

# Non-Line-of-Sight Coating Of Turbine Airfoils

## Directed Vapor Technologies International, Inc.

2 Boars Head Lane  
Charlottesville, VA 22903

### Dr. Balvinder Gogia

Phone: (434) 977-1405

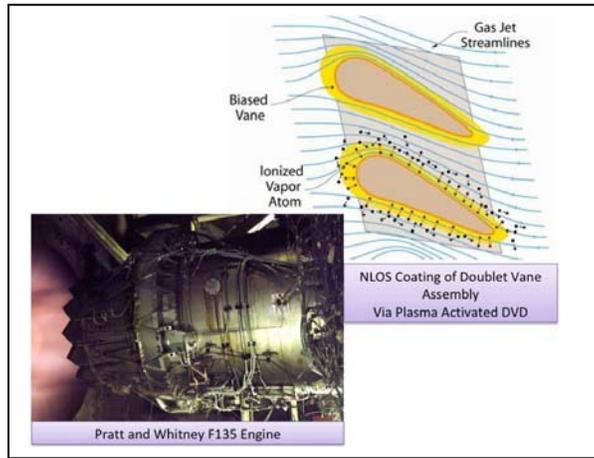
Fax: (434) 977-1462

Email: [bgogia@directedvapor.com](mailto:bgogia@directedvapor.com)

Website: [www.directedvapor.com](http://www.directedvapor.com)

**Command: NAVAIR**

**Topic: N07-006**



## PROBLEM STATEMENT

The operational performance (fuel efficiency and thrust) of gas turbine engines is greatly improved as engine operation temperatures increase. As a result, the hot structural components of gas turbine engines often operate at temperatures approaching their melting point. As engine designs advance, inlet gas temperatures continue to rise and failure by thermally-induced mechanisms must be avoided by such means as making airfoil components with internal cooling conduits. Compressor discharge air flows through these conduits in order to decrease the component temperature. Bleeding off compressor discharge air for this purpose, however, reduces engine efficiency. Thus, it is desirable to minimize the use of this air for cooling purposes. Exploiting the insulating abilities of thermal barrier coatings (TBC's) are the most realistic near-term technology to enable higher inlet gas temperatures by thermally protecting engine components<sup>1</sup>.

In the past decade, TBC usage has steadily increased due to their proven ability to extend the lifetime of expensive turbine engine components and their near-term potential to increase the operating temperature of gas turbine engines. A TBC works by creating a thermally insulating layer between the hot engine gases and the air-cooled component. In principal, the resulting temperature drop achieved across the coating (170°C or greater is possible)<sup>2</sup> "protects" the component surface by lowering the temperature that it is exposed to. Experience with TBC's on aircraft engine turbine airfoils has shown that current TBC systems provide a component life improvement of at least 2x and that some modest reduction in component cooling airflow can be achieved. Both contribute to a performance gain for the engines that use them. As TBC technology matures, much greater engine performance benefit, up to several percent thrust improvement or specific fuel consumption reduction, is anticipated if the full potential of an advanced TBC system is realized.

1) <sup>1</sup> Maricocchi, A., Bartz, A., Wortman, D., *Proceedings of the Thermal Barrier Coatings Workshop*, NASA CP 3312 (1995), P. 17.

2) Same as above

The success of current TBCs on turbine blades and vanes has made them integral to the design of hot section components of turbine engines. Perhaps nowhere are TBCs more critical than in advanced military engine designs such as the Pratt and Whitney F135 and GE/Rolls-Royce F 136 engines, which are being developed for the F 35 Lightning II Joint Strike Fighter (JSF). These new engines have incorporated advanced designs and materials that will expose the high pressure turbine (HPT) to even higher temperatures. The temperature increases affect not only the HPT but the low-pressure turbine (LPT) as well. The result is a strong need to apply TBCs onto the blades and vanes found in the HPT and LPT.

The drive to maximize the work extracted from the gas stream in the LPT of these advanced engines results in the need for turbine airfoils to increasingly direct the hot gas stream. The result has been more complex-shaped doublet airfoils in the LPT. Thus, many LPT vanes now have tightly spaced, low radius, bowed airfoils. **The doublet LPT vanes have many hidden and partially hidden surfaces making the application of TBC coatings using conventional techniques, such as electron-beam physical vapor deposition (EB-PVD), extremely difficult.** Current state-of-the-art techniques used to coat turbine airfoils with ceramic thermal barrier coatings (TBCs) are typically line-of-sight (LOS). These coating techniques offer limited capability to coat hidden and deeply concave surfaces. As a result, the achievable coating thickness is limited and coating distribution is inconsistent on complex-shaped parts. Furthermore, suboptimal coatings are developed on surfaces with limited line-of-sight to the coating source, reducing the life of the coatings in a turbine environment.<sup>3</sup>

### **WHO CAN BENEFIT?**

The acquisition program sponsoring this research is the advanced next generation strike fighter aircraft program. Non-line-of-sight (NLOS) coatings on complex components are of very high interest for the engines being developed for this program. The directed vapor deposition (DVD) process is used to apply high quality thin and thick film coatings to a wide range of components by precisely directing evaporants, resulting in efficient, high rate deposition of tailored coating architectures and compositions onto complex components. The unique NLOS capabilities of the DVD process apply equally to all other advanced engine designs currently in development for both military and commercial aviation applications. Directed Vapor Technologies International, Inc. (DVTI) is currently working with various engine manufacturers on various aviation related projects, though the DVD process is versatile enough to be of invaluable service to OEMs in a wide range of industries and markets. The DVD approach offers significant overall advantages in the application of coatings for:

- **Environmental Barrier Coatings**
- **Oxidation and Hot Corrosion Resistance**
- **Hard Chrome and Cadmium Replacement**
- **Thin Film Li-Ion Battery Production**
- **Superconductors**
- **Optical Coatings**
- **CMAS Resistance**
- **Wear Resistance**
- **Corrosion Resistance**
- **Solid Oxide Fuel Cells**
- **Medical Devices**
- **and more...**

---

<sup>3</sup> Navy SBIR N07-006 "Non-Line-of-Sight Coating Of Turbine Airfoils"

## BASELINE TECHNOLOGY

Currently, TBC top coats are applied to turbine components primarily using an EB-PVD process. EB-PVD uses an electron beam to evaporate material in a high vacuum environment. Evaporation of this material produces a vapor cloud in which parts are rotated. Condensation of the vapor on the parts then produces a coating. The EB-PVD process uses sufficiently low chamber pressures such that the mean free path between vapor molecule collisions is on average much greater than the source-to-substrate distance. As a result, component surfaces that require coating must be in the LOS of the vapor source to be coated since no mechanism exists to alter the vapor molecules path once its initial trajectory is set by the evaporation process. As a result, very thin coatings with suboptimal microstructures are produced on NLOS surfaces because very few vapor molecules impact such surfaces and those that do generally impact at highly inclined angles of incidence. The inclined incidence angles do not lead to the growth of the desired columnar TBC microstructures, where the columns are perpendicular to the substrate surface, nor do they result in the required column density.

Further drawbacks to the current EB-PVD method of coating application is the inefficiency of the process. EB-PVD machines operate in a high vacuum, requiring hours of pump up and down time, which negatively affects the rate at which full scale production can occur. Material waste is another facet of the inherent inefficiency of the process<sup>4</sup>. Only about 3% of the coating material settles on the desired substrate, the majority settles on the chamber walls and any other fixtures inside the coating chamber. Financially, this material waste increases the costs of the process and creates extra environmental hurdles as the excess material must be removed and disposed of.

## TECHNOLOGY DESCRIPTION

DVD is an advanced approach for vapor depositing high quality coatings. It was initially developed at the University of Virginia and is exclusively licensed to DVTI. It provides the technical basis for a flexible, high quality coating process capable of atomistically depositing dense or porous, compositionally controlled coatings onto line-of-sight and non-line-of-sight regions of aircraft components. Unlike other EB-PVD approaches, DVD is specifically designed to enable the transport of vapor atoms from a source to a substrate to be highly controlled. To achieve this, DVD technology utilizes a trans-sonic gas jet to direct and transport a thermally evaporated vapor cloud onto a component. Typical operating pressures are a range requiring only fast and inexpensive mechanical pumping, resulting in short (several minutes) chamber pump-down times. In this processing regime, collisions between the vapor atoms and the gas jet create a mechanism for controlling vapor transport. This enables several unique capabilities:

- 1) **High rate deposition:** Vapor phase collisions between the gas jet and vapor atoms allow the flux to be "directed" onto a substrate. Since a high fraction of the evaporated flux impacts the substrate (i.e. the materials utilization efficiency is increased) instead of undesired locations (such as the walls of the vacuum chamber) a very high deposition rate ( $> 10 \mu\text{m min}^{-1}$ ) can be obtained.
- 2) **Non Line-of-Sight Deposition:** As illustrated in Figure 1, the gas jet can be used to carry vapor atoms into internal regions of components and then scatter them onto internal surfaces to result in NLOS deposition.

---

<sup>4</sup> Hass, D.D., Slifka, A.J., Wadley, H.N.G., *Low thermal conductivity vapor deposited zirconia microstructures*; Acta Materialia, Vol 49, 2 April 2001.

- 3) **Controlled intermixing during multiple source evaporation:** The use of high frequency e-beam scanning (100 kHz) allows multiple source rods to be simultaneously evaporated. By using binary collisions with the gas jet atoms, the vapor fluxes are intermixed allowing the composition of the vapor flux (and thus, the coating) to be uniquely controlled. This allows alloys with precise compositional control to be created even when large vapor pressures difference exist between the alloy components. It also enables multilayered coatings to be deposited in a single step.

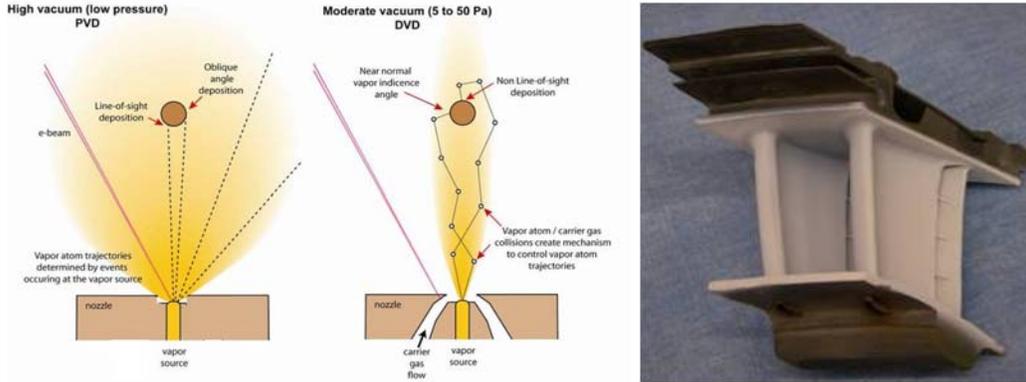


Figure 1. The carrier gas flow and moderate operating pressure enable NLOS coating onto doublet vanes and other complex parts. (Commercial engine component shown.)

It has also been shown that hollow cathode plasma activation can be used to increase the density of DVD layers as desired. This enables a large percentage of all gas and vapor species to be ionized. The ions can then be accelerated towards the coating surface by an applied electrical potential increasing their velocity (and thus the kinetic energy) and, thus, allowing the coating density to be increased.

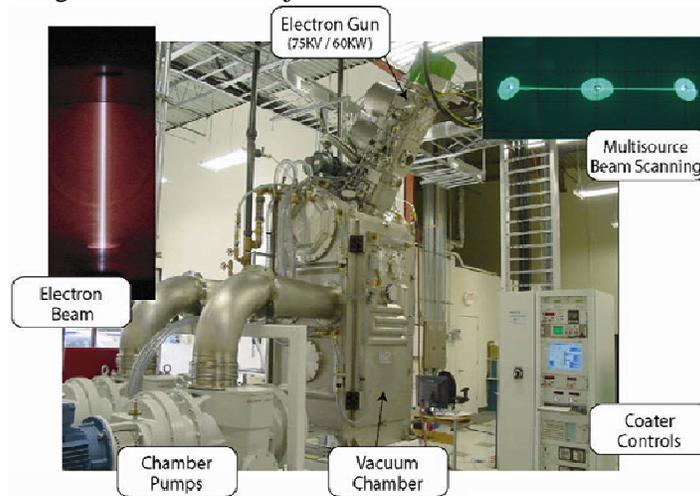
These characteristics combine to make DVD a useful tool for coating complex turbine components that have NLOS regions, regardless of the coating type. No other coating method can currently lay TBCs, Environmental Barrier Coatings (EBCs), or other coating types into these regions with the same uniformity and architecture as DVD.

Attribute	DVD	EB-PVD	Air Plasma Spray
Equipment costs	Moderate	Very High	Low / Moderate
NLOS capable	Yes	No	No
Deposition rates	Very High	Moderate	Very high
Single or multi-step process	Single	Single	Single
Deposition Efficiency	Very High	Low	Moderate
Coating Cost	TBD (projected to be 50% of EB-PVD)	Moderate	Low
Coating Durability	Excellent	Good	Poor
Compositional Control	Very Good	Limited	N/A

## CURRENT STATE OF DEVELOPMENT

The DVD coating process achieved coating thicknesses up to 30X those attained through EB-PVD on test coupons. Coatings applied to the most difficult NLOS regions of an advanced engine vane show significantly improved coating uniformity in early tests, while simultaneously creating the desired coating microstructure. Through the course of this project, DVTI has been able to determine enhanced NLOS coating conditions that have led to improvements over EB-PVD. As of October 2009, we are at a TRL 5. TRL 6 will be achieved following a successful engine test on the coatings, which we anticipate taking early 2010. We are also continually refining the processing conditions to further improve the end product.

In order to continue advancing the DVD technology towards TRL 9 and therefore be full-scale production ready, DVTI must successfully qualify the technology and resultant coatings for OEM use in the manufacture of desired products. DVD applied coatings are currently undergoing this qualification process, as well as for applications in fields of industry unrelated to aviation. DVTI put into operation a prototype production-scale coater in 2006 (Figure 2). Successful qualification of the projects mentioned above and the resulting work orders will enable the company to construct a larger coating machine capable of handling production on a much larger scale than is currently available. Our preferred business model is to provide production coating services for industry OEMs based on our unique expertise with the technology. However, DVTI is willing to license its technology on a non-exclusive basis in appropriate circumstances and has recently executed just such an agreement with a major OEM.



*Figure 2.* The prototype production-scale DVD coater has been used to coat turbine engine components for engine tests and a variety of other parts for customer evaluation.

## REFERENCES

Technical Point of Contact  
Title: NAVAIR Materials Engineering Division (4.3.4)  
Phone: 301-342-8010

## ABOUT THE COMPANY

Established in 2000, DVTI provides coating development services to OEM and implements the developed coatings in a production environment through continued partnership or licensing. The next generation advanced coating technology of DVTI, electron beam directed vapor deposition (EB-DVD), is the result of research conducted at the University of Virginia. Through a licensing agreement with the University of Virginia Patent Foundation, DVTI holds an exclusive worldwide license to these technologies. In 2005, the Virginia Piedmont Technology Council awarded DVTI with the Rocket Award, presented annually to a technology-based firm that demonstrates rapid transition from concept toward commercialization.

DVTI is led by CEO Harry A. Burns. He brings the experience of a retired CEO of \$500M international manufacturing company with 30 years senior executive management experience. DVTI is also fortunate to have as a part of its management a number of the researchers who have been instrumental in perfecting EB-DVD technology, including Prof. Haydn Wadley, Scientific Advisor, and Dr. Derek Hass, Director of Research and Development.

DVTI has twelve employees and its administrative headquarters are at 2 Boar's Head Lane, Charlottesville, Virginia. It also has a manufacturing facility at 4006 Hunterstand Court near the Charlottesville airport where it operates its own production scale DVD coating system. In addition DVTI has long-term access to two additional DVD coaters located in Charlottesville, Virginia.