc.) and flight regime (hover/low speed against forward flight). It is known from first flight tests that the adaptation is highly recommended to get optimal results with respect to pilot workload and handling qualities. Another possibility of active inceptors is to indicate aircraft system limits to the pilot. These can either be soft boundaries, where the pilot feels a limit on the stick but has the possibility to overrun the cue (soft-stops), hard stops that equal a hard limit of the control input, or a more general warning function such as a stick shaker.

Every critical limit that will be reached when increasing a control input can be indicated. Possible applications are a torque limit indicator (1st limit indicated through soft-stop on collective inceptor) or mast moment protection (soft-/hard-stop on cyclic stick). Monitoring the mast moment is especially important when performing slope landings. Increasing the safety of flight can be achieved by flight condition indications, such as a descent rate indicator (soft-stop on collective inceptor), a horizontal drift indicator (force on the cyclic stick) or a flight path guidance function (guidance by motion of the sticks). It is also possible to indicate the violation of a safety distance around an obstacle. Reduced structural weight and improved component life can be achieved by indicating through a soft-stop that peak loads are reached, especially interesting during maneuvering flight.

The active inceptors can either be an active classical long pole collective and center-stick, or two active short pole side-sticks for both the collective and cyclic control, mounted on the right and left side of the pilot's seat. One advantage of sidesticks is a much more ergonomic seating position leading to reduced fatigue. And since there is no control stick in front of the pilot, the probability of abdomen and thorax injuries in case of a ground impact (CFIT, etc.) is significantly reduced.

The U.S. Army and the DLR both operate experimental helicopters equipped with active inceptors. The U.S. Army AMRDEC RASCAL helicopter features an active collective and active center-stick, the DLR EC 135 FHS has two active sidesticks. Both organizations commonly work on the active inceptor technology within an U.S.-German MoU on Helicopter Aeromechanics. In the USA, the UH-60M upgrade will be equipped with active long pole collective and center-stick, for the CH-53K it is still in discussion which combination to implement. Most probably it will get an active long pole collective and an active short pole side-stick for cyclic control. First flight tests with the DLR FHS indicate that yaw control can also be performed by lateral movement of the left hand sidestick, making it possible to eliminate the pedals. The left hand sidestick would than combine collective and yaw control.

4.6.2.1 Capability

Haptic cueing exploits the human sense of touch by applying forces, vibrations and/or movements to, for example, controls held by the pilot's hands. An example is the control shake experienced directly from the control surfaces during the stall in non-servoed, fixed-wing flight control systems. In larger, served controls

systems, this important haptic cue cannot be felt directly so is simulated using a mechanical stick shaker using sensor data such as angle of attack and airspeed. Haptic technology has been applied to sidestick controllers used with digital fly-by-wire flight control systems, for example, in the Airbus A380. The technology is mature in commercial applications such as mobile phone vibrators and virtual reality games to complement visual displays. In the context of helicopters, research has investigated the use of haptic technology with advanced flight control systems to improve perception of, for example, torque limits (e.g., collective "soft stops" and "force feedback" used with care free handling systems) and flight path guidance. The cues can be generated electromechanically, for example, vibratory motors with an offset mass or piezoelectric actuators.

4.6.2.2 Strengths

The technology is very similar to tactile technology covered in Chapter 4 and is "eyes free" with negligible workload needed to interpret the cues.

4.6.2.3 Limitations

The technology requires integration with the control levers together with relevant sensors and processing to provide information to be displayed. Early actuator technology had a limited range of sensations but emerging techniques, such as piezoelectric, offer a wider range of effects and more rapid response times. The technology may be best suited to aircraft state information such as speed, height and drift, and may not be able to represent more sophisticated information such as obstacle proximity or recognition.

4.6.2.4 System Maturity

Haptic technology is mature for existing applications but as an aid to brownout landings, the system maturity is considered low. The actuator technology maturity is high but the strategy to present height and drift cues for helicopter landings is immature and the overall effectiveness for the task not understood.

4.6.2.5 System Integration Issues

The actuator technology must be integrated with the control sticks and driven from a central processor unit which is integrated with the navigation system.

4.6.2.6 Required Sub-Systems

Navigation system.

4.6.2.7 Human Factors

The cueing strategy, i.e., nature of the cue in terms of frequency, amplitude or movement and how this represents flight information such as drift magnitude, direction and rate of change must be designed to be readily interpretable. Although more modern actuator technology can provide a greater range of cues, more complex cues will require greater interpretation, training and workload to use effectively. The technology is ideally suited to HOCAS systems.

4.6.3 Dimensional Audio

4.6.3.1 Capability

Sound can be manipulated so that when played through stereo headphones it can be made to appear to emit from a controllable direction. The ability to spatially locate sound cues around the pilots head in both azimuth

and elevation can be used to improve speech intelligibility and enhance situation awareness, for example, spatial separation of radio communications channels. The addition of a head-tracking system enables audio cues to be placed in the world independent of head and aircraft movement. With the suitable additional sensors, audio cues can be used to provide the bearing to the real-world features such as obstacles or friendly/ enemy force locations.

4.6.3.2 Strengths

Audio cueing may lessen the load on the visual channel and provide an intuitive mechanism to relay spatial information, for example, direction of drift or proximity of obstacles around the aircraft. 3-D audio can complement visual displays by providing an initial cue to the direction in which to look, which has been shown to reduce target acquisition time in weapon aiming studies. Range information can be portrayed by changing the frequency or pulse repetition rate of the audio cue.

4.6.3.3 Limitations

3-dimensional audio provides a display system only and additional sub-systems are required to provide relevant information to be displayed. The audio cues do not provide recognition of features. Multiple, simultaneous cues may lead to confusion. Certification issues yet to be determined.

4.6.3.4 System Maturity

3-D audio systems have been developed and demonstrated in various research programmes but is not established as a mature avionics technology. The application to brownout landings, for example, height and drift indication, is immature.

4.6.3.5 System Integration Issues

The audio system requires integration with head-tracking, navigation and obstacle detection systems. The audio cues must be compatible and integrated with existing cockpit audio warnings.

4.6.3.6 Required Sub-Systems

Head-tracking, navigation (aircraft ground speed, height and drift), obstacle detection systems.

4.3.6.7 Human Factors

The cueing strategy must be optimised to ensure minimal workload associated with the interpretation of cues. Audio cues may be missed during periods of high workload/stress in the cockpit. The accuracy and resolution of the cue spatial separation depends on producing a Head-Related Transfer Function (HRTF) by measurement of individual pilots. The effectiveness of generic HRTF is subject to ongoing research. There is likely to be a maximum number of audio cues which can be interpreted simultaneously.

4.6.4 Head-Up Displays

4.6.4.1 Capability

Head-up displays were originally developed as gun sights for fixed-wing aircraft and provide an electro-optical display, boresighted to the aircraft with weapon aiming and basic flight information symbols super

imposed on the view of the world. The symbology is generated cursively by a CRT display and relayed onto a combining glass in front of the pilot. Raster imagery from a Forward-Looking Infrared (FLIR) sensor can also be overlaid. HUDs are rarely used in helicopters but are becoming more prevalent on commercial airliners and business jets.

4.6.4.2 Strengths

The HUD alleviates the need for the pilot to look down and accommodate to about half a metre to read panel-mounted instruments and then re-accommodate when returning to the distant external world. The HUD can provide information conformal with the external outside world view, e.g., horizon line. Symbology optimised for landing, for example, drift and height, could be displayed on a HUD.

4.6.4.3 Limitations

HUDs are boresighted to the aircraft and provide a narrow field of view of between 20° and 30° which, during fixed-wing flight, is mostly aligned to the direction of flight. The HUD has a very limited headbox which constrains how far away from the design eye point the full field of view is visible, i.e., the pilot's head movement must be limited when using the HUD. Helicopter pilots require good SA to operate at low altitude which demands a wide range of head movement. This is exaggerated by the low speed manoeuvrability of helicopters, including forward, backward and sideways flight together with large pitch angles during landing. This necessitates a display with a wide field of view and/or field of regard to maintain adequate situation awareness. The usefulness of a conventional HUD is therefore limited – velocity vector forms of symbology would not be aligned to the direction of travel, causing increased interpretative workload. The view through the HUD may not be in the direction of travel during critical manoeuvres close to the ground. The HUD requires a significant space to be integrated into the cockpit. For these reasons, HUDs are not commonly integrated into helicopters. The latest generation of jet fighter, i.e., the Joint Strike Fighter, has moved away from HUDs in favour of a helmet-mounted primary-flight display, which provides a greater field of view and field of regard and frees up cockpit real estate for a much larger and more capable head-down display.

4.6.4.4 System Maturity

HUD technology has been continually developed since the 1950s and is mature. Lightweight, compact HUDs have been developed for civil, commercial airline applications.

4.6.4.5 System Integration Issues

HUDs must be accurately aligned with the aircraft datum and rely on sub-systems to provide data to be displayed. The brightness of the symbology must be adjustable to cater for very bright day light environments and night time operations. The HUD symbology must also be NVG compatible to allow the external view and /or thermal imagery to be viewed through NVG. Alignment of conformal symbology must take account of the refraction of the optical combiner. Conformal symbology must be updated at sufficient rate to avoid mis-registration during aircraft manoeuvring.

4.6.4.6 Required Sub-Systems

Navigation system, FLIR, weapon systems.

4.6.4.7 Human Factors

The boresighted display, small field of view and small headbox provide only limited use, for example, for helicopter transit flight profiles (yaw/sideslip permitting). Mis-registration of conformal symbology will increase interpretive workload and reduce pilot's confidence.

4.6.5 Helmet-Mounted Sight and Display (HMSD)

4.6.5.1 Capability

The HMSD was originally developed to aid weapon aiming for short range missiles. A head-tracking system combined with a simple, monocular, reticule sight were integrated with the weapon control system. The pilot could designate an external target by moving his head to superimpose the reticule over the target, enabling off-boresight weapon aiming. This significantly improved the weapon release time compared to the conventional technique of extreme aircraft manoeuvring to bring the target into the small field of view of the HUD. Night capable HMSD have been developed in which a simple display module is integrated with an NVG.

4.6.5.2 Strengths

The HMSD is a relatively simple display system which affords a significant improvement in weapon aiming capability.

4.6.5.3 Limitations

The display capability has been developed specifically for the weapon aiming requirement, often using fixed LEDs as pointing arrows, which offer no flexibility for other requirements such as landing. More capable raster displays (e.g., CRT or LCD) have been developed which are discussed under the Day Display and Display NVG technologies. HMSD has very narrow field of view, usually < 20°.

4.6.5.4 System Maturity

The system is mature and off-the-shelf but rapidly being superseded with more capable helmet-mounted display systems which incorporate weapon aiming symbology with flight instrument information**.** As a brownout landing aid the HMSD has little application although the underpinning technology principle of presenting information using a more capable display mounted on the helmet does, i.e., Display Modules and DNVG technologies are covered in other sections of Chapter 4.

4.6.5.5 System Integration Issues

The display is integrated with existing flight helmets and NVG. Day capable HMSD may use a miniature optics and visor coatings to project the sight information onto the visor. A head-tracking sub-system is required. Night capable systems require the display module to be integrated with NVG.

4.6.5.6 Required Sub-Systems

Head-tracking system, weapon control system, navigation system.

4.6.5.7 Human Factors

The HMSD provides a simple, intuitive display, tailored to a specific requirement. Additional audio cues (via the weapon control system) are used to notify the pilot of weapon lock. The miniature display adds negligible weight to existing helmets.

4.6.6 Summary on Capabilities and Limitations

Sensor and display technology capabilities and limitations are summarized in Tables 4-3 and 4-4. The generic technologies have been chosen to be representative of known programmes that exist or are being applied and developed as potential brownout solutions. The system maturity levels illustrated in these five tables have been assessed by combining two key criteria:

1) If the technology is likely to deliver a system solution within the short term (18 months); and
2) If the technology significantly contributes to a complete solution, i.e., aircraft state awareness or LZ awareness or both.

Table 4-2: System Maturity Level Key.

Category	Technology	Level Label
Achievable in the Short Term (within 18 months)	Significant contribution to an overall system solution	GREEN
Achievable in the Short Term (within 18 months)	Partial contribution to overall system solution	YELLOW
Medium to Long term solution (18 months to 5 years)	Promises significant contribution to an overall system solution	RED

Table 4-3: Sensor Technologies, Limitations, and System Maturity Levels.

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
SENSOR	RADAR	Active MMW Radar Altimeter sensor	Dust penetrating, precise height above ground level	Active 35 – 94 GHz	Dust penetration with centimetre accuracy	Limited range (the current range is up to 125 M), useful below helicopter	YELLOW	Above operational range would require conventional Rad Alt information	Source for display system	Inability to apply high resolution information to practical use	Part of German brownout solution
		MMW Electronic Bumper sensor	Moving obstacle detection and collision avoidance	Active 94 GHz see through dust	See through dust, 360°, low cost, light weight,	Low resolution, limited to motion only	RED	Latency in system integration, resolution requires further data analysis	GPS/INS, height above ground	Human machine interface for intuitive interpretation at acceptable workload, method in displaying the information	DEU, USA R&D projects
		Scanning Active Millimeter Wave (MMW) Radar sensor and display system	3-D image containing obstacles and terrain profile/surface	Scanning active 94 GHz	See through dust, can be small/compact, light-weight (few kilos)	Discrimination between manmade structure and moving obstacles	YELLOW	Latency in system integration, discrimination, further data analysis is required	GPS/INS, height above ground, terrain database	Method of presentation, completeness of information, interpretability	USA, CAN, DEU R&D projects
	LASER	Laser Altimeter sensor	Precise height above ground level	Active, Eye Safe 1.5 micron	Low cost, light weight, high accuracy	No dust penetrating capability, needs attitude correction	YELLOW	It requires other altimeters to provide useful information	Attitude and altimeters	Method of presentation, completeness of information, interpretability	
		3-D LADAR sensor	3-D image containing obstacles and terrain profile/surface	Scanning active, combination of Radar and Laser, Eye Safe 1.5 micron	High resolution, detailed 3-D image of LZ	Laser has no dust penetration	RED	Latency in system integration, discrimination, further data analysis is required	GPS/INS, height above ground, terrain database	Method of presentation, completeness of information, interpretability	USA, CAN, DEU R&D projects
	PASSIVE ELECTRO-OPTICAL	Visible Waveband or Low Light Level TV Camera sensor	2-D image containing obstacles and terrain profile/surface	Passive Visible Waveband	Detailed intuitive image of LZ	No dust penetration, limited depth/height information	YELLOW	Specific mounting on aircraft platform is required, resolution, completeness of information	Source for display system	Human interpretation is required	Part of German brownout solution

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
		Passive MMW Imaging sensor	2-D image containing obstacles and terrain profile/ surface	Passive 94 GHz see through dust	Dust penetration, intuitive image	Low resolution, large aperture at 94 GHz (50 cm), needs additional development to reduce size	RED	Difficult to implement onto operational airframe, low resolution, completeness of information	Require turret mounting with manual control	Quality/resolution of image/ completeness of information needs to be considered	GBR R&D project
		Thermal Imaging sensor	2-D image containing obstacles and terrain profile/surface	Passive MW or LW Infra Red	Detailed intuitive image of LZ in low ambient light level, Gen 3 High resolution	No dust penetration, requires turret and magnification/ zoom	GREEN	Mounting on aircraft platform, update rate, resolution	Source for display system, require GPS/INS	Manual control of sensor and pointing, require training to facilitate interpretation of information	USA R&D project

Table 4-4: HMI / Display Hardware Technologies, Limitations, and System Maturity Levels.

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
HMI / Display Hardware	HMSD Monocular, Non-Head Tracked	Night display through NVD / Day display / visor; LCD/OLED or other helmet display	Flight Symbology and video projected to head-up / head-out Pilot	Symbology / image projected on monocular display (day and night)	Wide spread, simple installation, mature (legacy product) battle proven, improves flight safety	Lack of conformal display capability (video and symbology)	GREEN	Integrated to legacy helicopter sensors, analog/digital	Helicopter sensors (e.g., attitude, GPS) according to customer requirements	Reduces workload compared to no HMSD	FRA, USA, ISR
	HMSD Monocular, Head Tracked	Electro-magnetic / Inertial / electro-optic / hybrid	Conformal (real-world projected) Symbology such as LOS, LZ, EW C4I, Sensor video projected on PF HMD according to LOS, mark new	System measures and calculates pilots head direction compared to helicopter, conformal symbology, video is displayed to match LZ by look and mark	Improves crew-coordination, reduces workload compared to non-tracked systems, improves mission efficiency and SA, option for "real world"	Video display – limited SA (monocular) Option for Add-on to existing HMSD	GREEN	LOS integration in cockpit and on helmet. There are head-tracked systems with no integration needed (all on helmet)	With basic capabilities same as non-tracked HMSD	More intuitive display, reduced training required	FRA, USA, GBR

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
	High-End HMD (Helmet Systems)	Stroke, Raster (video) Visor projected, dual-eye, wide FOV, high resolution, head-tracked HMD	High resolution WFOV, sensor fusion for enhanced SA, "helmet-mounted sensors"	High resolution display (LCD/L-COS), projected on visor to both eyes	Enhanced SA, ideal for piloting sensors (e.g., FLIR), sensor fusion and all-weather flight	High integration affords, not easy to integrate in legacy A/C or chance of device, high cost	YELLOW	Sensor-HMD integration needed for piloting sensor and fusion	Same as head-tracked HMD, for advanced applications – DTED, EGI and sensors (e.g., FLIR) needed	Enables pilots to compensate for lack of information by using WFOV and high resolution binocular display FRA	FRA, USA, ISR GBR

Table 4-5: HMI / Display Symbology Technologies, Limitations, and System Maturity Levels.

Category	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
HMI/Display Symbology	Alphanumeric display system for gathered information	Flight instrument display presented head up or head down	Conventional 2-D symbology	When presented head up reduces division of attention to cockpit displays	Low update rate, not optimised for landing, no LP indication, doesn't present obstacles/ hazards, head-down presentation reduces SA of outside world	YELLOW	Latency, resolution, completeness of information, workload associated with interpretation	Can be driven from conventional/ legacy sensors, e.g., RadAlt, Doppler velocity, Air data, engine data	Relevance of information to task, interpretability, workload	Commonly used
	2-D Graphical display system for gathered information	Optimised landing display including drift, height and LP cues, presented head up or head down	2-D Low-speed Symbology	Improves awareness of LP, drift, height, rate of descent by interpreting 2-D graphical displays	Increased workload to interpret display, encourages instrument flight control strategy, doesn't present obstacle/hazards, head-down presentation reduces SA of outside world	GREEN	Latency, resolution, completeness of information, workload associated with interpretation	GPS/INS (IMU), RadAlt, Air data	Interpretability, workload, instrument flight control strategy, situational awareness	DEU, USA

Category	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
	3-D perspective graphical display system for gathered information	Optimised landing display including drift, height and LP perspective cues	3-D Conformal landing symbology	Improves awareness of LZ and LP, drift, height, rate of descent by interpreting intuitive 3-D graphical displays, visual flight control strategy	Requires HMD, head-tracker and precise navigation solution, doesn't present obstacles/ hazards	GREEN	Latency, requires optimal integration of head-tracker display, display generator and navigation system	GPS/INS, terrain database, precise altitude, head tracker, HMD	Configuration of conformal cues, latency, registration, usability, workload	GBR
	Computer generated imagery display system for gathered information from passive and active sensors	Synthesised, perspective image of outside world containing obstacles and terrain profile/surface	Architecture to process sensor and terrain database information and generate a synthetic view of world	Continuous image presented before and after brownout, multi-spectral capability	Processing with adequate update rate, presentation to pilots, dependent on sensor performance, certification	YELLOW	Latency, resolution, completeness of information, registration, navigation accuracy, human machine interface for intuitive interpretation at acceptable workload	GPS/INS, height above ground, terrain database, image processing/ feature extraction/fusion algorithms	Method of presentation, completeness of information, interpretability	USA, CAN

Table 4-6: HMI / Display Technologies, Limitations, and System Maturity Levels.

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
HMI/DISPLAY	TACTILE	Display system for gathered information	Drift and height / ROD display	Tactile stimulus to pilot for cueing	Highly alerting, intuitive cue, non-visual, minimal increase in workload	Adds a garment layer, optimal information and cue presentation to be established, certification	RED	Mounting on human, rapid disconnect for egress, integration with sensors, cue strategy	GPS/INS or Doppler velocity, RadAlt	Drive algorithm, tactile symbology (directional command vs. avoidance), desensitisation, integration with clothing	USA, NLD

Table 4-7: Flight Control Technologies, Limitations, and System Maturity Levels.

Category	Technology	Types	Capability	Technical Principle	Strengths	Limitations	System Maturity Level	Systems Integration Issues	Required Sub-System	Human Factors	Examples
FLIGHT CONTROL	DIGITAL FLIGHT CONTROL SYSTEMS	Computer processed advanced flight control laws	Increased stabilisation through additional modes and holds, coupled to navigation system to hover hold or hover to land transition	Uses precision aircraft state data from GPS/INS and accurate height, air data and engine sensors with improved flight control laws	Not a sensor system but drastically reduce workload	Does not directly improve SA. Significant platform upgrade. Requires high level of certification for primary flight system	GREEN	Deeply integrated with suitable platform sensors, avionics and primary flight controls	GPS/INS, RadAlt, Engine data, Air data, control inceptors, actuators	Drastically reduced workload, additional training to operate according to a brownout procedure	Integrated into various helicopter and is currently in operation

4.7 DISCUSSION

The purpose of this discussion section will be to answer the following questions:

1) What are the technologies that are available to provide a brownout solution, and what is the level of maturity of each technology?
2) Has any country abandoned a potential solution, if so why, and what is that country's alternate path?
3) What are the most realistic technologies for a short-term brownout solution (12 – 18 months) that could be used on all helicopters / tilt rotor aircraft?
4) Which technologies indicate the most long-term potential?
5) What example brownout solutions promise to fulfil the day, night worst case scenarios defined earlier?

4.7.1 Technology Availability and Maturity

A comprehensive range of generic technologies have been identified through awareness of Government and industry research and development programmes across NATO countries. This range includes technologies developed to improve general DVE capability and those specifically focused on the brownout landing task. Analysis of the technologies summarised in Tables 4-3 through 4-7 provide the following conclusions:

1) Specific brownout solutions are immature and there is currently no solution available off the shelf.

2) The most mature technologies are those already developed for existing flight applications, namely, TV cameras, thermal imaging, head-mounted display modules (day display and DNVG) and conventional flight instrument symbology. These technologies are already in service in some countries and provide enhanced SA and improved workload in current helicopter operations. However, their effectiveness in brownout is limited.

3) Head-mounted displays are considered essential to host symbology, reduce division of attention and preserve SA of the outside world. Modular HMDs are available in the short term whereas fully integrated HMDs are less mature.

4) Conventional flight symbology is not optimised for the landing task, for example, lacking sufficient drift and height cueing.

5) Low speed symbology, optimised for landing, is being developed and promises a quick solution to reduce spatial disorientation, albeit with an instrument flying style of flight.

6) Conformal symbology is being developed and also promises a quick solution to reduce spatial disorientation whilst preserving a visual flying style of flight and providing awareness of the LZ and LP location.

7) Conformal symbology is more complex to integrate than low speed symbology.

8) Thermal imaging provides the ability to recce the intended LZ prior to brownout but will not see through dust.

9) Day time and Low Light TV cameras cannot see through brownout. However, their low cost and compact size offer the potential to be easily mounted on the airframe to look into areas which are not significantly obscured by dust. For example, multiple LLTV cameras could be used to monitor the landing gear and touch-down area immediately under the helicopter.

10) To improve LP/LZ awareness in brownout, see-and-remember and see-through sensor technologies both require significant development.

11) Whilst in some cases see-and-remember and see-through sensors (LADAR and Active MMW Radar respectively) appear mature in their original application, e.g., obstacle warners and missile seekers, their integration into a useful brownout landing system is very immature and may require modification to the sensor itself.

12) See-and-remember and see-through sensor systems require further development in terms of resolution, sensitivity, processing, display/HMI and physical packaging.

13) Synthetic vision system techniques promise an effective HMI for see-and-remember and see-through sensors but SV technology and the certification/safety arguments are immature.

14) Passive MMW imaging provides a see through capability with imagery in an interpretable form, however, the sensor technology is immature.

15) Tactile cueing technology promises an alternative form of presentation of simple drift and rate of descent cues but is not production ready and issues remain concerning human factors, integration with the aircrew clothing and certification.

4.7.2 Short-Term Brownout Solutions

The most promising short-term mitigation strategy is to augment current landing procedures, e.g., zero speed with improved aircraft state cues. The development and optimisation of symbology offers a promising short-term, partial solution. Improved awareness of drift and rate of descent presented in a form that can be used to control the helicopter should increase safety. Current development programmes of 2-D head-up and head-down, low speed symbology and 3-D head-up, conformal symbology both promise early exploitation. The UK is pursuing a short-term solution based on thermal imaging for recce and recognition of surface hazards in the LZ prior to the recirculation of dust, complemented by head-up, conformal symbology which can be relied upon within brownout. Germany is pursuing a short-term solution based on downward looking LLTV cameras complemented by head-up, 2-D low speed symbology. The US continues to develop the BOSS 2-D low speed symbology on head-mounted and panel-mounted displays. Canada is commencing a comparative study between the HMD 3-D conformal landing symbology and the 2-D BOSS symbology system.

4.7.3 Promising Long-Term Solutions

Medium-term mitigation strategies aim to provide a “see-in-the-dust” capability either using see-through or see-and-remember, integrated sensing systems. In the long term a more comprehensive solution may be based on a fully certified, synthetic vision, primary flight display. Currently, see-through and see-and-remember system capability (i.e., imaging and display) is considered immature. Several R&D programmes are developing these technologies, based on active sensors (AMMW RADAR or LIDAR) combined with image processing techniques and terrain databases to present a synthetic view of the LZ. The challenges will be to ensure the sensor gathers sufficient information including terrain features and obstacles and to present the information in a readily interpretable way. The presentation relies on effective processing of the sensed data and presentation using synthetic vision techniques, both of which are immature technologies. The CONOPS of such a system have yet to be developed and are likely to impact the development timescale, particularly from a certification perspective, for example, should the display be presented to the NHP as an aid or to the HP as a primary flight display. Obstacle warners with a see-through capability using AMMW radar may mature in the medium term and the challenge will be to provide a sufficiently useful capability to justify the installation footprint on the platform (i.e., the sensor may only help a small part of the overall brownout problem space). The integration of the sensor output with existing displays must also be resolved. Tactile display technology may also mature in the medium term once integration issues with aircrew clothing and certification issues have been understood.

4.7.4 Abandoned Potential Solutions

Many technologies continue to be developed in pursuit of a brownout solution, indeed, all the generic technologies in Table 4-3 continue to be investigated. The maturity level of brownout systems is currently low and very few potential solutions have been abandoned. The US used a Blackhawk helicopter to flight demonstrate a head-down display with 2-D low speed symbology driven from an inertial measurement unit (Brownout Situation Awareness Unit – BSAU) but the solution did not proceed to the service implementation phase. The US also pursued the PhLASH concept using multiple 16 Mpixel IR cameras to present a perspective view to the pilot on a head-down display. The last good 3-D view before brownout was corrected for aircraft motion and continued to be presented as the IR sensors became obscured. This concept has also been discontinued. One significant limitation is if a vehicle enters the PhLASH area after its last frame has been digitized it cannot be displayed and thus becomes an unanticipated obstacle in LZ. A number of R&D programmes have been completed without delivering an exploitable solution, hence work continues. The UK prioritised 3-D conformal symbology and thermal imaging technologies following assessment and down

selection of typical, generic technologies illustrated in Table 4-3. This was primarily on the grounds of the technical maturity required for a short-term solution.

4.7.5 Example Brownout Solutions

Despite the low maturity level of current brownout solutions, the application of technologies can be illustrated using the scenarios defined earlier in Section 4.2.2. In each case, technologies have been selected using best experience to date, tailored to fulfil the defined information requirement and provide the pilot with improved SA for the brownout landing task.

4.7.5.1 Day Scenario

During day operations with good visibility for transit flight and knowledge of the LZ characteristics, the following additional information and supporting technology to complete the brownout landing task more safely is recommended:

1) Drift:
   - Provide an aircraft Standard/Spec Inertial Measurement Unit (IMU) coupled to GPS (e.g., EGI) for adequate resolution and update rate.

2) Height Above Terrain / Rate of Descent:
   - Provide continuous, dust penetrating Radar Altimeter (RadAlt) information from the onset of re-circulated particulates). Most known RadAlts have problems with dust which can depend on the airframe shape. It is very important to integrate a dust penetrating RadAlt to provide accurate height information throughout the landing phase.

3) Groundspeed:
   - Provide GPS or IMU velocity (due to unreliability of pitot tube system below 40 Kts IAS).

4) Attitude Indication:
   - Provide a vertical Gyro or IMU.

5) LZ situation awareness:
   - Not all the required information can be obtained by pre-recce, LZ preparation, and naked eye view prior to brownout. Some obstacles like metal poles or rocks might be hidden under loose sand and will be blown free through the downwash. Uneven terrain may not be detected early with the naked eye because of the colour scheme and the surface condition. Therefore, the condition of the LP (touchdown point) must be determined. This has been achieved using a dedicated crewman, for example, looking under the aircraft at the surface, however, this is also dangerous. Additional technology could be used, for example, one or two downwards looking TV cameras on fixed mountings on the airframe.

6) Presentation:
   - The flight information, drift, HAT/ROD, ground speed and attitude should be clearly presented to the pilot in a form that requires minimal interpretation, minimal increase in workload and minimal division of their attention from the outside world view. It is essential to present the

information within the Field-Of-View (FOV) of the handling pilot, i.e., a head-up, helmet-mounted display with overlaid low speed or conformal symbology. The current practice of using aircrew patter, in which NHP talks down the HP, whilst not providing a complete solution in itself, should be continued to add flight safety.

- The TV camera imagery could be presented on a head-down display to a crewman or NHP.

The technologies described for the day scenario are mature or maturing rapidly and will be available as a short-term solution.

4.7.5.2 Night Scenario

In addition to those technologies stated in the Day Scenario, further improvements in SA are required for the night scenario. With good LZ preparation, adequate night visibility for transit flight and awareness of the LZ characteristics together with an artificial light source (such as cyalumes or Tactical Area Lighting System (TALS)) marking the touch-down point, the following additional SA information and supporting technology is recommended:

1) LZ situation awareness:
   - Enhanced Night Vision.
     - NVG with Head-up Information Display Capability, i.e., DNVG.
   - Prior to brownout, an enhanced surface assessment will be required to compensate for the narrow FOV and the poor spatial resolution of NVG. This could be conducted by the NHP using an Electro Optical Sighting System (EOSS).
     - EOSS equipped with a Low Light Level TV Camera and/or Infra Red camera.
2) Presentation:
   - DNVG provides a head-up night vision and low speed or conformal symbology display capability.
   - The Low Light TV and/or IR camera imagery should be presented on a head-down display to the NHP.

The additional technologies described for the night scenario are mature or maturing rapidly and will be available for a short-term solution.

4.7.5.3 Worst Case Scenario

Due to the severe operational and environmental conditions that a worst case scenario can impose, (DVE together with an unprepared or unrecced LZ), there is a need for a self-contained landing capability which enables controlled/autonomous flight within highly degraded visual conditions, including within the dust cloud, using a high integrity, primary flight display. Improved platform stabilisation and control will be essential to reduce the pilot's dependence on visual cues. The technologies which aim to facilitate this capability are as follows:

1) Drift:
   - Digital Automatic Flight Control System (DAFCS equipped with advanced flight control laws)/ Coupled to the Navigation system – Automatic Hover to Land.

2) Height Above Terrain / Rate of Descent:
   - DAFCS/Automatic Hover to Land.

3) Groundspeed:
   - DAFCS/Automatic Hover to Land.

4) Attitude Indication:
   - DAFCS/Automatic Hover to Land.

5) LZ situation awareness:
   - There is a need for surface recce (including terrain surface, obstacles and other hazards). Emerging technologies include:
     - Third Generation High Resolution Thermal camera (turreted and/or Distributed Aperture Sensors(DAS));
     - Terrain database;
     - Imaging LIDAR/LADAR;
     - Active MMW imaging radar;
     - Passive MMW imaging;
     - Moving obstacle detection systems, e.g., E-Bumper using AMMW radar; and
     - Image fusion.

6) Presentation:
   - In comparison to the day and night scenarios, the HP may use imagery from onboard sensors, for example DAS, as a primary reference of the outside world. To achieve an adequate field of view this will require an integrated HMD. To maintain awareness of the LZ and LP locations, conformal symbology will complement the improved handling qualities resulting from DAFCS.
   - The NHP should also be equipped with an HMD linked to the DAS to provide the view of the outside world.
   - Additional imaging sensors (AMMW/PMMW/LADAR/E-bumper) may be used to provide a see through dust/weather capability, presented using a digital cockpit architecture using SV techniques.
   - SV could be presented on a large area head-down display visible to the NHP (and HP as an aid).
   - If the SV system is sufficiently mature it may be relied upon and presented to both aircrew on the HMD. In this case it is likely the SV imagery will include passive sensor imagery using image fusion techniques.

To safely achieve the worst case scenario, many technologies will need to be further developed, integrated and safety cases to be addressed in order to provide reliable situation awareness. DAFCS is seen as a key enabler and is available in the short term for specific platform types, i.e., Chinook CH47-F. However, DAFCS alone will not improve SA and additional technologies will be required. Conformal symbology will also be available in the short term and provides improved awareness of LZ and LP locations together with cues to complete the landing. However, effective surface recce in DVE will depend on the maturation of see-through sensor and

display systems (including SV) and associated safety arguments, hence, is considered to be a medium to long-term solution. An additional benefit of the worst case scenario capability is that conventional hover landings could be conducted safely within brownout; the more difficult zero speed technique, keeping ahead of the dust cloud to delay loss of visual cues, would no longer be required (albeit incurring greater erosion of the aircraft). It is anticipated that achieving a capability to enable operations in the worst case scenario will provide a significant step towards a future helicopter Day, Night All Environment capability.

4.8 CONCLUSIONS

A variety of technologies have been reviewed as potential solutions to improve safety during brownout landings. To understand how technologies may contribute it is important to understand the information that is required by the pilot during the zero speed landing task. This information has been broadly divided into:

- Aircraft state awareness – drift, ground speed, height above ground, rate of decent and attitude, for aircraft control and stabilisation; and
- LZ awareness – recognise surface, slope, surrounds, size, shape, obstacles and hazards through dust.

Technologies which improve aircraft state awareness are currently more mature than those which provide a see-through dust capability for LZ awareness.

In the short term, improved symbology driven from precise information sources such as an IMU promises the best method of improving aircraft state awareness. Symbology should be presented on a head-mounted display to reduce the pilot's division of attention away from the outside world cues. 2-dimensional low speed symbology or 3-dimensional conformal symbology for landing are both in development.

Improved aircraft stabilisation can also be achieved using advanced flight control laws in a Digital Automatic Flight Control System (DAFCS), for example, hover hold, controlled vertical descent and, when coupled to the navigation system, automatic transition to hover and landing. DAFCS will be available in the short term on limited platform types (i.e., Chinook CH-47F) but may not have all the functionality cleared for use in brownout. DAFCS is expected to become more widespread on new platforms in the medium term. DAFCS does not increase SA and technologies which provide increased LZ awareness will still be required.

LZ awareness may only be improved in the short term by non-dust penetrating sensors such as TV, Low light TV and infra red cameras. These enable recce of the LZ prior to brownout and/or a short range view of the touch-down point under the aircraft if this area remains clear of re-circulated dust (platform dependent). Conformal symbology also improves awareness of the LZ and LP locations.

In the longer term, LZ awareness may be achieved using see-through active and passive imaging sensors with appropriate data processing to provide a synthetic view of the outside world. Once the technical, safety and certification issues have been resolved, this see-all-the-time approach may negate the need for the zero speed landing technique in favour of a safer, conventional hover landing in dust. In the future, the combination of synthetic vision and DAFCS is anticipated to provide a true Day Night All Environment rotorcraft capability.

4.9 REFERENCES

[1] Ball, A. NATO HFM-162 Rotary-wing brownout working group meeting minutes: NASA Ames September 2007, IMASSA April 2008, ESG Munich, September 2008, USAARL Ft. Rucker April 2009, DRDC Toronto September 2009, ONR London June 2010.

[2] Finlay, B. (2009). International Technology Research into Helicopter Brownout, DSTL/CR33398 V1.0, 12 January 2009.

[3] Wikner, D. Milli-metre-wave Propagation through a Controlled Dust Environment, Sensors and Electronic Devices Directorate, Army Research Laboratory, Adelphi, Maryland 20783.

[4] Appleby, R., Anderton, R.N., Price, S., Salmon, N.A., Sinclair, G.N., Borrill, J.R., Coward, P.R., Papakosta, P., Lettington, A.H. and Robertson, D.A. (2000). Compact real-time (video rate) passive milli-metre-wave imager, 4th Joint Int Military Sensing Symposium, Paris, September 2000.

[5] Popular Mechanics (2006). Flying Blind in Iraq: US Helicopters Navigate Real Desert Storms, 3 October 2006.

[6] Curry, I.P., Estrada, A., Grandizio, C.M. and Erickson, B.S. (2008). Drift cues from a tactile belt to augment standard helicopter instruments. International Journal of Applied Aviation Studies, 8(1), 74-87.

[7] Curry, I.P., Estrada, A., Webb, C.M. and Erickson, B.S. (2008). Efficacy of tactile cues from a limited belt-area system in orienting well-rested and fatigued pilots in a complex flight environment (USAARL Report No.2008-12). Fort Rucker, AL, USA: Unites States Army Aeromedical Research Laboratory.

[8] Jansen, C., Wennemers, A., Vos, W. and Groen, E.L. (2008). FlyTact: A Tactile Display Improves a Helicopter Pilot's Landing Performance in Degraded Visual Environments. Lecture Notes in Computer Science 5024, pp. 867-875.

[9] 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.

[10] Schultz, K., McGrath, B., Cheung, B., Craig, G., Jennings, S. and Rupert, A. (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.

[11] Operator's Manual for Head-Up Display AN/AVS-7, TM 11-5855-300-10, NAVAIR 16-35HUD-2 Departments of the Army and Navy, 1997.

[12] Eshow, M. and Schroeder, J. (1993). Improvements in Hover Display Dynamics for a Combat Helicopter, Journal of the American Helicopter Society, January 1993.

[13] Keller, M., Neiswander, G., Schnell, T. and Szoboszlay, Z. (2008) Rotorcraft Hover Symbology Study for Operation in Poor Visibility Conditions, The University of Iowa, February 15, 2008.

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

[15] Szoboszlay, Z., Jennings, S. and Carignan, S. (2009). Results and Comments for the Loon Symbology Study, National Research Council of Canada Flight Test Report FTR-FRL-2009-0024.

[16] Thorndycraft, D., Marsden, D. and Jennings, S. (2008). Flight assessment of an integrated DNAW helicopter pilotage display system; flight trial 'HAWKOWL', SPIE Conference.

[17] Goff, C.P., Ball, A.N., Yapp, J.L., Pearce, S.J. and Crawford, F.L., (2010). Developing a 3-D Landing Symbology Solution for Brownout, , American Helicopter Society Forum 66, Phoenix, Arizona.

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

[19] Einthoven, P., Bender, J., Blanken, C. and Lawler, M. (2006). Development of Control Laws for the Chinook Digital AFCS Program, Presented at the American Helicopter Society 62nd Annual Forum, Phoenix, Arizona, May 9-11, 2006.

[20] Irwin III, J., Sherman, D. and Crispino, J. (2008). The CH-47F CAAS-DAFCS Coupled Flight Director, Presented at the American Helicopter Society 64th Annual Forum, Montreal, Canada, April 29th – May 1st, 2008.

[21] Priot, A.E., Hourlier, S., Barbarat, E. and Roumes, C. (2007). Adaptation to increased interocular distance: survey of Tiger pilots training Human factors and medical aspects of day/night all weather operations: current issues and future challenges. Meeting Proceedings RTO-MP-HFM-141, Paper 30 (pp. 30-31 – 30-12). Neuilly-sur-Seine, France: RTO.

[22] Irwin, J., Einthoven, P., Miller, D. and Blanken, C. (2007). ADS-33E Predicted and Assigned Low-speed Handling Qualities of the CH-47F with Digital AFCS, Presented at the American Helicopter Society 63rd Annual Forum, Virginia Beach, VA, USA, May 1-3, 2007.

[23] Jarret, D.N., (2005). Cockpit Engineering, Ashgate Publishing.