# Reducing blade damage caused by lightning

Arctura's ArcGuide® coating represents a groundbreaking approach in mitigating lightning-induced damage to wind turbine blades, a problem that costs the industry over $100 million annually. Designed to alter the electric field surrounding the blades, the coating encourages the formation of lightning leaders at specific receptors rather than within the blade itself, reducing the frequency of punctures. Laboratory testing on GE 1.5sle blades demonstrated a significant 73% decrease in punctures at prevalent strike angles. This enhancement could substantially reduce both downtime and repair expenses for the wind industry. Recent studies corroborate the coating's potential to diminish these financial losses.

### How lightning protection systems work

Most modern wind turbine blades are equipped with lightning protection systems (LPSs). The most common LPS uses one or more surface-mounted lightning receptors connected to a grounded down conductor: see Figure 1.

A typical lightning strike begins when the strong electric field induced by a charged storm cloud and downward stepped leader causes upward streamers and leaders to emanate from the grounded lightning receptors on the blade. A direct strike results when one of the upward leaders from the receptor connects with the downward stepped leader from the cloud passing a large amount of electrical charge safely to ground.

Unfortunately, this system has some flaws. Leaders will also form from the down conductor and other conductive components internal to the blade. Often, those internal leaders reach through the blade skin and 'win the race' to be the first to connect with the downward leader from the cloud. This creates a puncture through the blade skin, delamination, debonding of the trailing edge, or more catastrophic damage.

What's needed is a way to ensure that the leaders that form over the exterior surface of the blade at the receptors 'out-compete' those that form inside the blade and win the race to connect with the downward leader from the cloud.

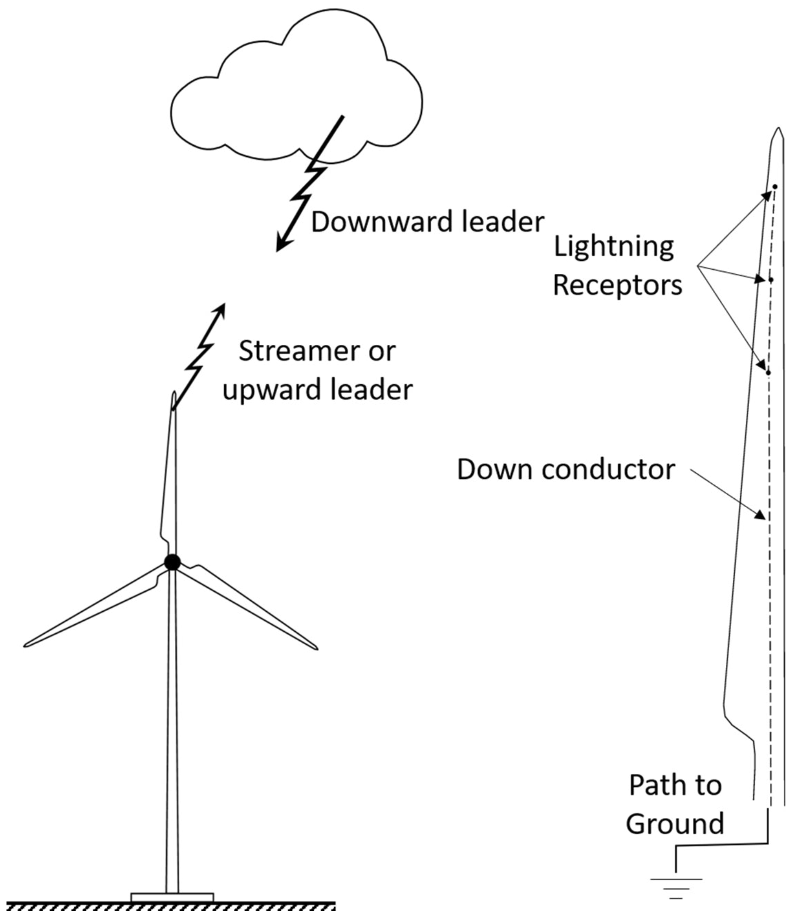



Figure 1

### Introducing the ArcGuide® Coating for enhanced lightning protection

The ArcGuide® coating is the result of a four-year DOE-funded R&D project. It is a polyurethane-based topcoat that is applied to the exterior surface of wind turbine blades in the vicinity of the lightning receptors. The coating enhances the performance of the LPS by making it more likely that lightning will attach to the receptors and less likely that it will penetrate the skin of the blade when attaching directly to the down conductor or other metal components inside the blade.

The coating contains a proprietary mixture of specially-designed conductive particles. The coating itself is not conductive; rather, the specially designed formula disrupts the electric field in the air above the surface in a way that leads to early formation of electric arcs, or 'leaders', at the receptors. The receptor-fed leaders then grow faster and further over the surface of the blade, out-competing the leaders that form inside the blade in the race to connect with the downward leader from the cloud.

This effect is easily seen in Figure 2, which was taken in the high voltage lab at Element Lightning Technologies, Inc., in Pittsfield, MA. In this photograph, a square fiberglass panel coated with the ArcGuide® coating on the left half and a baseline topcoat on the right half was arranged such that both halves were subject to the same initial electric field conditions. A mock lightning receptor was installed at the center of the panel.

The receptor is electrically connected to a high voltage generator, and the floor beneath the panel is electrically grounded. The outline of the panel, center receptor, and dividing line between the coatings have been highlighted. Increased leader activity is clearly seen on the left side, coated with the ArcGuide®, relative to the right side, coated with baseline topcoat. This increased activity is key to guiding strikes to the receptor and thus reducing the probability of punctures and damage elsewhere on the blade.

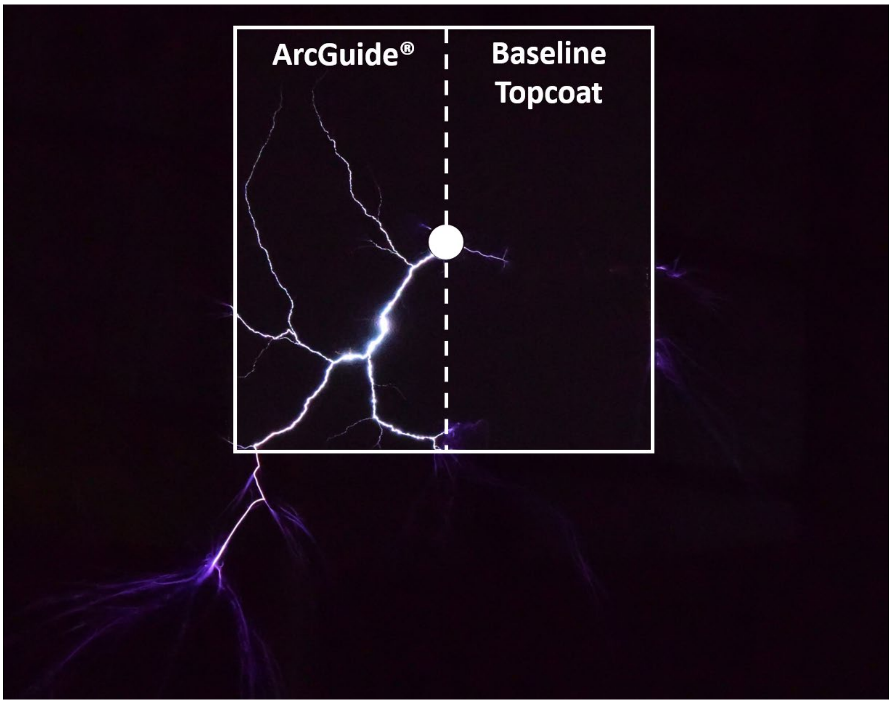



Figure 2

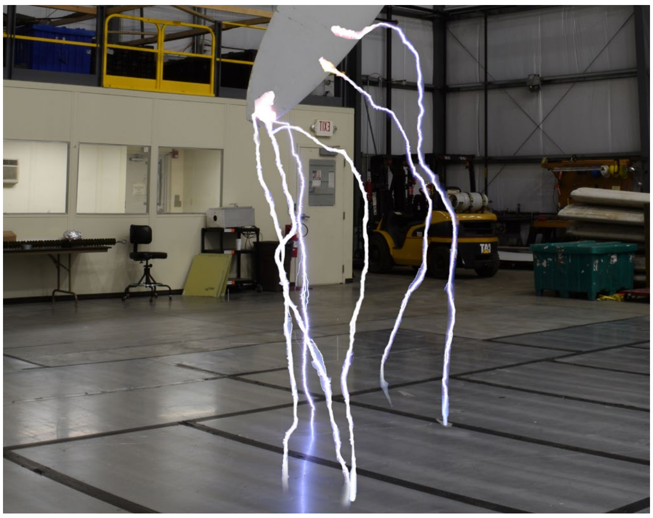
### How effective is it?

The effectiveness of the ArcGuide® coating at reducing blade damage was assessed using high voltage initial leader attachment tests per Annex D of IEC 61400-24 at Element Lightning Technologies' test facility.

Several retired wind turbine blade tips from GE 1.5sle wind turbines were obtained prior to recycling. We chose this turbine model because it is the most common machine operating in the United States today and is known to suffer from lightning damage. The selected blade tips were five meters in length, each having a single large lightning receptor on the pressure side of the blade roughly 15 cm inboard of the tip.

The IEC standard summarises lightning risk, testing, and general protection requirements for the wind industry. The standard calls for the blade tips to be suspended over a ground plane with the receptor at high voltage. The blades were tested at angles of 60°, 30°, and 10° with respect to ground. Shallower angles are harder to protect as the electric field is increased inboard and away from the tip receptor.

Figure 3 shows two composite images of all strikes to one of the blades hung at an angle of 60°. Each of the electrical arcs that span



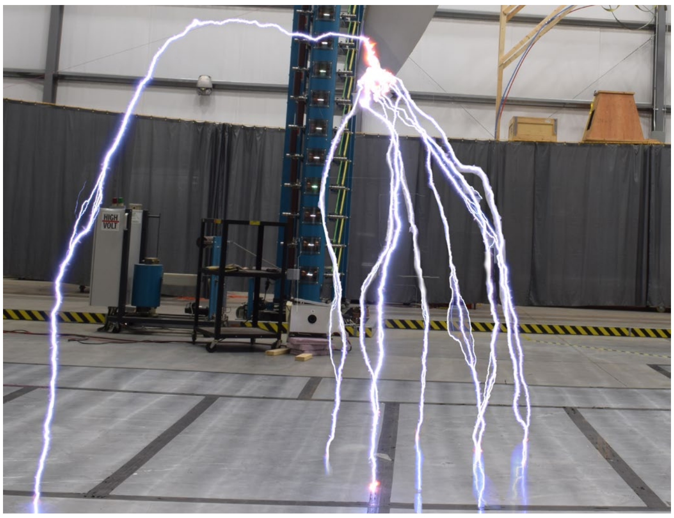


Figure 3

# Over four years of empirical testing and optimisation, in collaboration with Element Lightning Technologies and Mankiewicz, we have developed the ArcGuide® coating to reduce wind turbine blade lightning damage.

from the blade to the floor represent one test, or 'strike.' Image processing was used to combine multiple shots into a single picture. The baseline configuration on the left shows most of strikes terminating at receptor, as desired. However, two strikes punctured through the blade further inboard.

In contrast, the image on the right shows the same blade hung at the same angle, but in this case the ArcGuide® coating has been applied. All shots with the coating terminated at the receptor. More testing was completed with three different blades hung at 60°, 30°, and 10° with respect to ground, each with and without the ArcGuide® coating.

The blades coated with the ArcGuide® coating performed significantly better than the blades without the coating. Blades that were coated incurred no damage when tested at angles of 30° or higher. For the difficult-to-protect 10° case, the blades with the ArcGuide® coating suffered half as many punctures as the baseline cases.

In total, 154 strikes of three GE 1.5sle blade tips were conducted in the lab. For each angle and each configuration, baseline or ArcGuide®, a failure rate was calculated as the number of punctures divided by the total number of strikes, either punctures or flashovers to the receptor. The failure rate is plotted as a function of blade angle in Figure 4. Limited testing below 10° and at 90° indicate a 100% and 0% failure rate can be assumed at these angles, respectively, for both configurations.

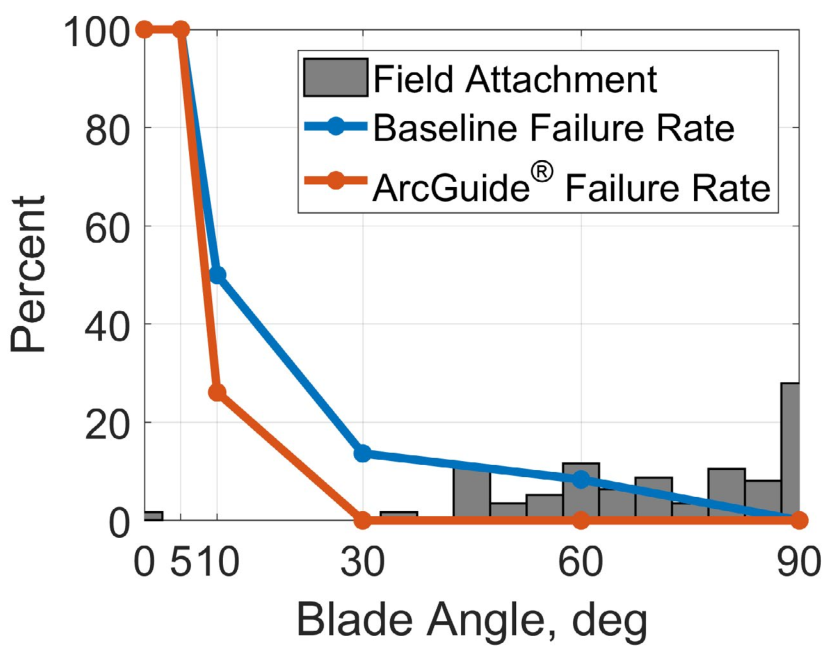
The histogram superimposed in this figure represents data on the attachment angles of lightning strikes on operational wind turbines obtained from a publication that analysed video footage of winter lightning strikes on 12 turbines over a five-year period in Japan. The attachment angles of 172 strikes in total were quantified.

The histogram shows the reported strike frequency, as a percentage of the total, as a function of blade angle. In this case, 90° refers to the blade extending straight up, and 0° refers to the blade extending horizontally, either ascending or descending. Nearly 30% of the strikes occurred with the blade in the vertical 90° position.

Of note is that 98% of the observed strikes attached at a blade angle greater than 30°, and no punctures in the lab were observed with the ArcGuide® coating at a blade angle of 30° or higher.

Applying the baseline failure rate observed in the lab, linearly interpolating between angles tested, to this distribution of strikes, 6.4% of strikes would be expected to puncture through the blade skin and cause damage.

Applying the ArcGuide® failure rate to this distribution, only 1.7% of strikes, the three at 0°, would be expected to cause punctures.




Thus, a 73% reduction in the frequency of punctures is predicted in the field with application of the ArcGuide® coating for typical GE 1.5sle blades.

The usual caveats about the stochasticity of lightning are relevant here and these results should be interpreted with caution. Even with the hundreds of strikes observed in the lab and in the field for this analysis, the datasets may not be completely converged.

### Will the coating survive a lightning strike?

The ArcGuide® coating was tested according to IEC 61400-24 to assess physical damage after a strike. After multiple worst-case 200 kA strikes, no damage was observed. The coating is expected to be maintenance free while remaining effective at increasing lightning protection for the lifetime of the coating regardless of the number or strength of lightning strikes.

### How long will it protect a blade?

The durability has been assessed using ASTM standards for coatings. The ArcGuide® coating shows comparable performance to industry-standard wind turbine blade topcoats. The coating manufacturer, Mankiewicz, has also evaluated it using their standard series of coating performance tests according to customer specifications.

### Concluding remarks

Lightning is a top cause of wind turbine blade damage, and lightning damage repairs represent a significant maintenance cost for the industry. Over four years of empirical testing and optimisation, in collaboration with Element Lightning Technologies and Mankiewicz, Arctura has developed the ArcGuide® coating to reduce wind turbine blade lightning damage.

In addition to the evidence presented here, a significant amount of data has supported the efficacy and performance of the coating. For example, high current testing suggests that the coating will be undamaged by strikes and adhesion testing shows that the coating will remain effective for the life of the blade. More information and a white paper, detailing this study can be found on Arctura's website arcturawind.com.

The is now available to purchase as the ALEXIT® BladeRep® topcoat ALP 20 with ArcGuide®.

www.bladerep.com