Plasma Streamwise Vortex Generators (PSVGs) for Control of Flow separation

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ABSTRACT

This SBIR program deals with the development of a Plasma Enhanced Aerodynamic Control (PEAC™) system to improve the aerodynamic performance of V-22 Osprey. The system uses non-thermal, dielectric-barrier-discharge (DBD) plasma actuators on the wings of the aircraft to improve its aerodynamic performance during varying flow conditions. The system also includes a real-time plasma actuator self-health monitoring system for fail-safe operation and identification of imminent failure modes. The work discussed here focuses on the design of an innovative plasma streamwise vortex generator (PSVG) for flow control. Currently, passive, rigid, mechanical vortex generators (VGs) are used on the V-22 Osprey wings to prevent flow separation during forward flight. Passive VGs, however, cause significant parasitic drag which limits the vehicle range, and are also ineffective in dynamic flow conditions, thereby limiting flight performance. Thus, the goal of this effort is to replace the passive, mechanical VGs with active PSVG system. Our experiments demonstrate that PSVGs can not only harvest energy from the external flow like passive VGs, but also improve their performance with Reynolds number, thus making them very suitable for flight control applications.

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OBJECTIVE

Design and develop active plasma streamwise vortex generators (PSVGs) for separation control.

PROBLEM

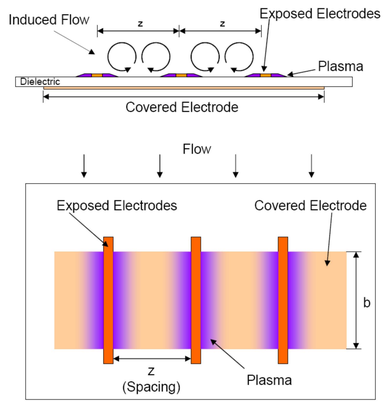
- Passive Vortex Generators (VGs) are used on the V22 wings to maintain attached flow in the initial flight stage from take-off to approximately half of the cruise speed.
- At cruise conditions, the flow is naturally attached, and the VGs are no longer needed. During this flight phase the passive VGs produce parasitic drag that reduces cruise efficiency.

PROPOSED SOLUTION

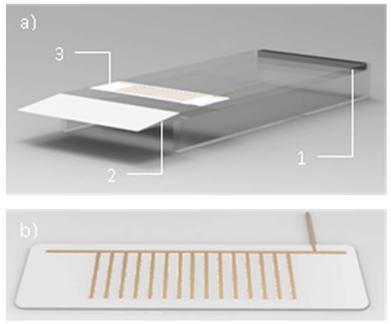
Replace *passive* mechanical VGs with *active* PSVGs.

Plasma streamwise vortex generators (PSVGs)

An active method to produce streamwise vortices like passive VGs, that produce no parasitic effects when not needed. The approach is Plasma Streamwise Vortex Generators (PSVGs) that are based on plasma actuator technology. The PSVGs consist of electrodes that are aligned parallel to the oncoming flow. These electrodes sit on top of a dielectric material that insulates these electrodes from a common covered electrode in a classic dielectric-barrier arrangement. The electrodes are supplied with an A.C. voltage that is high enough to cause the air between the exposed electrodes to ionize. The ionized air (plasma) in the presence of the electric field produced by the exposed and covered electrode arrangement results in a body force vector field that acts on neutral air. The body force vector field of the PSVG design results in the formation of counter-rotating vortex pairs. When located on a surface in a boundary layer, they produce the identical effect of passive wedge-type vortex generators. When not activated, the flush electrodes produce no parasitic effects on the flow.



FUNDAMENTAL EXPERIMENTS ON A FLAT PLATE

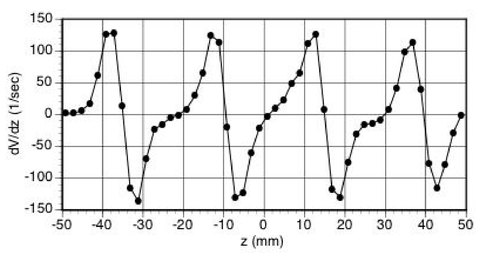


a) Rendered CAD model of boundary layer development plate.
1. Distributed sand grain roughness in order to promote rapid boundary layer transition.
2. A 2.2° linear, symmetric taper down to a trailing-edge thickness of 1.6 mm.
3. PSVG actuator test fixtures are flush mounted into a cavity machined into the plate surface to provide room for high-voltage leads and the dielectric material.

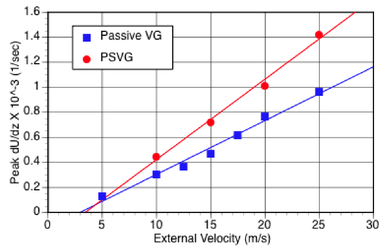
b) Close-up of PSVG array.

Comparison of Passive VGs and PSVGs.

In order to provide a baseline data set for comparison, the test fixture containing the PSVG was temporarily replaced containing a spanwise array of five passive trapezoidal vortex generators. A series of experiments was performed to provide a comparison between and downstream of both the passive VGs and the PSVG.



Example result shows the large spanwise periodic mean velocity gradient set up by the PSVG due to the generation of spanwise counter-rotating streamwise vortices.



Comparison of passive VG and PSVG performance. The similarity is quite remarkable with the PSVG producing somewhat larger values over most of the range of external velocities tested.

SUMMARY

- The PSVG system utilizes the body force vector field associated with flush-mounted DBD plasma actuators to create on-demand streamwise vortices.
- The PSVGs offer the ability to generate streamwise vorticity when boundary layer separation is imminent but effectively “disappear” when not needed.
- Unlike other DBD flow control actuators, PSVG performance improves with flow speed.
- Developed scaling relations for the PSVG performance provide predictive design capability for full-scale applications.

See AIAA Paper 2012-0824 for additional details on the PSVG study.