Annex A – TTPC-AER-TP2-2011 TASK OUTCOME REPORT FOR ENHANCED/SYNTHETIC VISION PILOTAGE SYSTEMS

TASK OUTCOME REPORT

TTCP Sub-element: AER **TTCP Reference No: CP 2C.1**
Task Title
Enhanced/Synthetic Vision Pilotage Systems

A.1 TASK DESCRIPTION

Most of the Nations are investigating the use of enhanced and synthetic vision systems in degraded visual environments. Numerous aircrew and aircraft have been lost in Afghanistan due to the pilot's loss of out-the-window visual cues in fog and dust conditions. During landing, the helicopter's own downwash creates a recirculating dust cloud, which both limits visibility to the ground, and produces false motion cues. Aircraft have also collided with terrain and obstacles while flying in-route at low levels, typically at night. Enhanced and synthetic vision systems offer the potential of greater situational awareness in degraded visual environments, increasing safety. The goals (and measures of effectiveness) are reduced accidents and an increase in the weather conditions available for operations. The specific objectives of this CP are:

- Develop guidelines for enhanced/synthetic vision systems for low level flight.
- Design and test terrain and obstacle avoidance and aircraft limiting cuing for contour flight through haptic, tactile feedback and visual displays.
- Design and test displays for approach and landing to non-surveyed sites in degraded visual conditions including brownout and whiteout.

A.2 ACHIEVEMENT OF TASK OBJECTIVES

Trial Hawkowl was conducted by the UK MoD and QinetiQ to provide a flight demonstration of an integrated day/night all weather system. The primary goal was to assess the benefits and limitations of the system during the execution of operationally realistic tasks in degrade visual environments. A MoD SeaKing Mark IV helicopter was modified with terrain imaging sensors (image intensifier, infrared, and passive mm-wave) and pilot displays (NVG-HUD, Panoramic NVGs with symbology, and a panel-mounted display). Sub-systems were integrated to provide the pilot with navigation information during low level flight enroute to the landing point. The primary symbols for navigation were a pathway-in-the-sky symbol and a flight path marker symbol showing the current direction of travel as shown in Figure A-1. Once near the landing point the pathway in the sky directed the pilot on the proper approach path to the landing point. A separate set of symbols then aided the pilot to a hover and landing. There was substantial participation by Canada under the TTCP agreement in this test, and the preceding tests (listed under a prior CP).

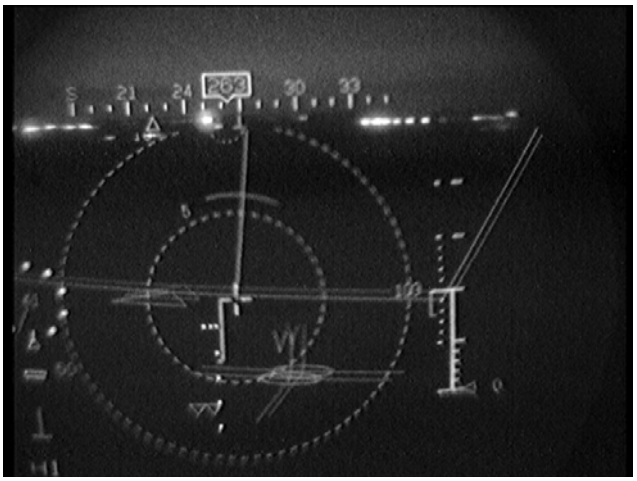

Figure A-1a): Hover Symbology for Hawkowl.

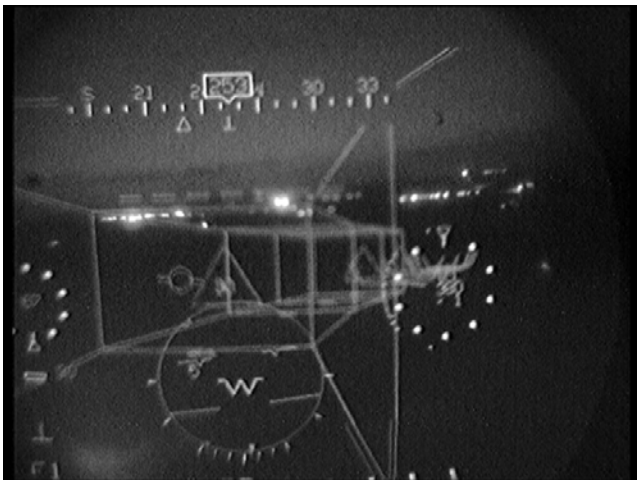

Figure A-1b): Low Level Flight and Approach for Hawkowl.

As Hawkowl was a flight trial as opposed to a simulation trial, numerous technical difficulties needed to be overcome including image from sensors that not perfectly aligned, filtering aircraft state data, integrating GPS with inertial navigation, and tracking the pilot's head orientation angle. The system included mission planning and route generation. Operationally representative tasks were conducted for the trial which was flown in 2007.

The state-of-the-art system at that time proved to be an effective approach in general; specific technical shortcoming were identified [1]. The information gained enabled robust advice to be provided to the MoD for the specification of future Technology Demonstrator Programme requirements and the specification of day/ night all weather capability for current and future platforms.

Figure A-2: Imaging Sensors and Pilot's Panel-Mounted Display.

The US has designed and tested a new flight path marker symbol to work with synthetic terrain imagery to aid the pilot in contour flight at moderate speeds (typically 60 – 100 knots), and low altitude (typically 50 – 100 ft). In particular, the flight path marker took advantage of knowledge of terrain height ahead of the aircraft to indicate the predicted height above terrain and predicted point on the ground the aircraft was

expected to fly over a fixed distance in front of the helicopter. The symbol worked both with and without a predetermined route. This display was tested in simulation first, and later in flight test on the US Army RASCAL fly-by-wire UH-60 ([2]-[4], Figure A-3).

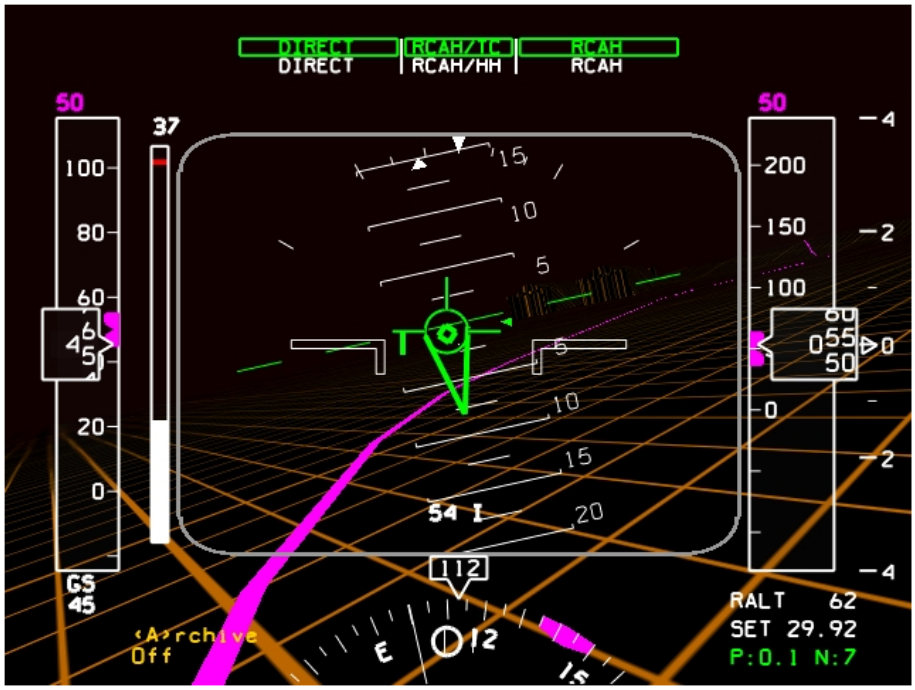

Figure A-3: New Flight Path Marker Symbol (ATP-FPM) Used with Synthetic Terrain Imagery as Flown on the US Army Fly-by-Wire RASCAL UH-60.

Average altitude error below the target altitude of 50 ft was reduced by 1/3 in flight test as compared to the traditional flight path marker symbol as shown in Figure A-4. Ground track error was reduced by 1/2 compared to the traditional flight path marker symbol as shown in Figure A-5.

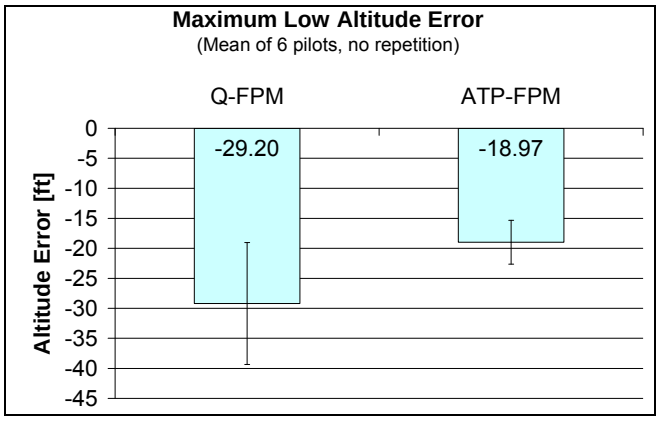

Figure A-4: Flight Test Result – Maximum Low Altitude Error.

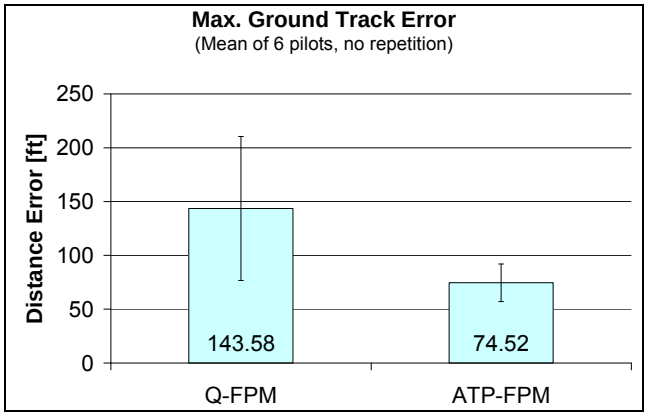

Figure A-5: Flight Test Result – Max. Ground Track Error.

Concentrating on the generation of the synthetic terrain image, the US Army AMRDEC issued a Small Business Innovative Research (SBIR) contract to Monterey Technologies Inc. with sub-contractors Aireyes and Nav3D. The synthetic terrain image started out as being from a preloaded terrain elevation database. However, the system had a simulated radar, which would morph the database in real time (Figure A-6). Three dimensional fusion occurred when the simulated radar was within range of terrain features, and within the sensor's field-of-view. Another 2-D fusion occurred when simulated infrared imagery was available. The pilot could see the infrared imagery through the synthetic terrain grid. Grids were highlighted when they were scanned by the radar so the pilot could see if upcoming terrain was scanned yet [5].

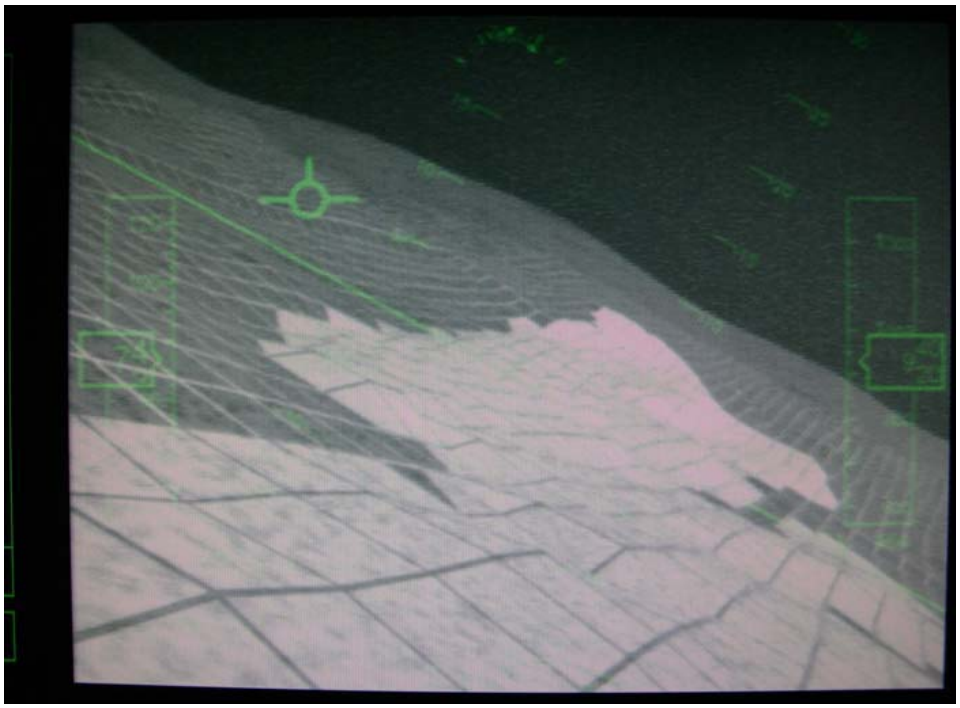

Figure A-6: Pilot's Display for the Integrated Multi-Sensor Synthetic Imaging System (IMSIS) Used in Simulation by the US Army AFDD.

Eleven US military rotorcraft pilots participated in the simulation. The radar validated synthetic terrain was considered by the evaluation pilots to be almost as useful as a good infrared image (which is not always available due to clouds and fog). The combination of infrared imagery and radar validated synthetic terrain was considered by the pilot group to be the most effective navigation aid.

The US has been developing a guideline for the design of displays for terrain and obstacle avoidance. The guideline itself is currently a US-Israel MOA task, but it contains many examples done outside the MOA by a number of different Nations and industry. This guideline is currently in draft form. When completed, at approx. end of 2013, this guideline will be released to the public. TTCP Nations have the desire to monitor progress and receive the design document, under a new focus area FA 2C.4 “Visual Cueing for Rotorcraft Pilots”.

Progress has been made in the Canada and the US in the area of haptic (body motion) feedback through the collective stick. In both cases this feedback was done with an electrically driven fly-by-wire collective stick. Information type was both limit cueing (felt as bumps) and desired stick position (felt as detents). TTCP Nations have the desire to monitor progress under a new focus area FA 2C.5 “Audio, Tactile, and Haptic Cueing”.

Australia has provided audio advisory/caution/warning files which were implemented at NRC Canada in the fly-by-wire Bell 412, the US Army AFDD synthetic vision simulator, and the US Air Force Research Lab helicopter brownout simulator. One audio file provides advisory information that the pilot’s guidance to landing has started. Caution and warning files informed the pilot of excessive vertical speed close to the ground. In simulation these two areas were identified as needing a non-visual information channel due to the pilot’s very limited area of attention on the display at any given time. Several iterations were completed between the US and Australia to refine the syntax. TTCP Nations have the desire to monitor progress and possibly work toward collaboration in the future under a new focus area FA 2C.5 “Audio, Tactile, and Haptic Cueing”.

The Sandblaster program was funded by DARPA and used the US Army AFDD RASCAL Blackhawk aircraft (2009). This program combined a radar sensor from Sierra Nevada Corp., a Honeywell computer to fuse radar and pre-stored terrain elevation data, aircraft state symbology developed by Honeywell and Sikorsky, and a fly-wire-wire flight control system with Sikorsky control laws for automated approach and hover. Sikorsky was the prime contractor. An example pilot’s display is shown in Figure A-7.

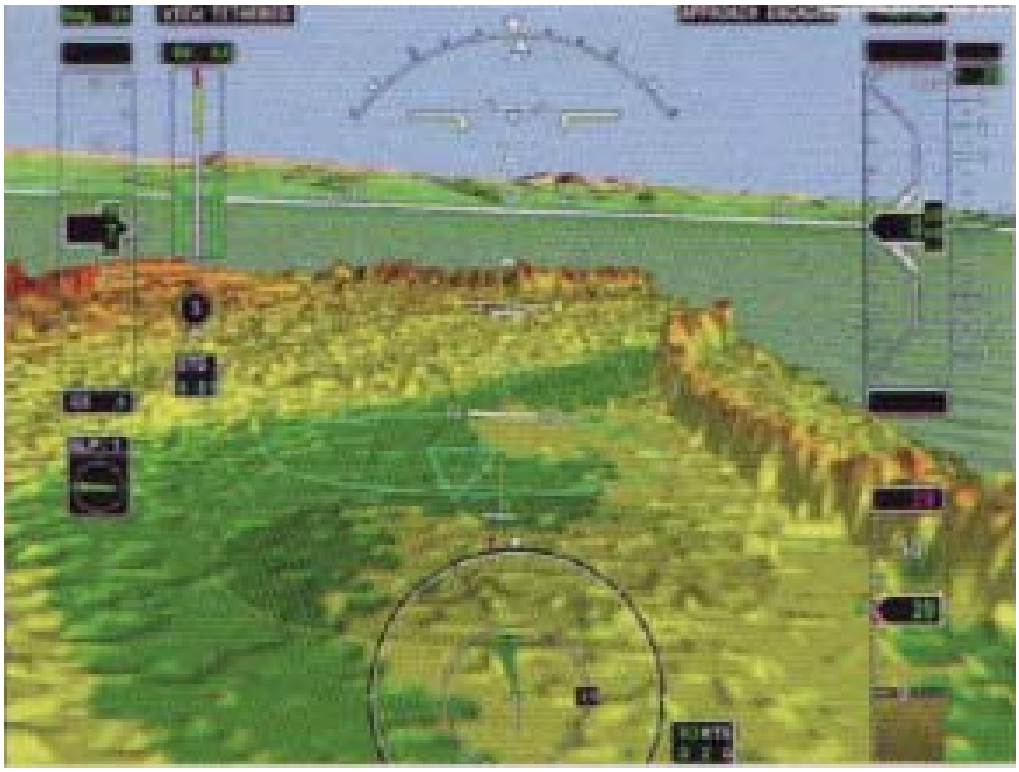

Figure A-7: Sandblaster Display Includes Radar Data (Close) and Pre-Stored Terrain Elevation Data (Far) and Symbology.

The Sandblaster system worked as designed in actual flight conditions. Pilots noted that the radar resolution was lower than desired, and it took longer than desired to scan the landing area. The benefit of this sensor was the ability to see through dust (tested separately from the RASCAL flight test). A vehicle was driven onto the landing area and this was seen on the display by the pilots. Curtains were used to block the pilot's out-the-window view. The auto-approach flight control system worked well, reducing workload and thus enabling the pilot to scan for obstacles and move the desired landing point if necessary.

The UK has been working over the last three years to develop a Low Visibility Landing (LVL) solution for brownout [6]. This research programme was concluded in March 2011. It matured a 3-Dimensional (3-D), head-mounted conformal symbology system in conjunction with AgustaWestland and Ferranti Technologies Limited (FTL). It was an accelerated technology development program designed to reduce accidents and incidents caused by spatial disorientation in brownout. It is a pragmatic approach, balancing effectiveness, time and cost. The UK MoD has undertaken flight trials on an Army Lynx and conducted simulation trials in a Merlin Simulator. The simulation demonstrated that a viable 3-D conformal symbology system could significantly reduce unacceptable landings in brownout.

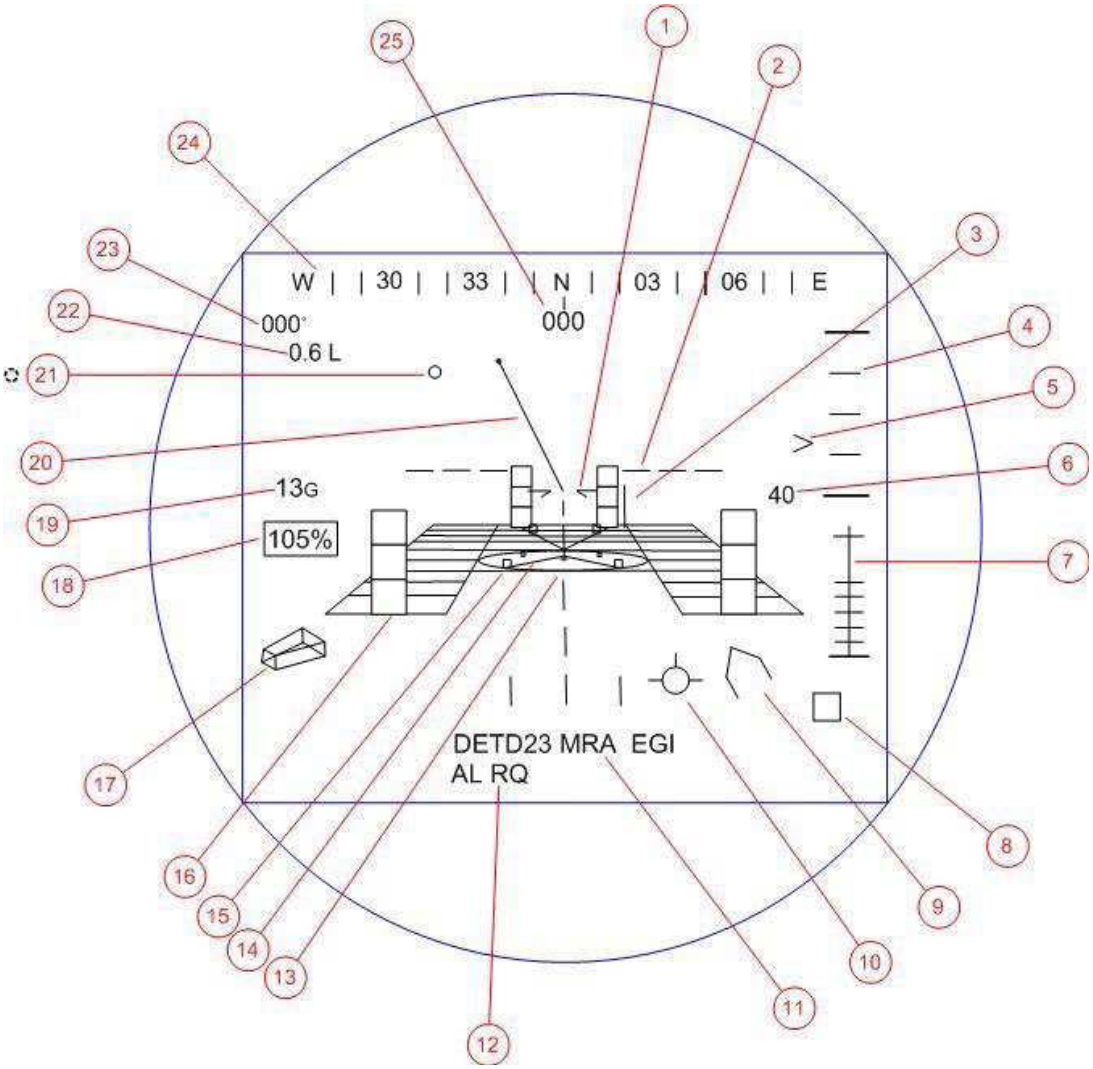

Figure A-8: Low Visibility Landing (LVL) Symbology.

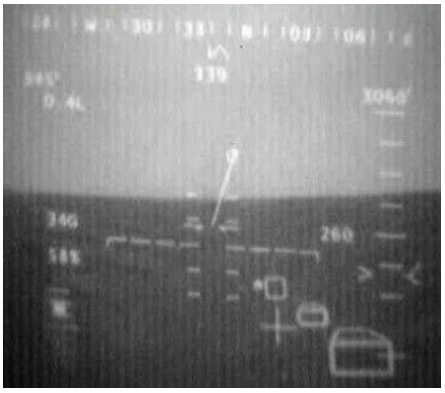

Figure A-9a): Start Approach.

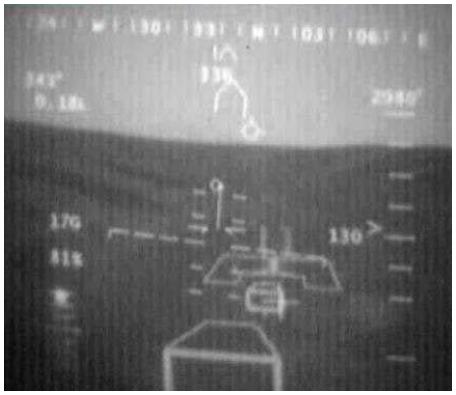

Figure A-9b): Nearing LZ.

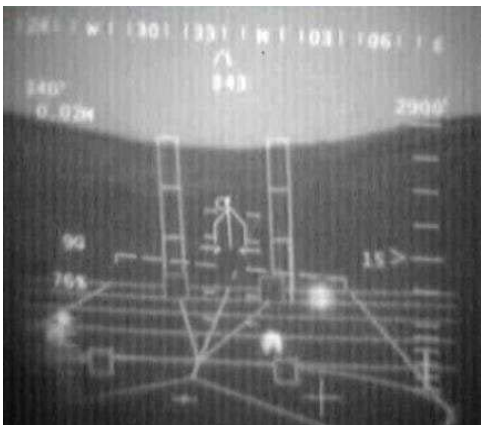

Figure A-9c): At LZ.

Over the last year the UK have de-risked some of the remaining technical challenges with the system to enable this solution to be transitioned to a platform if required.

In the US, early work in this collaborative program started at the Univ. of Iowa, under contract from the US Army AFDD [7]. This symbology set was designed to aid the pilot to hover, land, and take-off in degraded visual environments such as brownout and whiteout. Figure A-10 shows the simulator developed for the test. The simulator was placed inside a large projection dome, with brownout dust clouds at low speeds and altitudes.

Figure A-10: University of Iowa Simulator for Brownout Landing.

Figure A-11 shows two of several displays tested. On the left is the Common Avionics Architecture System (CAAS) display, versions of which are used on the CH-47F, and MH-60 helicopters. The left pane shows a new integrated scrolling radar altimeter and vertical speed indicator, replacing the CAAS dials. This simulator had the first implementation of the integrated altitude and vertical speed indicators, which are important elements to what is now called the BOSS symbology set. On the right, synthetic vision terrain imagery has been added as well.

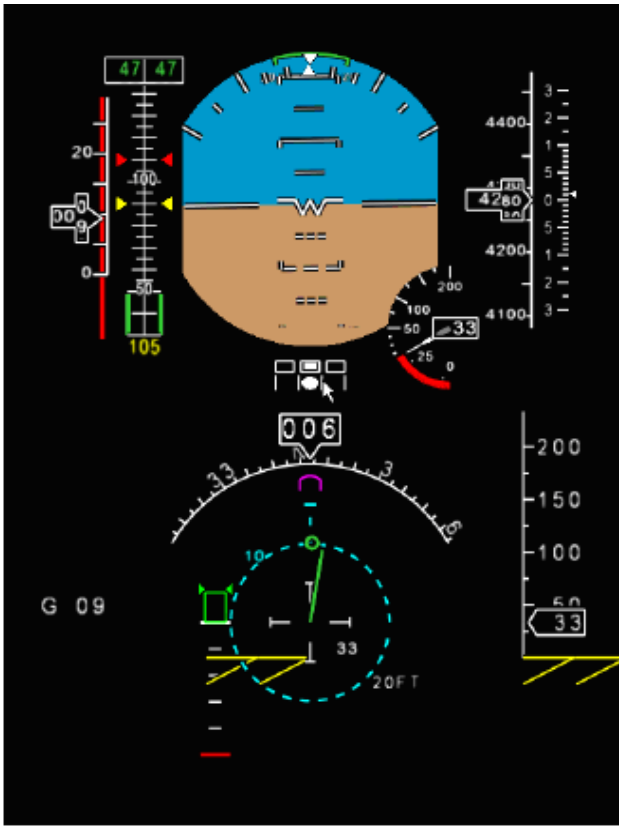

Figure A-11a): CAAS Display Modified with an Integrated Altimeter and Vertical Speed Indicator.

Figure A-11b): Synthetic Vision Display.

The display with the integrated altimeter and vertical speed indicator were significantly better in pilot ratings compared to the standard dials for the comprehensive objective hover task and were associated with lower amounts of altitude error during the 30 second hover in the hover task.

From examination of the objective and subjective data for both the hover task and descent to land task data, the synthetic vision displays consistently ranked at the top in ratings and performance. This indicates that the synthetic vision was well accepted and preferred for flying in the degraded visual environments. Data showed that the synthetic vision terrain image significantly reduced the amount of lateral and forward velocities at touchdown during the descent to land task during the brownout. The synthetic vision displays were consistently rated the highest in terms of spatial awareness and for reducing ground collisions.

Work continued in the US on the landing display for degraded visual environments at the NASA-Ames Vertical Motion Simulator, shown in Figure A-12 [8]. At this point, the symbology set was formally called BOSS (BrownOut Symbology System). Key elements of the BOSS symbology set were:

1) Same symbology for the panel-mounted and head-mounted display.

2) Camera imagery or synthetic terrain imagery are fixed along the centreline of the aircraft, eliminating the need for a gimballed sensor.

3) Symbology set is designed to overlay and enhance terrain imagery in the background (earth referenced flight path marker and horizon line).
4) Integrated altimeter and vertical speed indicator.
5) Horizontal speed guidance from cruise speeds to near hover.

Figure A-12: NASA-Ames Vertical Motion Simulator with Panel-Mounted Displays and NVG-HUD.

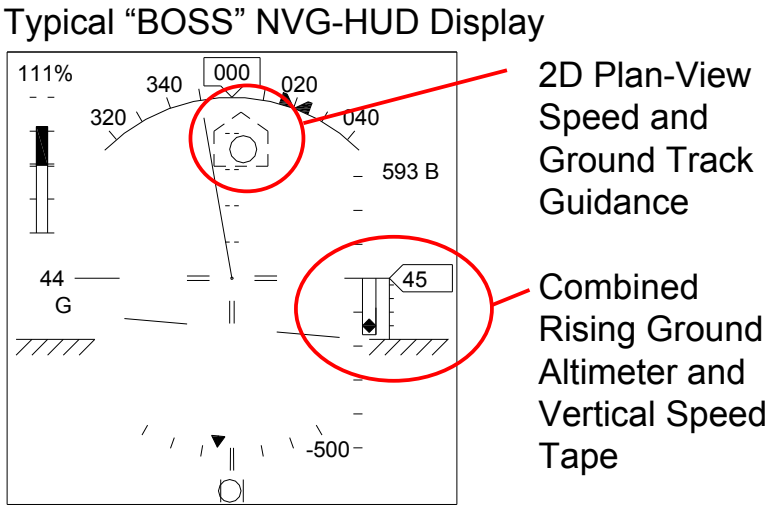

Figure A-13: BOSS Display as Flown on the NASA-Ames Vertical Motion Simulator.

Figure A-14 shows the main test matrix for the BOSS simulation on the NASA-Ames Vertical Motion Simulator. As shown in the figure, a baseline AVS-7 symbology set was flown, which is the current US standard NVG-HUD. Figure A-15 shows significantly worse vertical speed performance with the AVS-7 symbology set compared to all the variants of BOSS tested (each having the integrated altimeter and vertical speed indicator). Some of the results were believed to be due to the greater sensitivity that the BOSS vertical speed indicator had.

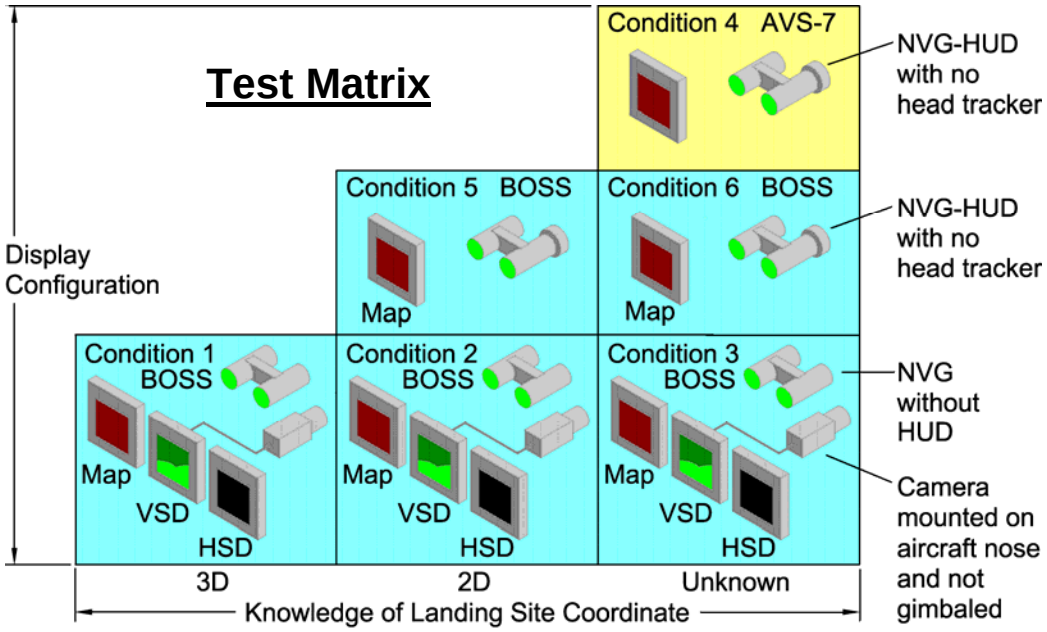

Figure A-14: Test Matrix for NASA-Ames Simulation.

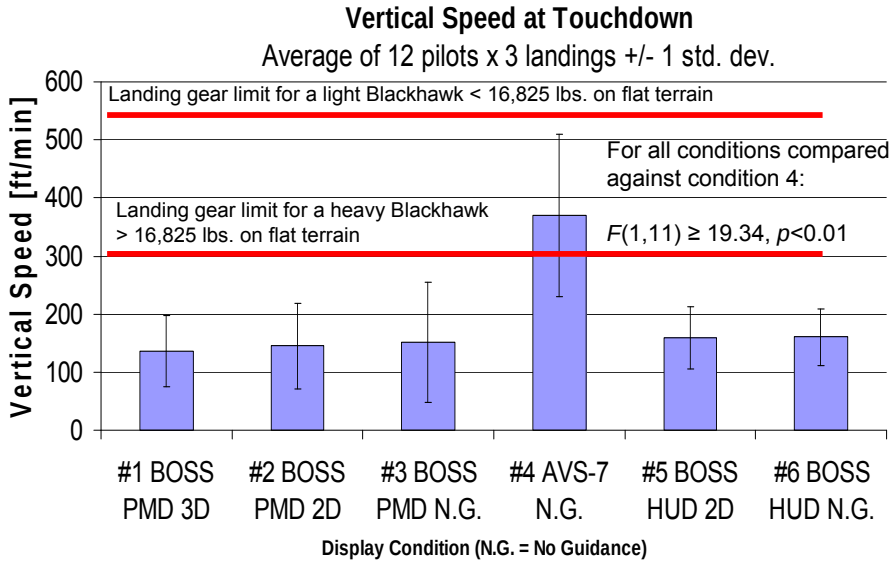

Figure A-15: Vertical Speed at Touchdown, BOSS Study in the NASA-Ames Simulator.

One comparison in the test matrix was BOSS symbology on the NVG-HUD vs. BOSS symbology on the Panel-Mounted Display. No significant differences were seen in pilot performance between display types; both could be used effectively. Another comparison in the test matrix was whether the BOSS system knew the 3-D, or 2-D coordinates of the landing point, or lacked the coordinates entirely. Figure A-16 shows that distance errors significantly increased between knowing the coordinates in 2-D, and not knowing the coordinates at all. However, errors increased by only 1.4 to 1.7 times. Therefore the BOSS symbology set was still used effectively even without knowledge of the landing coordinates. Distance errors were significantly worse for the AVS-7 set compared to all variants of the BOSS set. Also, there was no significant difference in landing position error or any other parameter between the use of 2-D and 3-D coordinates, meaning a simpler system could be used. For all display conditions, lateral speeds averaged between 0.5 and 1.5 knots at touchdown, with one standard deviation as high as 2.7 knots. Data showed that lateral speed at touchdown was higher than desired.

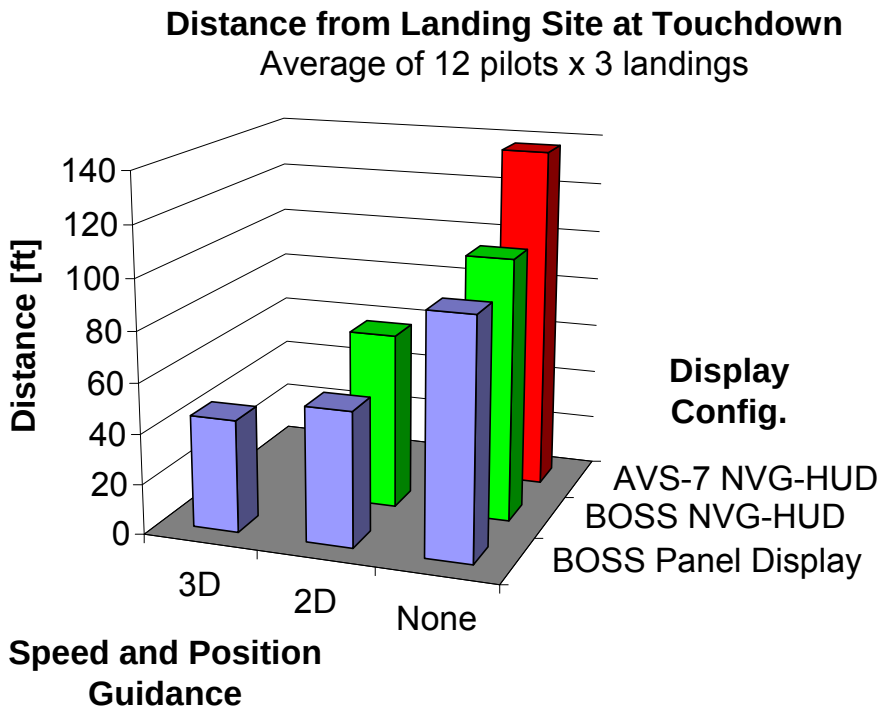

Figure A-16: Distance from Landing Point, NASA-Ames Simulator.

In comparing pilot ranking between BOSS and AVS-7, all thirteen pilots chose a variant of the BOSS symbology (with speed and position guidance) as their first choice. None of pilots ranked the AVS-7 as first choice and ten of them listed it as their last choice.

In addition to the NASA-Ames simulation, the US Army AFDD and BAE Systems conducted a simulation of symbology over background terrain imagery [9]. The Valley View software (developed under the Monterey Technologies SBIR contract) morphed pre-stored terrain elevation data in accordance with simulated 94 GHz radar data. BOSS symbology was overlaid on top of the terrain imagery in one case (Figure A-17). In another case, the BAE LVL symbology was display on a head-mounted display (Figure A-18), and terrain-only imagery was presented on the panel-mounted display.

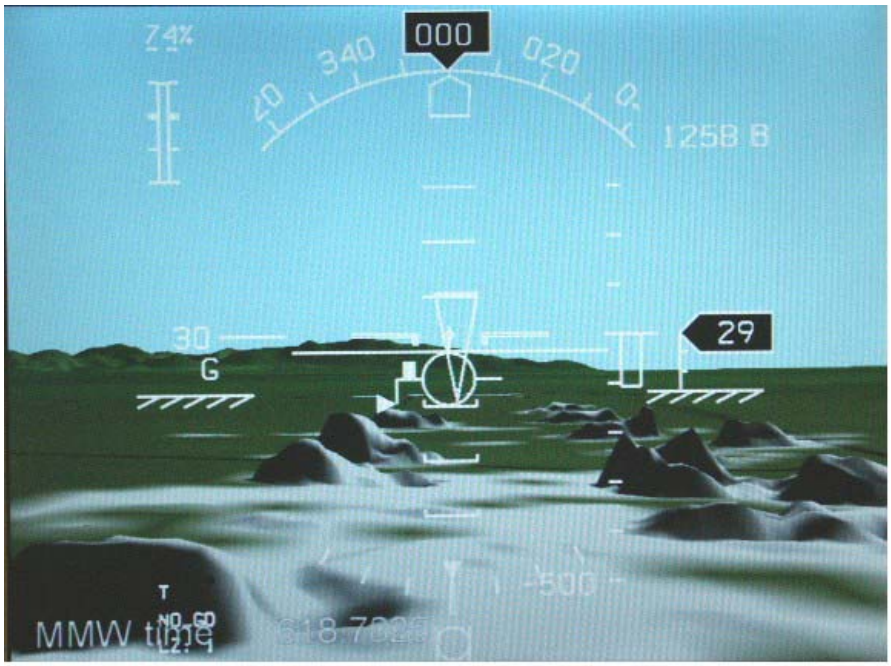

Figure A-17: BAE Terrain Elevation Data Morphed with Simulated Radar Data.

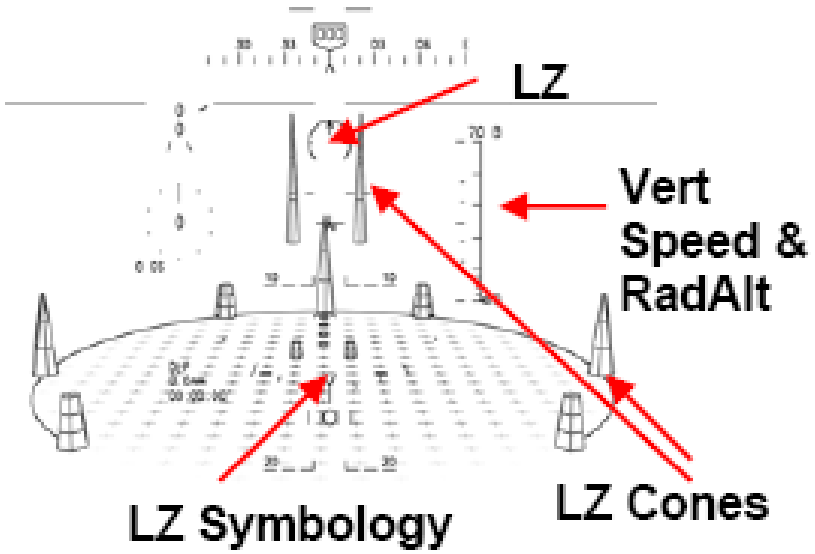

Figure A-18: BAE LVL Symbology.

Results indicate that the BOSS display formats (both Dual PMD and Single PMD) were preferred by pilots and were also associated with higher levels of flight performance in comparison to the HMD symbology display. Results from the display rankings showed that pilots preferred having the radar as opposed to not having it as it added to situational awareness of obstacles and increased confidence in the rendered terrain being accurate.

The US Army Applied Aviation Technology Directorate (AATD) initiated a program to develop a radar and associated pilot's display for terrain following and landing in degraded visual environments. The radar and display system was called HALS. A novel 94 GHz radar built by Sierra Nevada Corp. was mounted on the nose of a UH-60, which was very similar to the Sandblaster radar. Radar data morphed the pre-stored terrain elevation database. BOSS symbology was superimposed on the terrain image. This system was flight tested in 2010 (no ref, Figure A-19). A re-packaged radar that is more streamline and the latest version of the BOSS symbology is expected to be flight tested in late 2011.

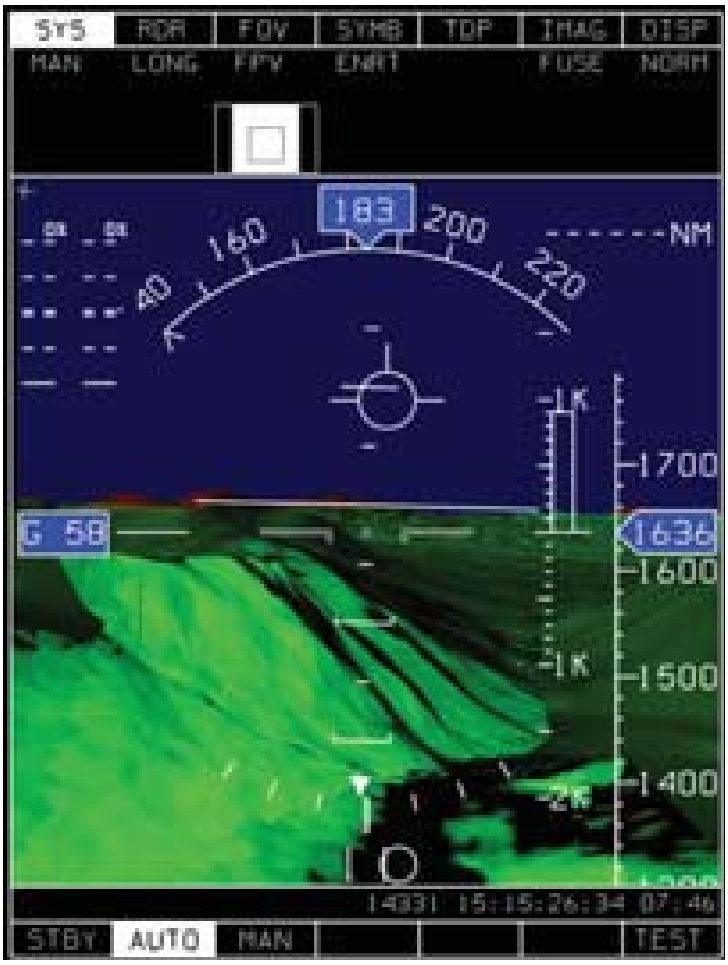

Figure A-19: HALS Enroute Page with BOSS Symbology.

Under this TTCP collaborative program, the National Research Council (NRC) Canada test flew two new versions of the US provided BOSS symbology set (Figure A-20). This flight test was named Loon [8]. Variations of displaying target speed, landing position, vertical speed, and radar altitude were implemented. Pilots from Canada, UK, and US flew the variations in the Bell 412 aircraft at the Ottawa airport. Pilot comments were incorporated into the next version of the BOSS display. Most importantly, pilots demonstrated for the first time that they could perform approaches to landing without outside visuals in a real helicopter. This test would not have been conducted without the TTCP agreement in place. NRC continues to fly the BOSS symbology set for demonstrations to visiting student test pilots and other demonstrations.

Figure A-20a): National Research Council Canada Bell 412 Research Helicopter.

Figure A-20b): Pilot Flying Approach Using BOSS Display with Hood to Obscure the Out-the-Window View.

Separate from the Loon test, CAE Corporation developed the Augmented Visionics System in coordination with NRC Canada [10]. A Neptec LADAR was used to update a pre-stored terrain elevation database. The US designed BOSS symbology was then overlaid on top of the terrain and obstacle imagery (Figure A-21). This system was flight tested in 2010 at Yuma Proving Ground on the fly-by-wire Bell 412 operated by NRC Canada. Most of the terrain shown on the pilot's display was from a pre-stored terrain elevation database. New obstacles, detected by the LADAR, were shown as added blocks on the terrain, of approx. the same size as the obstacles. The system worked as designed, in actual flight conditions, and using real sensors.

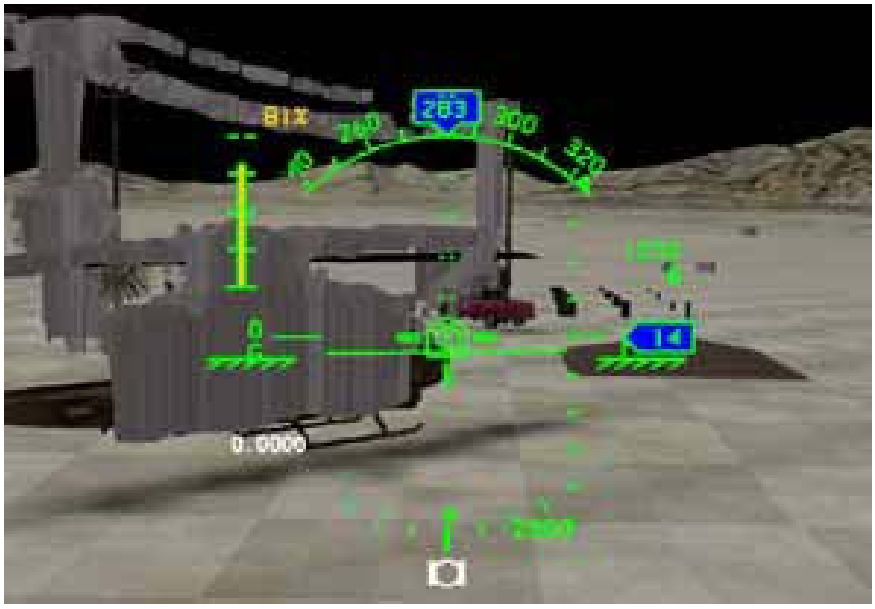

Figure A-21: CAE Corporation Augmented Visionics System (AVS) with BOSS Symbology Superimposed.

US efforts to further develop BOSS and couple it to a LADAR were implemented in the 3D-LZ program. The H.N. Burns Engineering Corp. LADAR system would provide the background image of the terrain and obstacles, with BOSS symbology superimposed to enable the safe control of the aircraft. Simulations were conducted at the US Army AFDD and the US Air Force Research Lab (AFRL) in 2008-9 [11]. Modifications included matching the switching linear scale of the velocity vector and target landing point symbol to the switching linear scale of the plan view LADAR imagery. As shown in Figure A-22, lateral speed at touchdown was improved to be less than 0.5 knots on average and even out to one standard deviation, except when the landing point is relocated by the pilot during the approach. The number on the x-axis in Figure A-22 is the distance to the top of the screen on the finest scale. Pilots were asked not to move the landing point until this finest scale was active. As shown, moving the landing point during the approach had negative effects on lateral speed at touchdown. The landing point was not moved during an approach in the actual flight test, but was moved during hover manoeuvres.

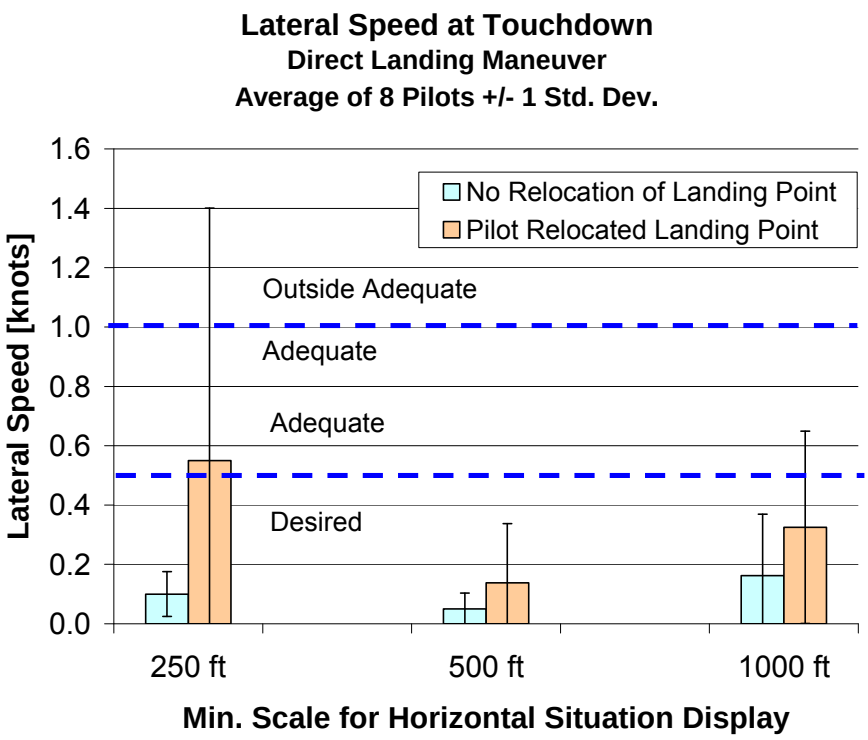

Figure A-22: Lateral Speed at Touchdown for BOSS Symbology (distance scale to top of screen shown on axis, speed scale was 1/10 the distance scale).

Check-out flights for the 3D-LZ system were conducted at Moffett Field with curtains installed on the windows. Finally, actual brown landings were conducted at the US Army Proving Ground near Yuma, Arizona in 2009 [12];[13]. Figure A-23 shows screen shots of four time-synchronized video streams, one before the brownout and one during the brownout. The LADAR had a dust rejection filter which had nearly 100% accuracy in rejecting dust returns. The LADAR was never turned off during the entire approach, landing, and take-off sequence and the 3-D database had imperceptible small amounts of points due to dust. As can be seen in Figure A-23, the pilot's vertical and horizontal situation displays looked nearly the same, before and after the dust; pilots were able to see obstacles during the entire manoeuvre.

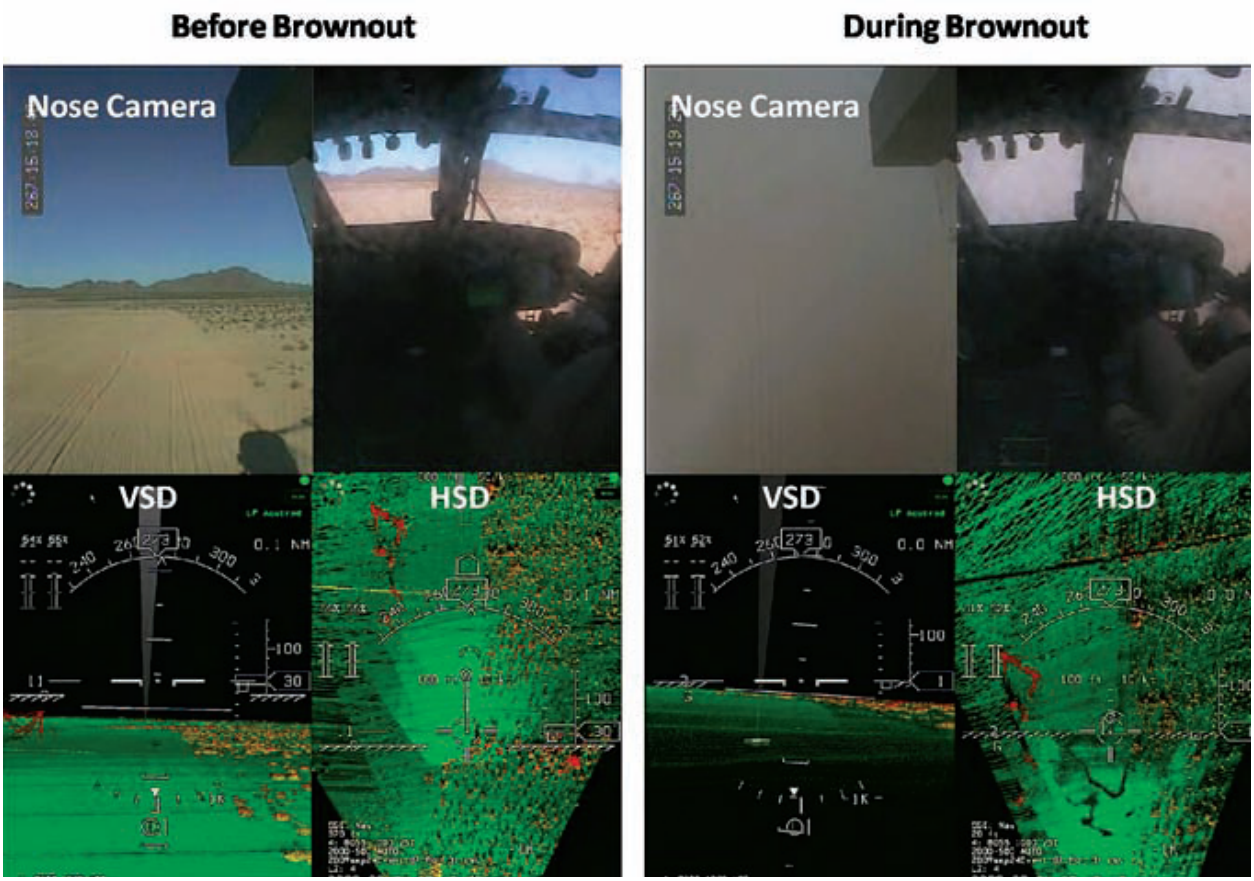

Figure A-23: 3D-LZ Display Screen Captures during Actual Brownout Landings in an EH-60L Aircraft.

Pilot data showed that vertical speed and longitudinal speed were within desired on average. Lateral speed was adequate on average, as opposed to desired (1/2 knot < lat. Speed < 1 knot). The flight control system was a standard rate-command UH-60L mechanical system with some stability augmentation, and heading hold. Improved handling qualities through better flight controls are expected to improve the lateral speed parameter. Of particular note during the flight test were two comments:

1) Pilots wanted to keep their eyes on a single display, with forward-view terrain and obstacle imagery.
2) Pilot workload was so high, pilots commented that they no extra capacity to look for obstacles in the terrain image near the landing point.

Pilots focused exclusively on the symbology near touchdown as that was required for safe control of the aircraft. Also, pilots were able to verify the landing site was clear of obstacles earlier in the approach.

Figure A-24 and Figure A-25 show the vertical and lateral speed parameters for each landing. The “switched display” is a single display that switches between a Vertical Situation Display (VSD) and a Horizontal Situation Display (HSD) at 40 knots. The “dual display” is two displays, one being a VSD and the other being an HSD the entire time. The single display condition was a baseline single display (combination of VSD and HSD), with infrared imagery in the background.

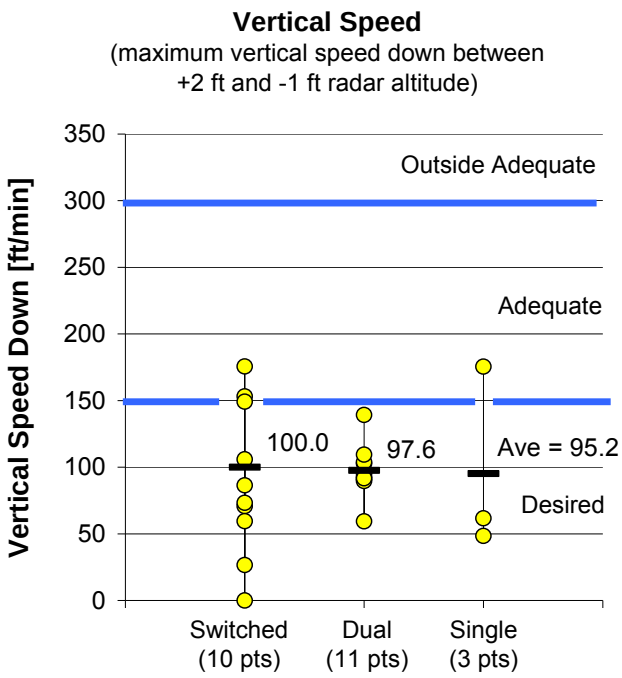

Figure A-24: Vertical Speed Recorded During All Brownout Landings.

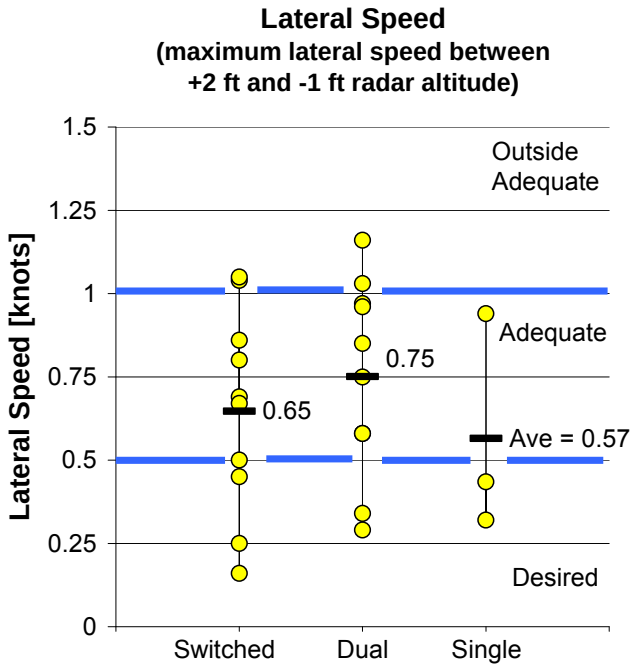

Figure A-25: Lateral Speed Recorded During All Brownout Landings.

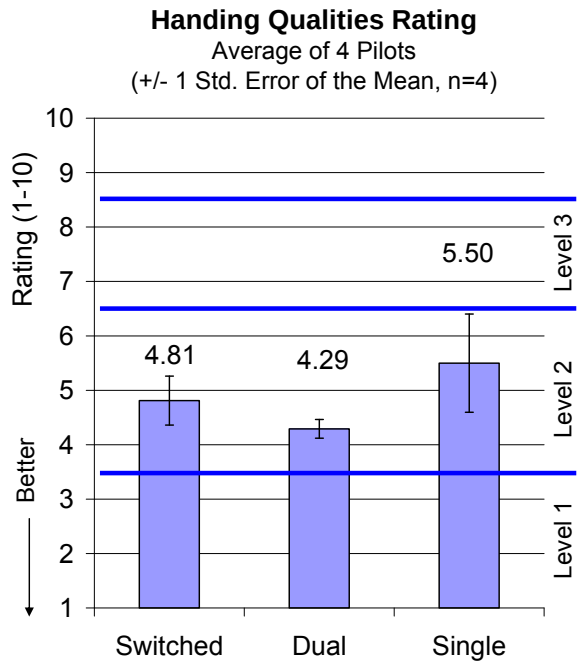

Figure A-26: HQR Rating for 3D-LZ.

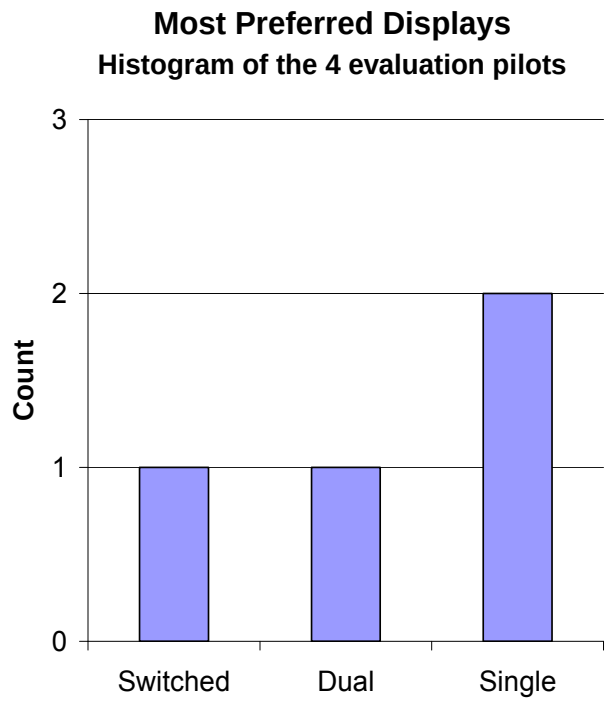

Figure A-27: Display Preference for 3D-LZ.

Two more simulations were conducted in the US at the US Army AFDD with eight pilots each. The first was to improve the guidance algorithms to make them more aggressive [14] to reduce the time in a brownout. The second simulation was to test a new logarithmic scale for current velocity, target velocity, and hover/ landing position [15]. Pilots from the US, Canada, and Australia participated in the second simulation. The logarithmic scale allows the entire approach from 80 knots to be performed without a scale change on any parameter, and represents a major step forward in display design. The most recent version of BOSS symbology is shown in Figure A-28, which represents several years of development as outlined in this report.

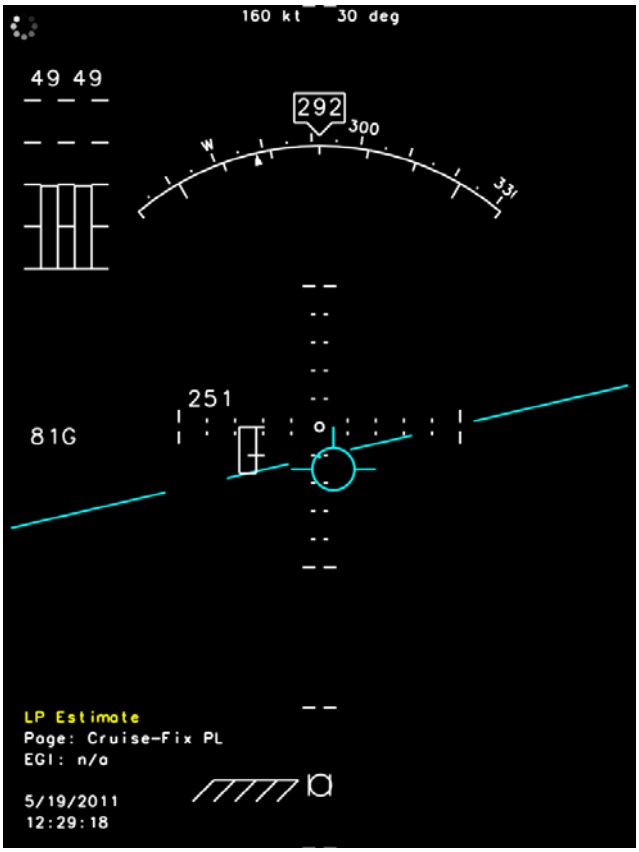

Figure A-28a): Final Configuration BOSS Enroute Page.

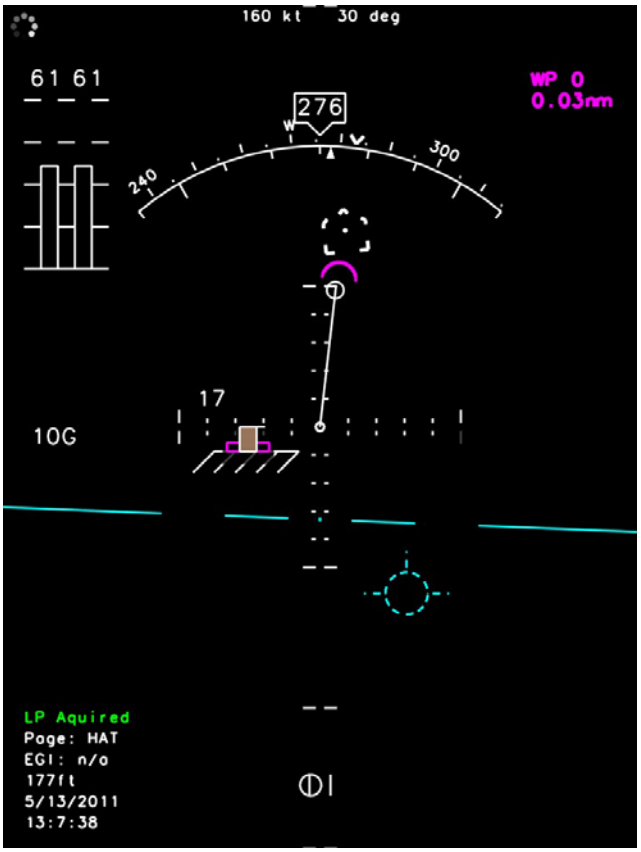

Figure A-28b): Final Configuration BOSS Hover-Approach-Take-Off Page.

The Australian Army has been operating the Aviator Night Vision Imaging System (ANVIS) Head-Up Display (HUD) with its Night Vision Goggles (NVGs) for a number of years. To assist the Royal Australian Navy as it heads towards NVG operations, AS conducted a simulation trial to evaluate the ANVIS HUD symbology for shipboard landings.

Figure A-29: ANVIS HUD Symbology Set.

Trials were held in DSTO's fixed-base simulator. The objectives of the trial were to assess the standard ANVIS-HUD for maritime operations and compare it with the Seahawk Head-Down Display (HDD). Three tasks were selected to evaluate the symbology set: launch and recovery of a Seahawk helicopter to a FFG frigate, along with a three-leg over land task flying over a diverse terrain database. Two highly experienced Navy pilots, both with in excess of 3000 rotary wing hours and over 1000 deck landings, participated in the trial. The NVG experience was 25 hours for one pilot and 200 hours for the other pilot. Neither pilot had any symbology experience however an experienced Army QFI presented a course on the symbology set prior to the trial and was available for discussions during the trial.

Figure A-30: Seahawk Operating to Frigate at Night.

Figure A-31: AS Simulation of Seahawk Operating to FFG Frigate with NVGs and HUD.

A qualitative evaluation via questionnaires took place and included the following parameters: Clutter, Display effectiveness, Individual symbology effectiveness, Attention capture and Display usage for the HUD, and Display usage and Display effectiveness for the HDD. A quantitative evaluation also occurred with over 100 variables being logged. Ship-based parameters during recovery included glideslope maintenance and closure rate, and during launch included helicopter pitch variation and launch time.

Although the sample size was small, qualitative results indicated that for certain tasks the HUD provided better flight path assessment, better control, less errors, and improved flight safety due to more head out time. Quantitative results indicated that the HUD led to reduced launch time and less pitch correction required on launch compared to the HDD.

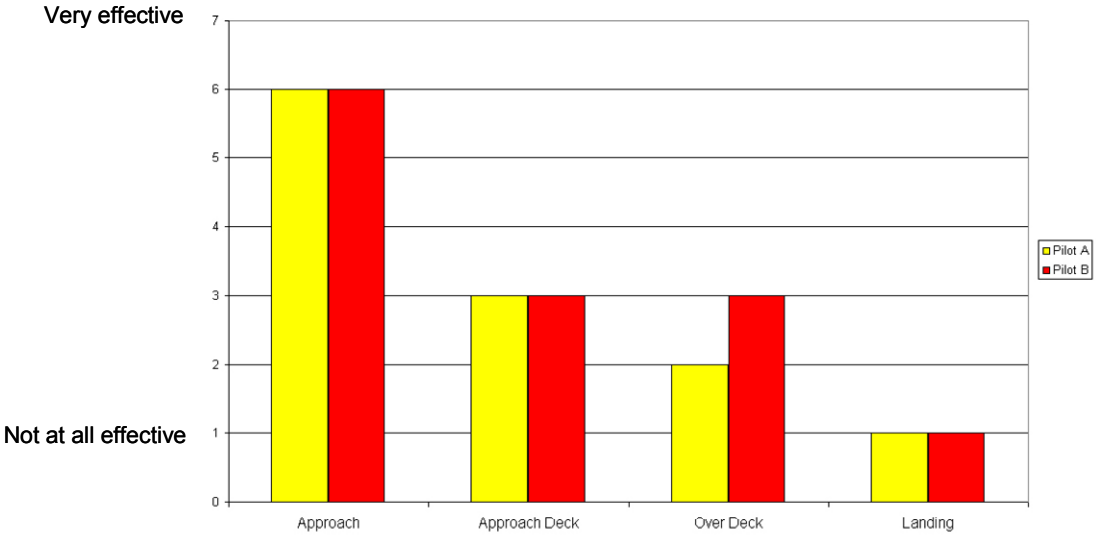

Figure A-32: HUD Effectiveness Ratings – Ship Recovery.

As a result of the simulation trial, some modifications to the ANVIS-HUD were proposed for further testing. Results were documented in [16].

A.3 CONCLUSIONS

A complete system to aid the pilot in brownout hover, landing and take-off should include symbology (for aircraft state), sensor information (for obstacles and terrain slope), and advanced flight controls (for improved handling qualities). A minimal system would have symbology only, to improve the pilot's ability to control the aircraft and avoid spatial disorientation. Symbology, by itself, does not improve the pilot's situational awareness of the landing zone slope and obstacles, but through procedure this can be managed to some extent. Simulation tools were used effectively prior to flight test by all four participating Nations. Canada, US and UK have demonstrated simulated brownout hover and landings in real aircraft, using symbology solutions overlaid on top of terrain imagery. In addition the US has demonstrated real brownout landings using symbology and LADAR imagery. There is full expectation that these systems will reduce brownout accidents if installed into the fleet.

A.4 RECOMMENDATIONS

Two different approaches to the symbology were developed. The UK developed the Low Visibility Landing (LVL) symbology. The US developed the BrownOut Symbology System (BOSS). A comparison of these two approaches is the next logical step, and is proposed under SA 2C.7 (DVEST).

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A.6 ANNEX A – PERSONNEL AND ORGANIZATIONS INVOLVED

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