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Active Flow Control in an Engine Inlet With Plasma Actuation

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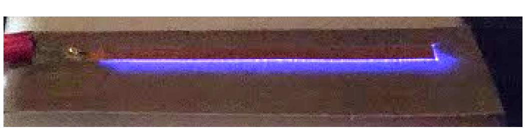
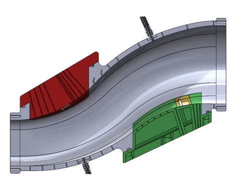
Gas turbine engines dominate propulsion in modern commercial and military aircraft. For fighter aircraft and unmanned aerial vehicles with curved intake ducts feeding embedded engines, ensuring a uniform flow field at the engine inlet is a critical performance requirement. Non-uniformities in the velocity and total pressure distribution across the engine face cause the turbomachinery components to rotate through regions of varying airflow, leading to cyclical fatigue and ultimately reduced lifespan. These deficiencies also increase the susceptibility of the engine to surge and compressor stall events, which can result in loss of thrust, component damage, and reduced fuel efficiency. A common cause of these instabilities is the boundary layer separation in inlets with high curvature and cross-sectional area changes. Such geometries are necessary for aircraft with embedded engines, allowing them to be integrated inside the fuselage, thus reducing drag, and increasing fuel efficiency and maneuverability.

A promising active flow control method is the use of plasma actuators (PA) based on a dielectric barrier discharge. These devices use high voltage alternating current (AC) applied across two electrodes separated by a dielectric barrier to generate plasma. The resulting plasma is subject to a body force in the presence of the electric field and creates a synthetic jet that transfers momentum into the surrounding airflow. Added momentum in the flow re-energizes the boundary layer and delays or prevents flow separation at the wall, improving the uniformity of flow field. The PAs are less than a millimeter thick and are flexible enough to conform to the curved inlet walls, minimizing aerodynamic interference. Further, these synthetic jets operate without moving parts, relying solely on a voltage signal, making them a lightweight and simple flow-control device (a).

The objective of this research is to experimentally demonstrate how PAs can manipulate airflow through a generic S-duct inlet (b). Testing is conducted with the S-duct attached to an in-draft wind tunnel that induces a typical cruise airspeed of Mach 0.8 at the S-duct inlet. Interchangeable PA cartridges are installed on the wall of the S-duct at locations where previous experiments with the same S-duct indicated flow separation. Pressure taps drilled into the S-duct wall, upstream and downstream of the PAs, measure their effectiveness in re-attaching the boundary layer and stabilizing outlet flow conditions. The plasma intensity and PA durability is assessed by recording the plasma light emissions with a photoelectric diode and spectrometer to monitor changes in characteristic wavelengths. A proposed test matrix identifies the effects of PA voltage and frequency on flow uniformity at the exit of the S-duct inlet.



(a) Plasma actuator with plasma on.



(b) S-duct cross-section

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