# Sensor-Based Technology for Rotary Wing Aircraft in Low Visibility Environments

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## *ABSTRACT*

*Over the past several decades, low visibility operations have created major safety issues for rotary wing aircraft. In fact, 58% of helicopter losses and 52% of fatalities resulting from non-hostile actions are due to degraded visual environments (DVE). Landings in unprepared landing areas and low altitude, terrain following flight are particularly problematic due to risks of impact with ground obstructions such as wires, trees, fences, etc. To help restore visual references for low visibility flight and landings, a variety of sensor technologies have been developed. This paper will cover some of the primary sensor development efforts led by the US Department of Defence over the past decade. Due to their capabilities of providing imagery to the pilots, many of the developments have focused on radar and Laser Detection and Ranging (LADAR) sensors. Programs such as Helicopter Autonomous Landing System (HALS), the DARPA-funded Sandblaster program, the Electronic Bumper concept, and the Brownout Landing Aid System Technology (BLAST) developed by BAE have focused on radar solutions due the ability to image objects through environmental obstructions such as dust clouds. The Three-Dimensional Landing Zone (3D-LZ) system utilized a LADAR sensor to take advantage of its high resolution imaging capabilities. Designed by H.N. Burns Engineering, the system included a small particle tolerant scanning Laser Detection and Ranging (LADAR) sensor, a navigation database, and a graphics engine to display the imagery to the pilot. The imagery was overlaid by the Brownout Symbology System (BOSS) developed by the U.S. Army Aviation & Missile Research, Development and Engineering Center (AMRDEC). The BOSS system included landing guidance algorithms that drove symbols relating to control inputs to guide the pilot to the landing point. Versions of the system were flight tested by the US Army, Air Force, and Navy pilots in full Brownout conditions at Yuma Proving Grounds in 2009, 2014, and 2016. With 3D-LZ, pilots were able to safely land near obstructions in full brownout conditions with low velocities. The LADAR system was shown to successfully reject returns from the dust cloud and maintain a clear display of the ground for the pilots. Further, the LADAR was able to render the ground terrain/obstructions in high detail and resolution, including small rocks, wires, holes, ditches, berms, and fence posts. However, the CENTCOM Military Utility Assessment of 2016 determined that the 3D-LZ system provided no military utility. These conclusions were in stark contrast to the evidence and observations of the evaluation pilots.*

## 1.0 INTRODUCTION

Due to the reliance on environmental visual cues, landing rotary wing aircraft in low visibility conditions present a major safety concern and reduce joint forces operations. Furthermore, military operations often involve maintaining altitudes close to the ground. Consequently, wire strikes and controlled flight into terrain (CFIT) present additional risks to operational crews in low visibility conditions. In Operation Iraqi Freedom (OIF) and

Operation Enduring Freedom (OEF), there were 266 aircraft lost and 329 fatalities from non-combat mishaps compared to just 65 aircraft lost and 140 fatalities from combat incidents. According to the Rotorcraft Survivability Study, Joint Aircraft Survivability Program Office (2009), 80% of all helicopter mishaps are due to non-hostile action. Of these mishaps, 58% of the aircraft losses and 52% of the fatalities were caused by a degraded visual environment (DVE) resulting in CFIT, a wire/object strike, dynamic rollover, or a hard landing. The 2009 Department of Defence Aviation Safety Technologies Report called for an integrated system to increase the ability to provide visibility through dust obscurants or image the terrain prior to the manifestation of the dust cloud, save this information, and then display it to the pilots while the obscurants are present (often referred to as "see and remember"). The report also suggests that improved symbology to enhance situational awareness of the pilot may mitigate accidents. The system requirements were further driven by the Resource Management Directive 700. This document directs services to acquire Helicopter Terrain Awareness and Warning System (HTAWS) capability for all fleet helicopters as a solution to mitigate CFIT. Taken together, the military required a system capable of providing safe landings and safe terrain following operations (including wire strike detection/warnings) in low visibility conditions to reduce CFIT, hard landings, roll-overs, and impacts with obstructions.

## 2.0 MAJOR DVE SENSOR DEVELOPMENT PROGRAMS

### 2.1 Helicopter Autonomous Landing System (HALS)

Originally designed to quell the safety concerns of landing in brownout conditions, the US Army's Helicopter Autonomous Landing System (HALS) can handle a wide variety of DVE environments including darkness, smoke, fog, dust, sand, and dry snow. Developed by the Sierra Nevada Corporation, the HALS system relies on a 3D scanning, 94 GHz pulsed radar with a 1 degree pencil beam. Figure 1 provides photographs of the radar system, visual display, and radar hardware. While the sensor field of view of is $30^o$ x $30^o$, the imagery generated from the sensor feed is then fused with digital terrain elevation database (DTED) imagery to make a visual display for the pilots that is $60^o$ x $60^o$. Figure 2 provides examples of images generated from the radar returns compared with photographs of the same terrain. The imagery is then overlaid with the BrownOut Symbology System (BOSS) developed by Army researchers from the Air Flight Dynamics Directorate (AFDD). The BOSS symbology provides both aircraft state information and guidance to planned waypoints and landing points. A detailed description of the BOSS symbology can be found in Szbozslay, et al., (2014).

Because the HALS radar is transparent to small particles such as dust and dry snow, the system permits imaging of the environment even after the outside visual environment is completely obscured. As a result, multi-ship formations and multi-ship landings are possible using this system (Szoboszlay, et al., 2014). Landing a series of aircraft in the same area where brownout conditions are present can present hazards without an imaging system such as HALS. The first aircraft to land often generates a brownout cloud that does not quickly dissipate. Hence, the landing site is now masked for the aircraft waiting to land. Furthermore, the aircraft that have landed now serve as additional obstacles in the landing zone. Because the US Army often use multi-ship formations, the system was required to "see through" obscurants such as brownout dust clouds.

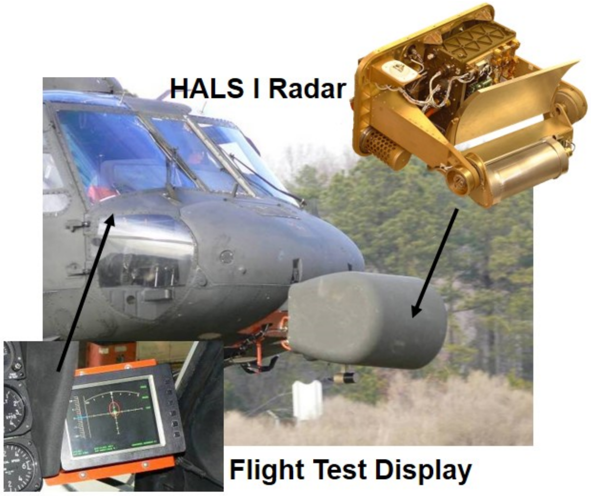

Figure 1. HALS I RADAR and Display systems

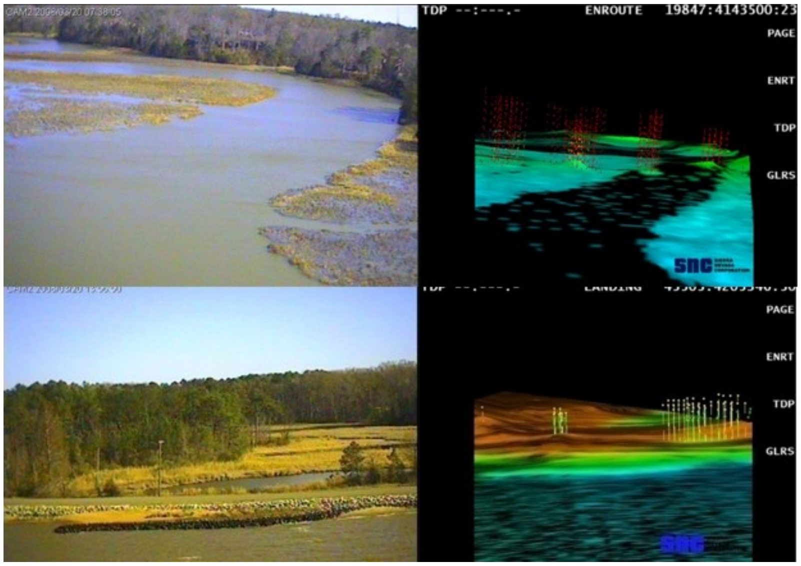

Figure 2. Photograph images (left panes) versus HALS radar imagery (right panes)

The HALS system has been successfully flight tested on an EH-60L helicopter (Cross, Schneider, & Cariani, 2013). The flight test revealed the HALS system can perform well in a variety of situations ranging from landing in full brown-out DVE conditions to low-level flight over mountainous terrain. Furthermore, the system was able to detect wire/cable obstructions during such low-level flights.

## 2.2 Sandblaster

In response to the growing need for a technological solution to help reduce the risks of landing rotorcraft in brownout conditions, DARPA sponsored a program entitled “Sandblaster.” The contract was awarded to Sikorsky Aircraft Corp. (teamed with Honeywell and the Sierra Nevada Corp.) to develop a system to quell the safety issues surrounding helicopter take-off and landings in “brownout” conditions. Specifically, the program called for the system to operate in zero visibility conditions with limited a priori information regarding an unprepared landing site. The system focused on the advancement of sensors to image the landing zone and visual displays to replace the pilots' visual cues during these critical phases of flight. The resulting architecture, known as the "Sensor data-driven, Localized, External, Evidential Knowledge base (SLEEK) was used to integrate the sensor data with Digital Terrain Elevation Data (DTED) databases and symbology for the pilots' displays. The resulting synthetic imagery was provided in a pilot's perspective view. Figure 3 provides a screenshot of the final display.

**Figure 3. Sikorsky's "SLEEK" pilot display from DARPA's sandblaster program**

For the sensor, the team used Sierra Nevada Corp's 94 Ghz Millimeter Wave (MMW) radar. This sensor provides a "see-through" capability for brownout take-off and landing manoeuvres. Similar to the HALS program, this "see-though" sensor was critical in meeting the US Army's requirement to perform multi-ship operations. However, it should be noted that the radar's imagery provides much lower resolution imagery compared to LADAR systems and does not provide sufficient detail to perceive the identity of many of the ground obstructions. The sensor was used to populate an external evidence grid based on the probability of an object occupying a segment of the grid. This was integrated with an on-board terrain map to provide an obstacle map.

The Sandblaster system also leveraged a planned "fly-by-wire" upgrade for the US Army's UH-60 platform, known as the UH-60M variant. Sikorsky provided advanced flight controls that greatly simplified the control inputs needed from the pilot to perform landing operations. Known as a "coupled approach," the Sandblaster's flight director algorithms would essentially allow the aircraft to fly a stable hover above the pre-planned landing site with almost no input from the pilot. Using a button on the cyclic, the pilot could then lower the aircraft down to the ground. The symbology also provided predictive flight path guidance to increase the pilot's situational awareness. If the pilot determined that the landing zone was unsuitable for a landing, the landing point could be repositioned on the fly using a directional switch on the cyclic control stick.

The final sandblaster system was successfully tested in flight in February, 2009 using the U.S. Army Aeroflight Dynamics Directorate (AFDD), AMRDEC's UH-60 test aircraft located at Ames Research Center, Moffett Field, CA. Although the flight test did not include brownout conditions, a total of 3 pilots were able test the system for 2 hours each with no system failures. Tests included take-off and landing manoeuvres in 3 different landing zones with a variety of terrain and proximate obstacles. Unfortunately, the UH-60M upgrade was cancelled and the Sandblaster system was never deployed in an operational context.

## 2.3 Electronic Bumper Radar

Under the US Air Force's Small Business Innovative Research (SBIR) program, an effort known as "Electronic Bumper" was developed. The concept was to build a low-cost, light weight sensor suite to provide increased safety during DVE landings. The goal was a package weighing 10 pounds or less that cost less than $10K capable of sensing stationary or moving obstacles 360$^o$ around the aircraft during landings in DVE. Furthermore, the electronic bumper system was to provide cable warnings and obstacle avoidance to the pilot during such manoeuvres. The final configuration(s) was required to be both an add-on kit for legacy aircraft as well as a fully integrated solution for advanced aircraft.

The "electronic bumper" system concept originated from analogous sensors integrated into the bumpers of automobiles. Such sensors provide gross collision avoidance cues to the driver, particularly during parking or reverse manoeuvres where the driver's field of view is limited. The system for the helicopter needed to incorporate the elevation axis and sense obstacles all the way around the aircraft rather than simply the front and rear. Preliminary designs called for a series of small Electronically Reconfigurable Antenna (ERA) sensors, each of which could cover 90$^o$ of azimuth angle (see figure 4).

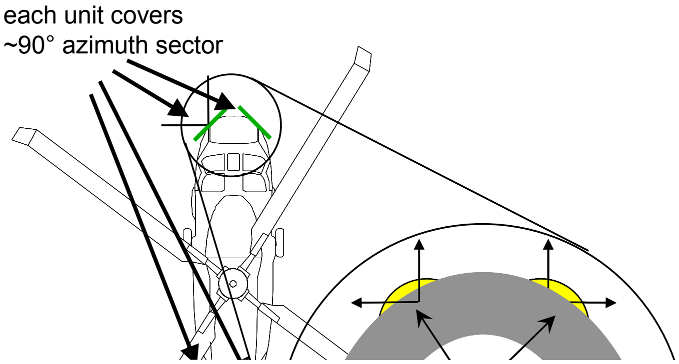

Figure 4. Electronic Bumper Concept

To convey the sensor data to the pilot, an innovative display concept known as the "rubber band" symbology was developed by the US Air Force. Using plan view DTED or LADAR imagery as a reference, a circular band representing a set distance around the aircraft would be provided. This virtual band around the aircraft would then be inflected at the spots where obstacles were encountered, similar to the reaction of a rubber band. Figure 5 provides an illustration of the display concept, where the center crosshair represents the position of the pilot's aircraft.

Figure 5. "Rubber Band" Display Concept

Although promising, the electronic bumper program never led to a fieldable system. This concept has largely been abandoned in lieu of other more promising technology.

## 2.4 "BLAST" Radar

Because many of the US military helicopters are heavier than intended, adding more systems that increase the weight are extremely undesirable. Consequently, the Brownout Landing Aid System Technology (BLAST) program was developed in another attempt to provide a light-weight obstacle detection capability in DVE conditions. Led by BAE Systems, the BLAST program used a commercial 94 GHz MMW technology that had already been fielded in other systems. Similar to the HALS and Sandblaster radars, the sensor can sense the ground terrain and obstacles through obscurants such as dirt, dust, smoke, and fog. The primary advantage of the BLAST radar is in its compact, lightweight package weighing in at a mere 10 lbs. The radar uses a 1 degree pencil beam in a 2D mechanical scan (+/- $34^{o}$ in both axes). It also utilizes a dual axis monopulse antennae that improves angular accuracy 10 to 1 with a 15dB signal to noise ratio. The scan pattern was optimized for a target landing zone.

The radar is paired with a visual display presented in first person perspective. Similar to HALS and Sandblaster, the sensor imagery is overlaid with unique symbology to provide the pilot with aircraft state and navigational information. The sensor imagery can be integrated with DTED databases to provide terrain rendering. Due to the improved spatial accuracy, the BLAST radar provides good definition of obstacles and their shapes. Figure 6 provides an example image of the sensor display without the symbology.

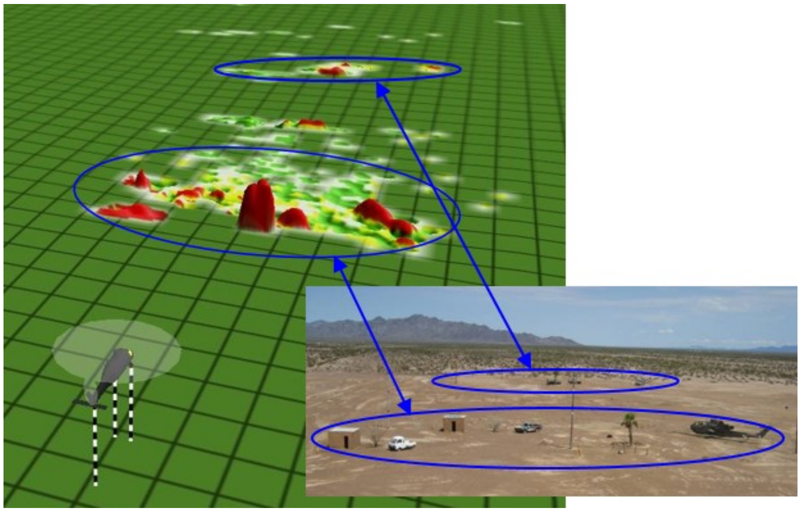

Figure 6. BLAST Radar sensor display imagery

The BAE BLAST system was tested in full brownout conditions on a Bell UH-1 test aircraft in April, 2011 at the Yuma Proving Grounds in Arizona. This test put the technology readiness level at 6, meaning that the technology had been tested in a relevant environment. The results of the flight test showed that the system could detect ground obstructions in brownout conditions and the symbology was able to provide all of the appropriate aircraft state information to allow the pilot to fly safely. The BLAST radar remains a light-weight, small sensor option for DVE applications.

## 2.5 Three-Dimensional Landing Zone (3D-LZ)

Originating from a systems engineering analysis of the US Air Force's operational requirements for rotorcraft operations in brownout conditions, the 3D-LZ program was developed initially for the combat search and rescue (CSAR) UH-60 aircraft. Because the Air Force's rotary-wing aircraft often land in unprepared landing zones, small obstacles that are difficult to detect during final approach such as wires, ditches, berms, rocks, vehicles, fence posts, etc. can present potential dangers to the aircraft and crew during landings. As a result, the DVE solution was be required to provide the pilots with detailed imagery of the landing zone with a specific ability to image small obstacles near the pre-planned landing point.

The resulting 3D-LZ system was comprised of a high-performance small-particle tolerant LADAR, a database that integrates navigational Digital Terrain Elevation Data (DTED) with data collected from the LADAR, a powerful processing and rendering engine to produce imagery for the pilot display, and an symbology set to provide the pilot with both vehicle state information and guidance to the landing point. The system also includes proprietary "dust rejection" algorithms that discard LADAR returns from dust particles. This prevents the database from being populated with the dust cloud and keeps the display clear of obscurants. Because the LADAR is an optically-based sensor, it cannot see-through the dust like a 94Gz radar. Hence, it is often referred to as a "see-and-remember" system as it images the terrain prior to the development of obscurants (such as dust) and stores the data in an on-board digital database. However, the LADAR does continue to receive some returns from hard targets and these returns are included in the database when received. The LADAR system and supporting architecture was developed by the H.N. Burns Engineering Corporation (HNB) while the symbology was produced by the Army's Aeroflight Dynamics Directorate. Early development of the landing guidance was completed by the Air Force Research Laboratory's Sensors Directorate in collaboration with the Human effectiveness Directorate.

The 3D-LZ system completed its first flight test in full brownout conditions at Yuma Proving Grounds in 2009 (Harrington, et al., 2010). The system included a color camera co-bore sighted with LADAR. This allowed the system to sample the true color of each LADAR return. While only useful in daytime conditions, this capability provides the pilot with near photographic detail of the landing zone. The display also used a false color scheme based on the elevation of the object above or below the planned landing point. This allowed the pilot to quickly assess the level of risk the object presented (i.e. rotor strike hazard or fuselage/landing gear hazard). A total of two displays were presented to the pilot: one plan view (i.e. birds eye view) and the other first person perspective view from the pilot's eye point. The perspective view was designed to provide the pilot with a traditional "out the window" view while the plan view provided situational awareness 360$^{o}$ around the aircraft. However, this design was later simplified to a single display due to the increased workload of dividing attention between the two displays during difficult DVE landings. This flight test provided initial evidence that the 3D-LZ system allowed pilots to perform safe, controlled landings in zero visibility without significant flight control modifications. In addition, the LADAR performed well in detecting small obstacles even in heavy dust. Nevertheless, the pilot workload remained high which limited the cognitive resources available to perceive and process sensor imagery presented in the display.

Over the next 6 years, the 3D-LZ system continued to undergo improvements and refinements in terms of the sensor, guidance algorithms, and the display/symbology. Additional flight tests were conducted in 2013 and 2016 at Yuma Proving Grounds in full brownout conditions. The details of the 2016 flight test is covered in another report under this lecture series. It should be noted that the 2016 flight test examined a LADAR by Sierra Nevada Corporation and another by Arete. The SNC sensor suite included radar (SNC, Sparks Nevada), a LADAR (Neptec Opal 120, Kanata Ontario Canada), an infrared camera (DRS 720p, Arlington Virginia) while the Arete suite used a LADAR (Areté, Colorado), an infrared camera (DRS 720p, Arlington Virginia). Similar to the Sandblaster program, both sensor systems fused DTED data with the sensor imagery to provide improved situational awareness. Obstacles were highlighted with false colors (e.g. yellow or red) based on elevation thresholds. An example image of the sensor displays is provided in figure 7. The flight tests demonstrated that pilots could land safely in full brownout conditions with low speeds in all 3 axes. In addition, pilots landed within 22 feet of the intended landing point.

In parallel, a Joint Capability Technology Demonstration (JCTD) program was initiated to redesign the existing Q-29 forward looking infrared (FLIR) sensor ball to incorporate a LADAR sensor (Savage, et al., 2014). The contract was awarded to Ratheon, corporation who began designing a new sensor ball known as the multi-function LADAR (MFL) that included room for both the existing FLIR sensor and the high-performance LADAR (see figure 8). The JCTD was successful in completing the design, although prototype systems were not produced under this program. The future implementation and manufacture of this sensor package largely depends on whether the Air Force decides to field the 3D-LZ system. Because a Military Utility Assessment Report determined the system has "no military utility" the implementation of the 3D-LZ technology is uncertain. It should be noted that this report was contradicted by opinions of the pilots that participated in the flight tests.

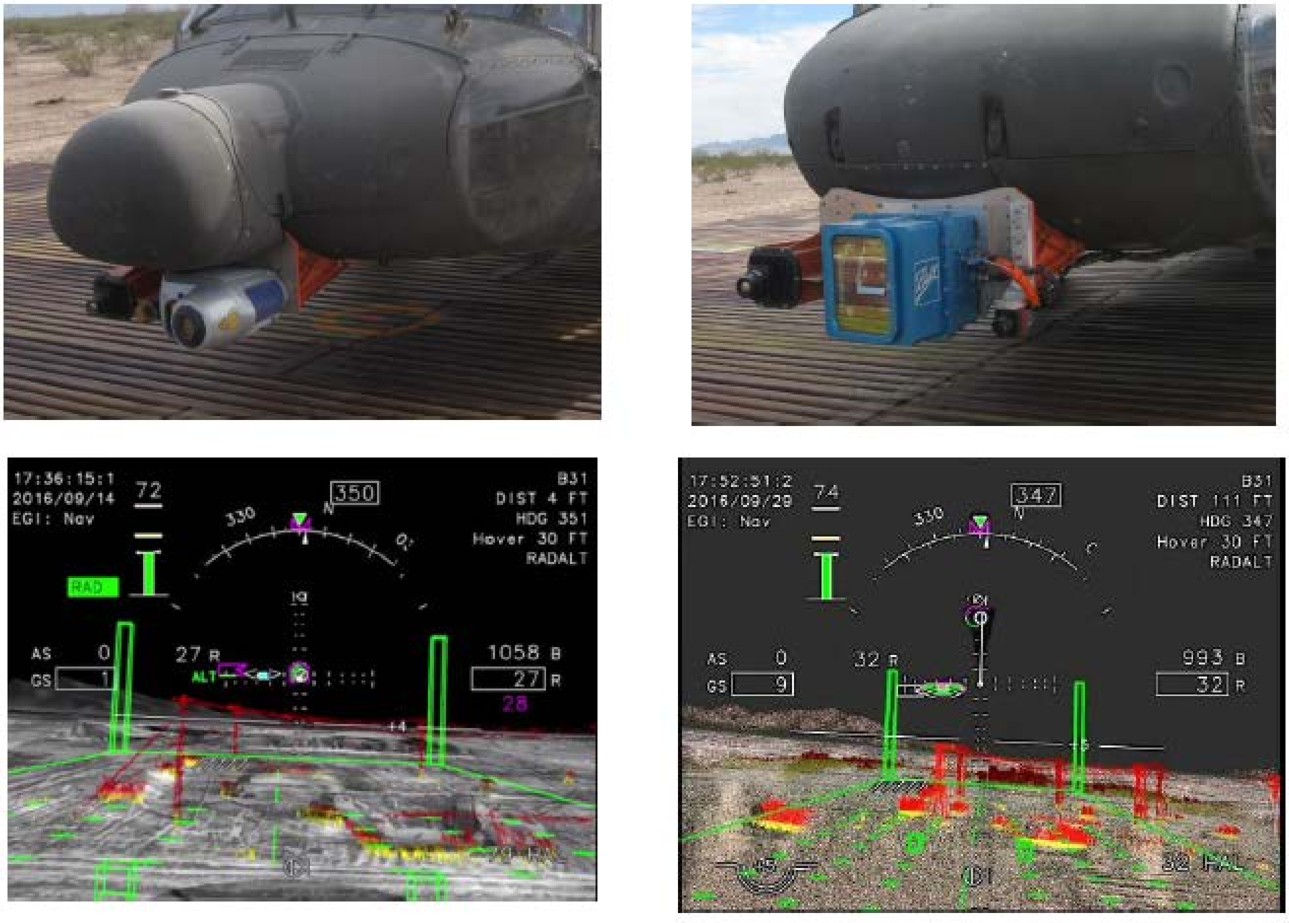

Figure 7. SNC sensor system (Left) and Arete sensor system (right) during the 2016 3D-LZ flight test

Figure 8. Ratheon Sensor Turret

## 3.0 CONCLUSIONS

Over the past 10 years, there have been several large DVE solution programs implemented by the DoD, largely in response to the growing operational need to prevent mishaps and improve safety of the aircrew and passengers. Many of the programs have followed a similar trajectory and system configuration consisting of several key elements including sensor(s), a pilot display of the sensor imagery fused with DTED data, a symbology overlay, and a false colorization scheme to convey elevation information. The major differences between the programs lie primary with the choice of sensor technology. These choices are largely driven by the performance requirements and budget of the sponsoring service. Nearly all of the US programs have used wither radar or LADAR sensors. Radar technologies have ability to penetrate obscurants such as dust, but are unable to provide detail of the imaged objects. Hence, pilots are able to know the location of objects, but not necessarily what the objects are. Nevertheless, these systems can detect new objects entering the landing and are compatible with multi-ship landings. Conversely, the LADAR sensors can provide high-resolution, nearly photo-realistic images of the landing zone but are unable to adequately penetrate obscurants. Because this sensor technology relies on a “see and remember” strategy, it is unlikely to produce useful imagery if the landing site is already obscured when the pilot begins the final approach. This is particularly problematic in brownout conditions when a lead aircraft lands and obscures the landing zone for aircraft landing subsequently. Emerging sensor fusion techniques (e.g. SNC and Arete’s 3D-LZ systems) may allow engineers to take advantage of the strengths of multiple sensors in a blended pilot display. While such DVE sensor solutions have not yet been fielded, the technology has matured rapidly over the past several years. It is anticipated that DVE systems will be in place in the near future.

## 4.0 REFERENCES

Szoboszlay, Z. P., Fujizawa, B. T., Ott, C. R., Savage, J. C., Goodrich, S. M., McKinley, R. A., & Soukup, J. R. (2014, May). 3D-LZ Flight Test of 2013: Landing an EH-60L Helicopter in a Brownout Degraded Visual Environment. In Proc. of AHS 70th Annual Forum, Montréal, Québec, Canada.

Cross, J., Schneider, J., Cariani, P. (2013, May). MMW radar enhanced vision systems: the Helicopter Autonomous Landing System (HALS) and Radar-Enhanced Vision System (REVS) are rotary and fixed wing enhanced flight vision systems that enable safe flight operations in degraded visual environments. In Proc. SPIE 8737, Degraded Visual Environments: Enhanced, Synthetic, and External Vision Solutions 87370G.

Harrington, W., Braddom, S., Savage, J., Szoboszlay, Z., McKinley, R.A., Burns, H.N. (2010). 3D-LZ Brownout Landing Solution. In Proc. of AHS 66th Annual Forum, Pheonix, AZ.

Savage J., Goodrich S., Ott C., Szoboszlay Z., Perez A., Burns H., "Three-dimensional landing zone joint capability technology demonstration,” *Proceedings of the SPIE Defense and Security Symposium, DVE Sensors II*, Baltimore, Maryland, May 2014.