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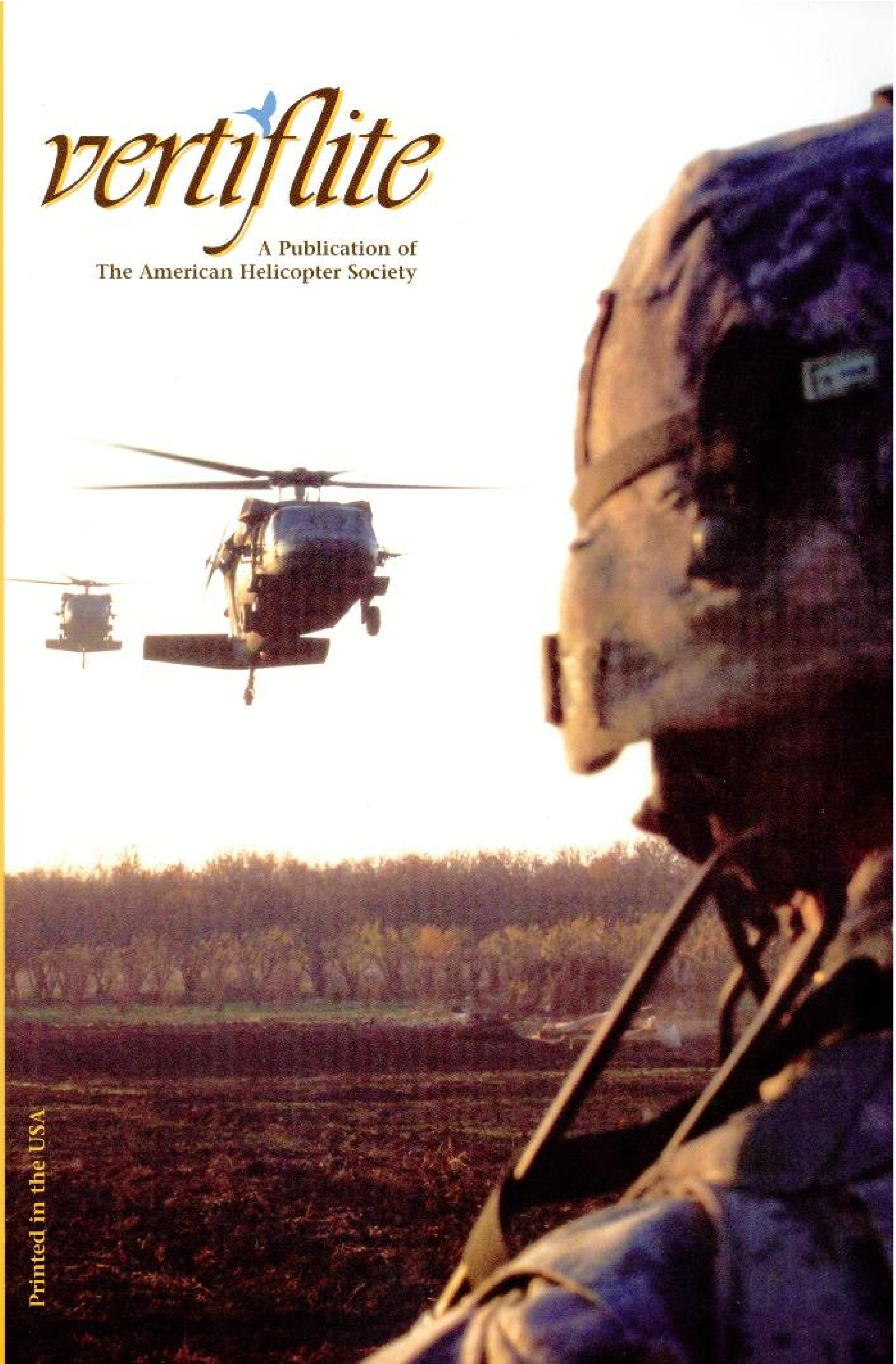

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# Enduring Power

## Advanced coatings protect helicopter engines from compressor erosion to save lives and money

By Frank Colucci

# Safety Spotlight

Early in Operation Enduring Freedom, a US Marine Corps CH-53E flying over Afghan mountains at about 10,000 ft lost power in one of its three engines and fell 200 ft to crash-land on a high plateau. Two Marines died in the rear of the helicopter. Five survivors suffered leg and back injuries. The engine stall that wrecked the Super Stallion underscored the danger of compressor blade erosion, and it helped a persistent Canadian company insert Russian compressor blade coating technology into American helicopter engines. MDS-PRAD Technologies Corporation has refined erosion protection for turboshafts. Retired Marine Deputy Commandant for Aviation Lt. Gen. Michael Hough, now a MDS-PRAD consultant, explains, "If you can keep those motors in pristine condition where erosion is minimal or non-existent, you're more likely to stay alive."

The American Helicopter Society awarded MDS-PRAD the Harry T. Jensen Award this year for its production application of an erosion-resistant blade coating (ER7) that can increase safety and decrease helicopter operating and support costs. Fleet Marine CH-53Es received T64-GE-416 engines with hard-coated blades in December 2003. By February 2007, around 330 engines were deployed and time-on-wing for high-time T64s in Iraq and Afghanistan was more than 10 times typical life of uncoated engines in the same sand environment. With T64 depot overhauls costing around $620,000 each, estimated Operating and Support savings were about $8 million per year for each CH-53E with coated compressor blades. Blade re-coating or replacement intervals have yet to be determined. "The beauty of the story is there is no engine to look at because they're all still flying," says MDS-PRAD president and chief operating officer, Phil Rodger.

Anti-erosion coatings 5 to 20 micrometers thick with 2800 to 3200 Vickers hardness now protect compressor blades for General Electric T64 and T58 engines in Marine CH-53Es and CH-46Es. Coated compressor blades enter production for the Rolls Royce AE1107 engine in the Marine MV-22B tilt rotor in the first quarter of this year. Sand ingestion tests are underway to evaluate coated blades in the Honeywell T55 for US Army Chinooks, and test blades are already flying in the Rolls Royce Gnomes of British Sea Kings and the Gems powering Lynx helicopters in Iraq. An Engineering Change Proposal will put coated blades in General Electric T700s for testing on US Navy Seahawks this spring.

MDS-PRAD Physical Vapor Deposition (PVD) facilities on Prince Edward Island and in Montreal have so far coated over a million gas turbine blades with a custom-engineered blend of titanium nitride and other ingredients. "We have different elements in different compositions all through the coating," says Mr. Rodger. Equally important, MDS-PRAD has refined test methods to characterize engine wear and qualify the coatings on hot, high-speed components. According to Mr. Rodger, "The real challenge is a system that will work in a gas turbine." He adds, "These types of coatings have been flying for 15 years and over 10 million hours. It's a question of knowing the substrates you're working with, the erosion mechanisms, and what thicknesses will work in what environments."

*Left: A Marine CH-53E hovers in dust to pick up the rotor head of another a CH-53E downed near Al Qa'im, Iraq, in December 2006. Erosive dust decreases T64 engine performance and flight safety.*

## Compound Damage

Helicopter engines gulp air and sand in desert landing zones, and erosion quickly impacts flight safety. Hard, fast-moving particles erode compressor blades, so air flow and performance both decline. Engine controls compensate with more fuel to drive the turbine faster. Higher turbine temperatures accelerate hot-section deterioration. "In that configuration, you get a pretty steep decrease in the horsepower the engine puts out," says former NAVAIR engineer and MDS-PRAD Washington representative, Marcio Duffles. "All of a sudden you don't have enough power to get out of where you are. If you're at altitude, you're coming down."

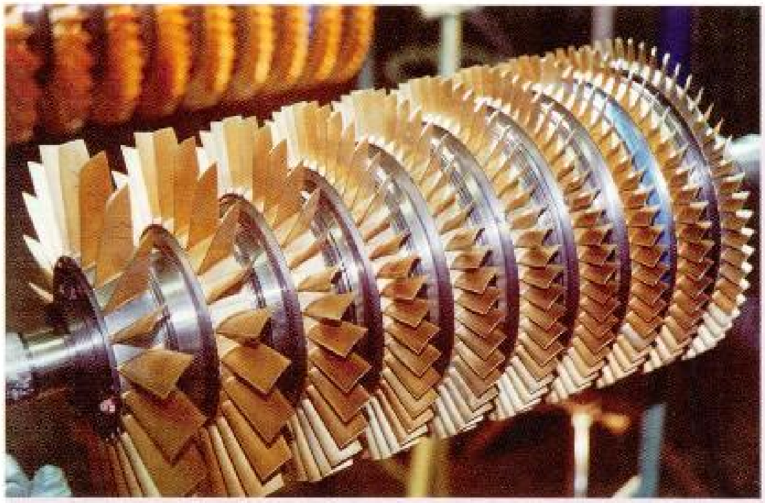
Though Engine Air Particle Separators (EAPS) afford T64s and T55s some protection, Marines and soldiers in high-hot combat theaters often removed the inlet add-ons. Lt. Gen. Hough says, "When they went to these places, they found out not only doesn't the EAPS work, it takes away a tremendous amount of airflow. . .They'd take the EAPS off and throw it away, but now the motor is getting the full brunt of that environment." Fine, sharp-edged grit encountered in Iraq and Afghanistan proved especially aggressive. "It's not the kind of sand you find at Yuma," observes Lt. Gen. Hough.

Without special protection, Marine T64s in Iraq averaged just 108 hours before performance deteriorated below NATOPS minimums and the engines had to be removed for overhaul. Army T55 engines lasted about as long, and Navy T700s in SH-60s did little better.

Compressor blades are the first high-speed engine components subject to sand erosion, but helicopter engines wear in several ways. At speeds up to 40,000 rpm, some first stage compressor blades suffer leading edge curl erosion. "The leading edge literally curls like a fishhook," explains Mr. Duffles. "The kinetic energy of the sand is so great it hits the material and causes plastic deformation."

Downstream, erosion follows the pressure side of airfoils and makes compressor blades thinner. According to Mr. Duffles, "They thin out and they literally crop off. You lose chunks at the tip of the blade. The compressor keeps going, but you lose efficiency." Compressor stators can also thin out and break at their roots.

Later compressor stages, combustors, and even turbines can suffer compound damage as first-stage metal and sand travel the length of the engine. Molten metal blobs adhere to and compromise airfoil shapes. Though



*The blades of this compressor from a Russian TV2-117 turboshaft are protected from erosion by a PRAD titanium nitride coating. MDS-PRAD brought the technology to North America.*

pulverized sand becomes less abrasive, it glassifies at high temperatures to plug cooling holes. T64 maker General Electric contends life of turbine components is not generally limited by sand erosion, but MDS-PRAD analyses have found turbine blade erosion in other engines. Protecting compressor blades from sand erosion protects the entire engine. "Basically, the compressor is like the heart," says Mr. Duffles. "When you keep the compressor blades from eroding in a sandy environment, you're keeping your heart healthy."

## Harder Hearted

NAVAIR investigated erosion countermeasures in the 1980s, and General Electric performed a sand ingestion test on the T700 turboshaft in 1987. Sand nevertheless remained a major problem in Operations Desert Shield and Desert Storm in 1990 and 1991. With T64s running about 120 hours between removals, the Navy/Marine Corps inventory of CH-53 engines was nearly depleted. NAVAIR subsequently tested a dozen anti-erosion coatings on engine metal coupons and chose three for further evaluation. Meanwhile, a hard coating solution emerged from Russian experience in Afghanistan and elsewhere.

With the Cold War over, MDS Aero Support division sought to sell jet engine test cells to the Russians, but during a tour of the Ural Works of Civil Aviation (PRAD) in Ekaterinburg, the Canadians questioned their Russian hosts about gold-colored airfoils seen on a helicopter engine overhaul line. Mr. Rodger recalls, "They said they'd worked on this erosion-resistant coating. The need came to them from some of the problems they had in the early 1980s." The PRAD titanium nitride coating was already protecting the TV2 and TV3 turboshafts in the Mil Mi-8 and Mi-25 helicopters. MDS saw an opportunity to market it in the West. "We were looking at the ways to take this technology to the next level," says Mr. Rodger.

A letter to NAVAIR in 1991 eventually started a three-year Foreign Comparative Testing effort sponsored by the Office of the Secretary of Defense in 1997. MDS-PRAD formed a joint venture to formulate and apply gas turbine blade coatings in North America, and it engaged the University of Cincinnati Aerospace Engineering Department to develop tests for coated compressor blades in erosive environments. Lab results correlated with a ground test at Kirtland Air Force Base. A T64 "rainbow" engine alternating coated and uncoated compressor blades ingested sand until it suffered a 25% loss of power. Teardown revealed the coated blades showed little of the thinning and cropping seen on uncoated blades.

Dense ER7 coatings alternate hard titanium nitride with softer layers to improve adhesion and durability. According to Mr. Rodger, "Typically what can happen is hard materials are good in wear protection, but they're also very brittle. You can damage the coating to where it falls off and creates more problems than you solve. The trick is to create a system that will stay with the parts over a long time. This is where the multi-layer system comes in."

Coated T64 compressor parts are made of Titanium, Inconel 718, and A286 steel. The development process

*A T64 "rainbow" test engine shows erosive damage of sand ingestion tests on uncoated compressor blades.*

*T64 compressor blades without the gold MDS-PRAD coating suffer edge cropping and surface pitting due to sand erosion.*

*T58 compressor blades were coated with ER7 to prevent the leading edge curl and other damage encountered in sandy environments.*

included surface preparation treatments and PVD zones to protect the fatigue resistance of the metal and preserve the complex compressor shapes.

## Analyses and Applications

NAVAIR tried the hard coating on a T64 Lead The Fleet Engine flown on a CH-53E first in desert training at 29 Palms, California and Indian Springs, Nevada, and then with Marine Medium Helicopter Squadron 462 in Operations Enduring Freedom and Iraqi Freedom. The Lead The Fleet Engine was removed from the aircraft after 374 hours by a faulty torque meter, but inspection at Cherry Point showed the compressor blades in excellent condition. "That was enough evidence it was going to be beneficial in a production mode," says Mr. Duffle.

When production coated engines reached the fleet, NAVAIR expected a two- to five-fold improvement in the 108-hour average overhaul life of T64s in erosive environments. Lt. Gen. Hough says, "Without this coating, we were dying on the vine for lack of motors in the '53 community." After around 18,000 fleet hours, the longest-running T64 with ER7 coated blades has exceeded 1,600 hours in service. Mr. Rodger observes, "Engines with the coating are lasting longer in a desert environment than they were uncoated in pristine environments."

Helicopter fleet fuel savings from erosion-protected engines are also real but unquantified. "Your compressor is healthy; hence you don't have to run your turbine quicker," says Mr. Duffles.

The T64 success justified coating the compressor blades on T58 engine. T58-GE-16A Engine Reliability Improvement Program engines with coated blades went into service on Marine CH-46Es in 2005. By March 2007, the high-time engine had logged 800 hours in the desert, double the best time of uncoated engines. General Electric Aviation and MDS-PRAD have discussed coating technology for the GE38 for the new Marine CH-53K, but the engine maker is also developing its own coatings.

The MDS-PRAD joint venture today operates independently in North America and Russia. Both Canadian sites are busy meeting demand for coated parts, and the company has invested in automated production equipment and rapid prototyping facilities to test for erosion in a gas turbine context. MDS-PRAD laboratories measure coating temperature effects, high-cycle fatigue corrosion resistance, and adherence under bending. Mr. Rodger explains, "We're realizing there are no standards. People don't know how to test for this and how it will work in the compressor."

Though military helicopters provided initial impetus for MDS-PRAD coating services, the market is growing to large civil turbofans and other engines. The Honeywell AGT1500 tank engine is due to undergo sand ingestion tests with coated compressor blades this year. "The big interest is on the industrial gas turbine side and the commercial helicopter side," says Mr. Rodger. "A lot of Middle-Eastern operators have compressors that erode, and they're looking to protect the efficiencies of their engines." The biggest workpiece coated so far has been a 20 inch long component for an industrial gas turbine.

Work is underway on a combination erosion-corrosion resistant coating to be tested on the Rolls Royce T56 turboprops powering fixed wing C-130 transports and P-3 maritime patrol aircraft. MDS-PRAD is also working with Penn State University on the LEER – Leading Edge Erosion Resistant – coating. "We can't stand still," acknowledges Mr. Rodger. "We've got to develop more resilient solutions. The new coating shows increases an order of magnitude compared to the one we have right now."

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