Wind tunnel experiments were conducted to understand boundary layer separation control on airfoils. The objective of this research was to better implement flow control strategies with single dielectric barrier discharge (SDBD) plasma actuator designs for airfoils that exhibit both leading and trailing edge stall characteristics at realistic flight speeds and Reynolds numbers. The NASA energy efficient transport (EET) airfoil was a platform to study the effect of plasma actuators on leading edge stall and boundary layer separation in a strong adverse pressure gradient, while the V-22 Osprey airfoil was used to study trailing edge stall with separation in a weaker adverse pressure gradient.

The EET airfoil was designed to have a spanwise plasma actuator on removable leading edges made from two different dielectric materials: Kapton and Macor. Two different plasma waveforms were also tested with the same electrodes, AC (alternating current) and nanosecond pulse (NP) driven. Aerodynamic force and moment measurements showed that both plasma actuators were effective at increasing the stall angle of attack and maximum lift for the range of Mach numbers tested, 0.1–0.4, and Reynolds numbers of 560,000–2,240,000. This indicated that the shear layer instability was highly receptive to both disturbances: either the body force from AC plasma actuator, or the nondirectional thermal disturbance of the NP plasma actuator. The shear layer instability also provided for an opportunity to quantify the effect of unsteady, or duty cycle, operation. The lift to drag ratio of the EET airfoil was improved the most by operating the AC plasma actuator at a reduced frequency of unity and the NP plasma actuator at 2 or higher.

The second part of the experiment examined the efficacy of plasma actuators on a V-22 airfoil for trailing edge separation control in the presence of new factors such as moving separation location, crossflow, turbulent boundary layers, and weaker pressure gradients at the line of vanishing shear. Initial consideration of moving separation location with angle of attack motivates the use of plasma streamwise vortex generators (PSVGs) which take up a larger percent of the chord dimension and produce streamwise vorticity from both crossflow momentum addition and by reorienting spanwise vorticity from the boundary layer. The PSVGs were compared to traditional passive vortex generators (VGs). These devices were installed on the wing section by which the angle of attack could be used to vary the streamwise pressure gradient. The experiment was performed for freestream Mach numbers 0.1–0.2 and a Reynolds number range of 790,000–1,590,000. Three-dimensional velocity components were measured using a 5-hole Pitot probe in the boundary layer. These measurements were used to quantify the production of streamwise vorticity and the magnitude of the reorientation term from the vorticity transport equation. Reductions in drag were well correlated to streamwise vorticity production. For the PSVG, vorticity production was proportional to the residence timescale of freestream momentum and operating voltage. These results indicate that the PSVGs could easily outperform the passive VGs and provide a suitable alternative for flow control. Finally, a design equation was proposed to create a PSVG equivalent to a VG including design parameters such as Mach number, angle of attack, operating voltage, and electrode length.