DRAWING A LINE IN THE SAND

How Army Researchers Will Conquer the Helicopter Pilot's Greatest Enemy

Abstract
Army pilots say that simply maneuvering a helicopter to land in the superfine dust of Iraq or Afghanistan is more dangerous than any threat of combatant fire. For them, sand is the greatest enemy. Scientists and engineers at the U.S. Army Research Lab at Aberdeen Proving Ground in Maryland are developing new coatings for engine components that will enable pilots to operate in any kind of environmental condition, making it possible to carry on in any hazards like dust, volcanic ash, debris, and smoke.

U.S. Army Research Laboratory, Aberdeen Proving Ground, MD
Public Affairs Contact: T'Jae Ellis - tanya.j.gibson.civ@mail.mil

Prepared for the Department of Defense by
THE CENTER FOR HOMELAND SECURITY AND RESILIENCE

Submission Date
August 14, 2017

DISCLAIMER

Drawing a Line in the Sand

How Army Researchers Will Conquer the Helicopter Pilot's Greatest Enemy

An entire minute--that's how long the pilots thought they had to safely hover before disaster would strike. But it only took 45 seconds for a cloud of dust to pluck their $70-million aircraft--an MV-22 Osprey tilt-rotor--and the 22 souls on board from the Hawaiian sky.

"I knew we were in trouble and it was going to crash," a Marine passenger told investigators.[1] "Before we hit the ground I closed my eyes and thought of my wife and child and how I was going to die before my child could understand who I was."

The aircraft that went by call sign "Mayhem 11" plunged from about 75 feet, freefalling for three seconds before it crash-landed and burst into flames. The May 17, 2015 incident claimed the lives of two U.S. Marines and injured the other 20 servicemen on board, some of whom had unclipped their safety restraints to quickly alight the aircraft, the investigation found. It happened during a pre-deployment training exercise at Bellows Air Force Station on the sandy southeastern shores of Oahu, Hawaii.

No regulations or flight standards were violated, the Marine Corps Forces Pacific said in a statement. Sand and dust churned up from the landing site below had adhered to the rotor's turbine blades, causing the left engine to lose power and ultimately fail.

It was far from the first time an Osprey, or other rotorcraft had crash-landed due to severe "brownout," a term used to describe an aircraft-induced dust storm[2], but the seemingly-avoidable tragedy in Hawaii put a public spotlight on a serious weakness affecting military rotorcraft, as conflicts in arid regions of the Middle East persist. The Army attributes brownout with half of the nearly 400 aircraft losses in combat operations from 2002 to 2015 caused by what's classified as a Degraded Visual Environment, which accounted for losses of $1 billion and 152 lives in that time period.[3]

The brownout phenomenon specifically afflicts helicopters due to "downwash." As the force of spinning horizontal rotor blades kicks up whatever lies below—dust, sand, smoke, ash, debris—the aircraft becomes engulfed in a churning cloud that destroys visibility and can imperil an engine in a matter of seconds.

Army pilots say that simply maneuvering a helo to land in the superfine dust of Iraq or Afghanistan is more dangerous than any threat of combatant fire.[4] For them, sand is the greatest enemy. And while avionics technology that helps pilots fly blind in the kind of zero- visibility conditions caused by brownout has advanced in recent years, the bigger problem— the one that can make some of the military's most formidable machines just fall from the sky,

1 http://www.military.com/daily-news/2016/01/29/billows-of-dust-a-sudden-pop-and-an-osprey-falls-from-the-sky.html

2 INVESTIGATING THE IMPACTS OF PARTICLE SIZE AND WIND SPEED ON BROWNOUT THESIS Brandy A. Swanson, Captain, USAF 2015 http://www.dtic.mil/get-tr-doc/pdf?AD=ADA614925

3 http://breakingdefense.com/2015/10/army-seeks-industry-help-to-stop-brownout-deaths-1b-in-losses/

4 https://www.stripes.com/news/desert-landings-rattle-pilots-nerves-1.4377#.WXC-NtPytP0

or else keep them grounded out of fear—is getting worse.

A Costly Problem

"We're seeing huge knockdowns on the scheduled maintenance," said Michael Walock, a physicist at the U.S. Army Research Lab (ARL) at Aberdeen Proving Ground, Maryland. "Typically engines are made to last 20,000 to 30,000 hours, with scheduled overhauls around 5,000 hours. Instead we're seeing them come back at 500 hours—sometimes even 50."

It's a huge maintenance cost—these are the most expensive parts of the machine. A typical engine runs around $750,000; the hot section, which is the most susceptible to degradation from sand ingestion, constitutes up to 40 percent of that, Walock said. That includes over 70 turbine blades, each carrying a $1,000 price tag, as well as a host of stationary components that are twice as expensive.

Sand ingestion is not a new problem—it was notorious for crippling tank and aircraft engines during the first Gulf War in the 1990's—but the scope of it has expanded as the U.S. military conducts operations across the arid regions of the Middle East and eastern Africa, said Dr. Anindya Ghoshal, the chief scientist for ARL's vehicle directorate.

"We find that some of the finest particulates are going through filters and destroying coatings," Ghoshal said, referring to the layers of protective film on turbine engine parts. "Sand is building up and clogging airflow passage. We're losing engines in flight, losing pilots in training missions. We've lost some within 10 seconds."

The U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC), approached ARL to come up with a solution. "We don't even fully understand the problem," Ghoshal said. But that hasn't stopped them from trying.

Call of Duty

Walock was sitting at his desk during office hours at the Bryan, Texas campus of Blinn College, a two-year community college, where he'd recently started as an adjunct introductory physics instructor. It was the summer of 2013.

It wasn't necessarily the best use of his four physics degrees (including two doctorates), but his wife had gotten a job at Texas A&M University, and he kind of owed her.

They'd gotten married in a hurry. They'd been planning on it of course, eventually, but not while they were living in different states—he'd been in the middle of his master's studies at the University of Alabama in Tuscaloosa while she was at the University of Wisconsin Oshkosh.

But the sergeant's phone call accelerated their plans: "Mike, I have bad news," he said. It was the call every reservist anticipates, one way or another. Walock had joined the military straight out of high school in 1995, a move he said was driven by patriotism. He'd grown up in the city of Detroit, Michigan; mom was a school bus driver while dad drove a dump truck. Joining the reserves was one way he could give back, he said, for the educational opportunities the military afforded him.

“I knew it was going to happen one day, and it finally did,” Walock said. He deployed to Afghanistan one month after that call, and was stationed for 11 months at a forward operating base in the mountainous, high desert area of Paktika Province, a two-hour’s flight from Bagram. He arrived there a newly married man.

In 2014, sitting at his office hours with a decade and two doctoratess under his belt, Walock got another unexpected phone call from the military. The circumstances were very different this time.

“Hey, I saw your resume,” said ARL’s Anindya Ghoshal. Walock had applied for a post-doc research fellowship at ARL that he’d seen online a year and a half earlier while finishing his second doctorate studies at the University of Alabama, Birmingham. Until that day, he’d heard crickets.

Ghoshal thought Walock’s expertise in magnetics and hard-coatings designed to extend the life of things like drill bits would translate well into what ARL was working on: thermal- barrier coatings. The goal of the program was to prolong the lifespan of gas turbine engines by making them more heat-tolerant and ultimately sandphobic, actually able to repel sand particles. This would go a long way in preventing mishaps caused by brownout-induced engine failure.

Walock signed on with Ghoshal’s team in August of 2014, due to start that September. He’d relieved himself of all other obligations. Then there was a hiccup. “It’s the government,” Walock laughs. His start date got delayed due to a paperwork hold up, so he sold hardwood floors at Home Depot for a few months while he waited. In December 2014, the wait was finally over.

Walock has the voice of a cartoon physicist. It’s a little nasal and carries well across the steel and concrete warehouse laboratory on Aberdeen Proving Ground, where he blasts various metals with intense heat. “My wife likes to call me the squarest person that ever came from the ghetto,” he said.

When you listen to Walock’s voice wax about how grains of sand can infiltrate an engine, you know he’s found his calling.

Loss of Aircraft, Loss of Life

“When you ingest sand in the engine you have two problems: one is a sustainment problem,” he said. The sand comes in and melts under the heat of the engine. That molten sand becomes a corrosive slag-like material[5], sticking to the ceramic coating of the turbine blades, filling cracks and pores, as chemical reactions force a volume change in the thermal barrier coatings. The result is more stress on the system.

As the density of the ceramic increases, so too does its thermal conductivity. Everything gets

[5] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140017770.pdf

hotter, pushing the metal beyond its capabilities.

The damage doesn't stop when the engine does, Walock explains. As the shut down engine starts cooling, the molten sand hardens and crystallizes on top of the blades, like glass, corroding the underlying coating. "You have thermal stresses that will pop off or destroy the coating—that's called 'spalling.'" Walock said. "Now next time I run the engine, there's exposed metal."

In the worst-case scenario, the pilot doesn't get a chance to shut down the aircraft's engine. Sand rapidly builds up, blocking narrow air passages and reducing power. "When you're hovering a helicopter, you're at max power," Walock said. "If you lose 10 percent power, you are crashing."

That's how Mayhem 11 went down in Hawaii. The buildup of sand caused backpressure, signaling to the engine controls that there was a blockage. The engine's power surged, in an attempt to free up airflow. The additional heat destroyed the engine in midair.

Loss of aircraft. Loss of life. That's a quick and dirty definition of a "Class A" mishap. Technically, "the total cost of property damage is $2 million or more; an Army aircraft or missile is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent disability."[6]

An upward trend in Class A aviation mishaps got the attention of the U.S. House Armed Services Committee, which demanded of top military officials in a defense budget hearing on March 16, 2016 whether they were able to "meet the demands of National Military Strategy." [7]

The committee's statistics showed a dramatic increase in the rate of Class A mishaps over the last few years as compared to their 10-year averages, especially in the Marine Corps. For the Army, committee Chairman Mac Thornberry cited a rate increase to 1.99 mishaps per 100,000 flight hours in 2016 from 1.52 in 2014.

Both the Army and Marine generals attributed the spike to reduced pilot readiness and maintenance issues. Billions of dollars in defense budget cuts led to a reduction in training hours for rotary wing aviators, they said.

ARL's research shows it's a little more complicated than that, at least where brownouts are involved.

'Satan's Baby Powder'

Part of it is rather obvious. There's a lot of sand and dust in the parts of the world we're talking about.

"Sand is everywhere, silica is everywhere--you can't get away from it," Ghoshal said. But

6 https://safety.army.mil/Portals/0/Documents/REPORTINGANDINVESTIGATION/TOOLS/Standard/Army_Accident_Classification_pre12272013.pdf
7 https://www.youtube.com/watch?v=RlVxuxwUEao&feature=youtu.be&t=38m23s

every part of the world has a unique composition, and for aviators in Afghanistan, it seems… worse.

Comparing the dust conditions in Iraq and Afghanistan, one MH-53 pilot called Afghanistan the "scariest environment imaginable," in a 2009 *Popular Mechanics article,*[8] while a gunner gave the theater's conditions a "pucker factor of 12."

That's in line with ARL's research. "I would expect engines returning from AFG would be worse-off than engines from IRQ," Walock wrote in an e-mail.

Afghanistan's sand is known to those who've served as "moon dust," and has been called "Satan's baby powder." It hangs in the air like a dense fog, making it possible to look straight at the sun, and it's so fine that it seeps into your clothes, pores and lungs, sticking to everything it touches.

"Helmand was a desert, but not of sand," wrote Martin Middlebrook, a photojournalist commissioned to produce a series of photos in 2010 by the Afghan government. "It seemed to consist of mud coloured talcum powder, so fine that everything became coated in a veneer of damaging dust."[9]

The sand in Afghanistan is unlike any other on the planet.

The Hindu Kush Himalaya area, which stretches across eight countries and into central Afghanistan, is the youngest mountain region on earth. Formed by the collision of the Indian and Eurasian tectonic plates some 60 million years ago, it's still geologically active, and it's rich in minerals.

That makes the Afghan desert among the youngest worldwide. Sand is formed over time by the process of weathering. When it's newer, it's more complex and irregular, said Ghoshal. Surface roughness can make an impact on sand's reactiveness to heat, and how an engine ingests it. There's also more clay and calcium content, which makes it stickier.

Compare that to the desert sands of Yuma Proving Ground, Arizona, where the U.S. Army tests equipment and materiel. The Sonoran Desert is their best shot to simulate environmental conditions in Iraq and Afghanistan. It may look somewhat similar, but winds have swept the sands of Yuma for some 200 million years. As a result, "When flying training helicopters there we may not see the problem," Ghoshal said.

Leaner, Meaner, Hotter

The other reason sand ingestion is becoming of greater concern is an unexpected offender: better performance. The military's aircraft engines are getting much-needed upgrades, becoming meaner and leaner, faster and stronger while using less fuel. The byproduct of all that increased power: more heat.

[8] http://www.popularmechanics.com/military/a5540/4199189/
[9] http://martinmiddlebrook.com/helmand

The Marine Corp's newest heavy-lift helicopter, the CH-53K King Stallion, is a beast. Manufactured by Lockheed Martin subsidiary Sikorsky, it's designed to be capable of hauling a 13.5-ton external load dangling from its belly—more than three times as much as its predecessor, the CH-53E—over 110 nautical miles from ship to shore. Three new GE engines will significantly boost the King Stallion's horsepower, while consuming 20 percent less fuel than the CH-53E.[10]

"Whenever we're designing new engines we're trying to push the envelope and get as much power and efficiency out of it as possible," Walock said. "You're always pushing the limit."

What's the byproduct of all that increased power and efficiency? Heat.

That's one reason why the Osprey's engine is more susceptible to surge than say, a Black Hawk; more is demanded of it. The Osprey's value proposition is in its tilt-rotors, which allow it to hover like a helicopter and then fly horizontally like a plane. Because they're smaller than a typical helicopter, the prop-rotors have to spin at a higher velocity to stay airborne.[11]

Older systems, which are physically larger and less capable, held a lower core temperature than newer ones. While the BlackHawk's T700 engines are coming back for overhaul much sooner than expected, Walock said he doesn't know of any Class A mishaps attributable to brownout-related engine failure.

In newer engines, "everything that goes through combustion—dust, pollution, volcanic ash—is going to melt," Ghoshal said.

"Those engines that run hotter are nowhere near as tolerant as old engines," Walock said. In short, ARL's coating-technology effort is critical to the prevention of Class A mishaps.

Limiting Infiltration

In the short term, ARL, in partnership up with academia and other military partners including AMRDEC, Naval Air Systems Command (NAVAIR) and NASA, has developed a number of promising solutions. [12] "We think we found several coatings that show potential as far as limiting infiltration," said Walock. "If sand can't get into the coating, it's not going to do the damage that it is now. That could solve sustainment problems."

Implementing the coatings into existing engines is relatively easy, Walock said. The technology is similar to how they currently apply ceramic coatings; it would be a matter of changing feedstocks to use different materials in a similar application process.

Longer term, the "holy grail" is figuring out how to stop sand from sticking. There's a lack of fundamental knowledge of the physics and chemistry of adhesion, Ghoshal said. Once

10 http://lockheedmartin.com/us/products/ch-53k-helicopter.html

11 http://www.military.com/daily-news/2016/01/29/billows-of-dust-a-sudden-pop-and-an-osprey-falls-from-the-sky.html

12 http://technopress.kaist.ac.kr/download.php?journal=aas&volume=4&num=1&ordernum=3

they have an understanding of how one thing sticks to another on an atomic level, they can engineer a multi-scale model and completely change the way high-temperature materials are developed.

“Sandphobic coating is the next revolutionary thing,” said Ghoshal. “It will give us the ability to operate in any degraded environment.” Just as night-vision made it possible for warfighters to maneuver in darkness, sand phobic coatings will allow them conquer any environmental condition.

Helicopters will be able to take off, operate, hover and land in more than just dust storms, giving them a “significant tactical edge,” Ghoshal said. They’ll be able to fly through pretty much any degraded environment: the burning tires of urban warfare; the ash of a volcanic cloud.

“We’ll be able to operate no matter what.”

##