Making Sense of Sandblaster

DARPA looks to transition the brownout landing system from a successful demonstration to a production application.

By Frank Colucci

Safety Spotlight

Clear-air tests of the Sandblaster brownout landing system this January showed synthetic vision integrated with millimeter wave radar and fly-by-wire flight controls could indeed help pilots land safely in degraded visual environments. The US Defense Advanced Research Projects Agency (DARPA) sponsored 39 hours of Sandblaster Phase II flight tests at Moffett Field, California on the RASCAL (Rotorcraft Aircrew Systems Concepts Airborne Laboratory) Black Hawk. The Army Aeroflightdynamics Directorate (AFDD) provided the JUH-60A helicopter with its research flight control system and cockpit displays. Under DARPA contract, Sikorsky Aircraft integrated point-in-space flight control software with a Honeywell terrain database and Sierra Nevada Corporation (SNC) radar. The Sandblaster system took the fly-by-wire RASCAL to a 25 ft safety hover hands-off in simulated brownout and showed pilots landing zone obstacles on a head-down display. "The limit was the limit placed on RASCAL," explains DARPA program manager Dr. Derek Tournear. "There was nothing in the Sandblaster system that would have prevented us from going all the way to the ground." Actual brownout landings will nevertheless have to wait for Sandblaster Phase III development, and DARPA now looks for military sponsors to transition the promising technologies to production. According to Dr. Tournear, "We're in discussions with the Army, US Special Operations Command, the US Marines and Navy, and the Air Force. The primary focus is to look at what they want to see done. They all have different needs."

All of the US armed services consider landings in dense, recirculating dust, sand or snow a hazard to helicopters and tilt rotors (see *Vertiflite*, Spring 2007). The Office of the Under Secretary for Defense Installations and Environment notes brownout mishaps cost more than $100 million per year and accounted for a third of all helicopter accidents in Operations Enduring and Iraqi Freedom. Sandblaster Phase I characterized the dust clouds generated by specific US military rotorcraft. The Phase II demonstration gave DARPA brownout test data and cockpit video correlated with radar returns and the SLEEK (Sensor-driven Localized External Evidence Knowledge) database. It also gave the US government the complete design for the prototype system. Sikorsky Sandblaster principal engineer Brad Kronauer observes, "The system is really a great starting point and integration piece for future capability."

The DARPA Strategic Technology Office chose the Sikorsky team in 2006 to build an affordable, self-contained brownout landing system compatible with existing aircraft such as the UH-60 Black Hawk. Target price was $175,000 per unit per vehicle with a weight less than 50 lb. Dr. Tournear says, "Right now, we still believe that target price is what we're shooting for, but we're trying to get that weight below 30 pounds." The Sandblaster demonstration system weighed about 150 lb including the nose radar and the synthetic vision processor behind the cockpit.

The RASCAL Black Hawk (left) with nose-mounted radar demonstrated the Sandblaster system at Moffett Field, California in January. The JUH-60A has a fly-by-wire research flight control system and multifunction cockpit displays to implement the Sandblaster point-in-space control logic and show synthetic vision displays.

A production processor could fill two circuit cards, and a production system could benefit from lower-cost radar technologies. However, different operational users may want a brownout solution integrated with different capabilities and sensors. Dr. Tournear notes, "We did enforce that Sandblaster was basically sensor-agnostic so we could plug in additional sensors, or sensors in place of the ones we had in Sandblaster." The Air Force Research Laboratory and Office of Naval Research continue their see-through sensor work to defeat brownout, and the Army has shown interest in a multi-mode radar for more than just landing.

Last spring, the Army Aviation Applied Technology Directorate (AATD) successfully tested the Helicopter Autonomous Landing System (HALS II) radar in real brownout at Yuma, Arizona. HALS II and Sandblaster test pilot CW4 Terry Duquette explains, "We fully demonstrated that 94 GHz radar can see through with no perceptible degradation in full brownout conditions." However, unlike the smaller, simpler Sandblaster radar, HALS II can be used to avoid obstacles including powerlines enroute to a landing. HALS II software was used to clean up the Sandblaster radar output for the SLEEK synthetic vision processor and RASCAL displays. A more advanced HALS III radar may fly on a production-representative BLACK HAWK in 2010.

Pieces of the Picture

The Sandblaster team integrated four key technologies: fly-by-wire flight controls with point-in-space approach capability, millimeter-wave radar, a digital terrain knowledge grid, and low-speed cockpit symbology. All the pieces came together in simulators before flying in the RASCAL Black Hawk. "We did leverage simulation quite a bit in the integration and development of Sandblaster," says Mr. Kronauer. "We went from simulation of synthetic vision into driving the LRUs [Line Replaceable Units] using the real control laws." Non-realtime desktop computer simulations led to a high-fidelity fixed-base simulator with a pilot in the realtime loop. The Sandblaster Pilot-Vehicle Interface first displayed the simulated radar-only view of the world and later integrated synthetic vision scenes generated by the actual SLEEK processor.

Sikorsky certified point-in-space approaches for the S-92 Search and Rescue helicopter. Sandblaster flight controls used the same block diagrams interfaced with the fly-by-wire control laws developed for the UH-60M Upgrade. However, while S-92 SAR software commits the pilot to a selected termination point, Sandblaster

Sandblaster demonstration flights were flown at Moffett Field in clear air down to a 25 ft safety hover dictated by the RASCAL testbed. The flights nevertheless showed the system could fly to a landing hover hands-off and show pilots obstacles in the chosen landing zone.

enables the pilot to modify the approach around obstacles seen on the RASCAL display. According to Mr. Kronauer, "The whole point of the program was to allow the pilot to use the data from the radar to make a judgement whether that planned point was appropriate to the landing zone." With a symbolic view of the landing zone, the pilot is able to select a hover point and then "beep" collective down to the ground without rollover, excessive descent rates or collisions.

Sandblaster flight control logic developed in the Sikorsky simulator in Connecticut went to the RASCAL Development Facility in California to run on a flight control computer identical to that in the research helicopter. The RASCAL Black Hawk was already used to develop control laws for the coming UH-60M Upgrade. Sandblaster logic was integrated with RASCAL flight control software and tested in the lab before installation on the JUH-60A. AFDD engineers meanwhile designed and fabricated Sandblaster aircraft modifications installed by maintenance contractor L-3 Vertex. SNC technicians installed and later removed the Sandblaster radar.

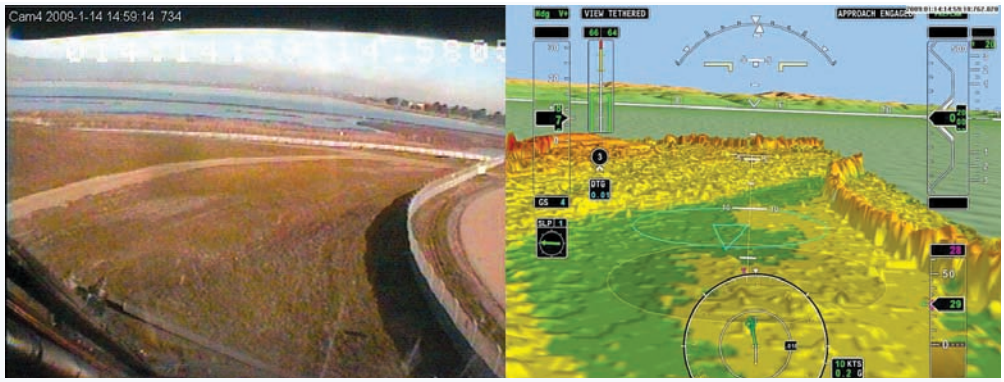
The fixed-azimuth Sandblaster radar was designed to spot obstacles from only 1,000 ft to touchdown. The HALS II radar with selectable azimuth works from 6,000 ft to touchdown and can warn of obstacles in cruising flight. Range and azimuth of millimeter wave radars are tied to aperture size, and the 94 GHz band selected for Sandblaster and HALS II required an antenna about a third as large as a 35 GHz alternative. Image quality from mechanically scanned radars is usually limited by how fast the antenna can scan. However, rolling drum technology in both SNC radars makes fast scans without blurring, and the company is working on electronically scanned arrays for future sensors.

Sandblaster overlaid the radar symbology on Digital Terrain Elevation Data (DTED) compiled by the National Geospatial-Intelligence Agency. The Honeywell SLEEK merged the stored data and realtime returns to generate a cartoon-like representation of upcoming terrain with obstacles. "The Sandblaster viewpoint is fairly unique," says Dr. Tournear. "The viewpoint is behind and above the helicopter. On your synthetic vision display, you can see 360° around your helicopter, much like if you were playing a video game. . . . The pilots really enjoyed that."

Sandblaster symbology was derived from that used on Honeywell's fixed-wing Integrated Primary Flight Display (IPFD). "We didn't do anything exotic with the symbology," explains Sikorsky chief Research & Development pilot Russ Stiles. "If we went way out and did this exotic system, it would be much harder to integrate with the UH-60M." He adds, "We took advantage of everything that's going on behind the scenes with the radar and evidence grid and created a display that's very easy to use. It doesn't take a lot of interpretation."

Hands Off, To A Point

The Sandblaster approach display annotates the SLEEK terrain grid with deceleration and radar entry points. The radar entry point defines a 6° glide path at 40 kt and 100 ft AGL at 1,000 ft slant range from the landing point. From the radar point, the pilot sees a synthetic vison image of the landing zone overlayed with a circle showing where the helicopter will set



The Sandblaster composite display shows Digital Terrain Elevation Data, real-time radar symbology and low-speed flight symbology to represent the view lost in dense dust clouds.

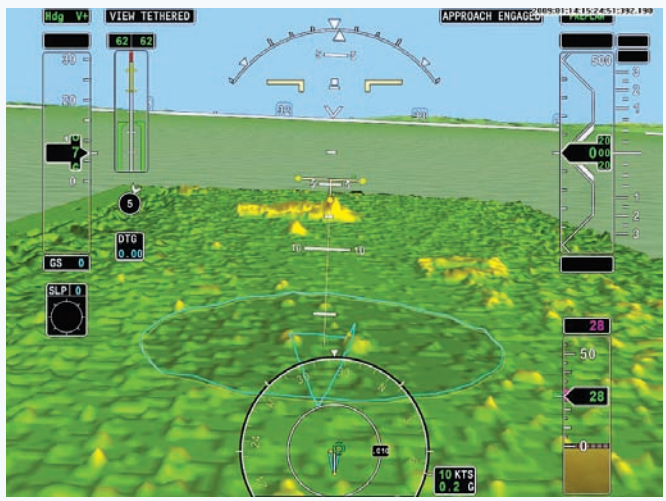
down. A triangle in the circle shows left, right, and tail wheel positions. "It turned out it was extremely precise," says Mr. Kronauer. "If you did nothing, the aircraft would arrive at the location projected in the scene."

From the radar point to flight termination, the Sandblaster sensor populates the landing zone with symbolic obstacles. A pilot confronted with a boulder or truck near the landing gear triangle beeps the radar to another spot and moves the termination point to safety. "Once the pilot decided he had a good location, he would let go, and the aircraft would arrive at the spot," concludes Mr. Kronauer.

The RASCAL Black Hawk is flown by a research pilot in the right seat with fly-by-wire controls and a safety pilot on the left with override authority. Sandblaster symbology appeared on the 6 by 8 inch multifunction display at the right-side research pilot station. With a helmet visor to block their outside view, the Sandblaster evaluation pilots focused on their head-down display and started their approach at 70 to 90 kt. "It was fairly simple from there," says Mr. Stiles, "You just pushed the button, and it executed the profile coupled."

The JUH-60A fly-by-wire system uses the same BAE active inceptor control sticks adopted for the UH-60M Upgrade without the soft detents and other tactile cues in the production helicopter. Sandblaster evaluation pilots CW4s Terry Duquette and John Wood came from AATD at Fort Eustis, Virginia and CW4 John Moseley from the Concepts and Requirements Directorate at Fort Rucker, Alabama. Each pilot made multiple landings and scored the utility of the system. The RASCAL safety pilot for all the tests was the Chief of the AFDD Flight Projects Office, Major Steven Braddom, and AFDD provided the RASCAL aft-cabin systems operator, Kevin Kalinowski.

AFDD set up a small Sandblaster obstacle course at Moffett Field with obstacles ranging from a 1 ft high boulder to a 4 ft tall fence to represent objects at an unprepared landing zone. The Sandblaster test area also included a simulated Forward Arming and Refueling Point. According to Dr. Tournear, "the pilots indicated from what they saw . . . they were clearly able to avoid obstacles. You're not able to discern the obstacles, but you're able to detect a threat to the aircraft." A wire detection test at the end of the Sandblaster demonstration showed the see-through sensor could reveal powerlines.



Sandblaster flight symbology was derived from fixed-wing symbology used by the Honeywell Integrated Primary Flight Display. The inverted triangle shows the footprint of the helicopter main and tail wheels.

The research flight control system of the RASCAL is not engaged below 25 ft for wheels-on-the-ground landings, but the testbed helicopter provided Differential GPS with centimeter accuracy to compare with the Sandblaster navigation solution. Sandblaster itself used the Honeywell H-764G Embedded GPS/INS on the JUH-60A, the same EGI used on the production UH-60M. Throughout the Sandblaster demonstration, the DTED database provided a static image of the upcoming terrain. "The SLEEK worked extremely well," notes Dr. Tournear. "The only work that is need in the future would be to make SLEEK a dynamic evidence grid."

Broader View

Separate from the DARPA Sandblaster demonstration, the Army's Utility Helicopter Program Manager sponsored a Cooperative Research And Development Agreement (CRADA) between AATD and Sikorsky to try a more versatile radar in blinding brownout. Last March, a test Black Hawk flew the Sierra Nevada Corp. HALS II radar into Yuma landing zones alone or behind

a UH-1 to evaluate the penetrating power of the radar in dust. While Sandblaster used a fixed-angle, fixed-azimuth radar to complement its DTED data base, HALS II offered two scanning angles to spot obstacles on landing or enroute. According to CW4 Duquette, "The radar in brownout allows you see obstacles; you can't identify them with radar but you know something is there." The sensor also proved useful in enroute mode, able to spot holes and other landing hazards on the ground. Wires were clearly detected head-on but disappeared at 10 or 15 degrees off axis.

AATD test pilots used the Brownout Situational Awareness Upgrade (BSAU) previously developed for legacy UH-60A/L and CH-47D helicopters to preserve their situational awareness in the cloud. The 5 by 6 inch BSAU display provides precision hover symbology to prevent rollover. "We did full brownout landings with BSAU and position maintenance with BSAU to demonstrate the radar. That was our safety release valve," explains AATD pilot CW4 Terry Duquette. However, like the Sandblaster RASCAL, the HALS II test Black Hawk was limited to a 25 ft safe hover. HALS II symbology alone was not good enough for actual landing, and pilots did not want to switch from radar to BSAU displays in a dust cloud.

The original HALS I radar packaged processing electronics in the Black Hawk cabin. The more integrated HALS II relied on the aircraft for only its power supply and displays. A productionized HALS III soon under contract could be integrated with a Sandblaster-like terrain database, but like the DARPA radar will still lack the resolution to identify the obstacles it detects. See-through symbology is nevertheless a powerful safety advantage in dense dust. According to CW4 Duquette, "All they're really trying to do is give the pilots some situational awareness in a brownout situation."

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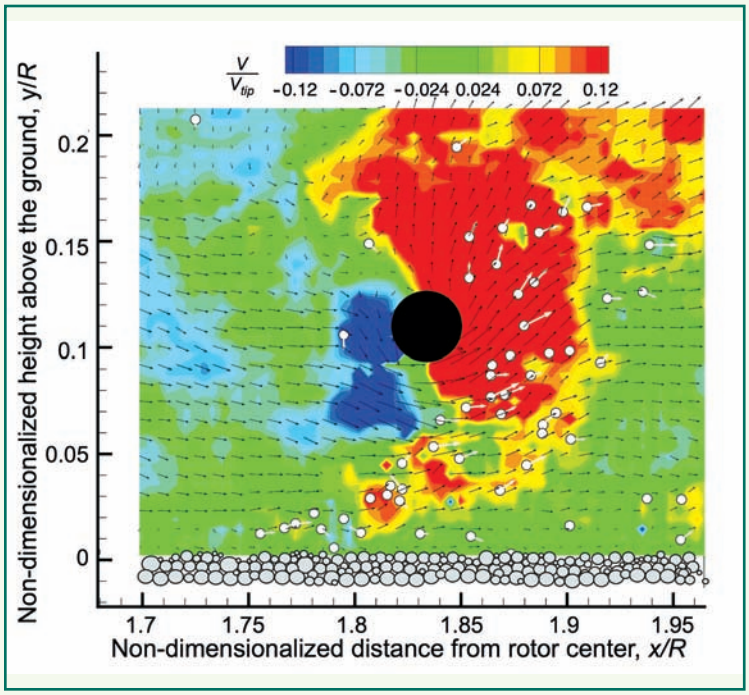
University Program Examines Brownout

Sandblaster data will provide input to the Multidisciplinary University Research Initiative (MURI) on Brownout sponsored by the Air Force Office of Scientific Research (AFOSR) and led by the University of Maryland Department of Aerospace Engineering. The five-year program begun in August 2008 aims to give the Air Force a comprehensive understanding of the brownout problem and predictive tools to assist in mission planning. "It's a fundamental science effort to understand the physics of brownout," says Dr. J. Gordon Leishman, Minta Martin Professor of Engineering at the University of Maryland. "You're looking at the fundamental mechanisms, at how the downwash from the rotor stirs up the dust and how it develops this cloud."

Laboratory and field experiments with small rotors and jets will use Particle Imaging Velocimetry (PIV) and other techniques to gain insight into the brownout phenomenon. Computational Fluid Dynamics (CFD) will also model the complex interaction of the two-phase brownout fluids – air and sediment. According to Dr. Leishman, "This is genuinely a team effort with a broad range of expertise being brought to bear on the problem. It's actually a much more complicated problem than you might think. . . . The air effects the way the sediment moves, and the sediment effects the way the air moves." The University of Maryland will provide general rotorcraft understanding and fluid mechanics expertise. Arizona State University and Iowa State University will concentrate on CFD. Dartmouth College will contribute its knowledge base in sedimentology.



A dual-phase PIV image from University of Maryland researchers shows sediment trapped in the upwash region of a vortex. Such measurements will help characterize and predict brownout.

The magnitude of the brownout hazard is determined by the gross weight of rotorcraft and other factors. "Our goal is to provide the Air Force with a predictive tool that would quantitatively assess that," says Dr. Leishman. Such tools might tell mission commanders to adjust payloads or the timing of successive landings to mitigate brownout hazards. Planned experiments will measure the size of dust clouds and how much dust is suspended under different conditions to validate mathematical models generated by the research. "This capability will help with mission planning. . . to decide whether or not you fly these helicopters out to the field."