Dynamic stall control by NS SDBD actuator for forward and reverse flow

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In the last two decades, nonequilibrium plasmas have demonstrated the ability to affect a variety of flows of aeronautical interest [1], including mitigation of stall on steady airfoils. Plasma actuation shows promise to address dynamic stall in rotorcraft as it is a nonintrusive, active control method. In this study, nanosecond pulsed Surface Dielectric Barrier Discharge (ns-SDBD) plasma devices are used to control boundary layer separation on a pitching airfoil [2-6]. Actuators operate in continuous mode in the range of 50-500 Hz with 20kV, 25ns FWHM pulses. For a Reynolds number of 4.5×10^5 and reduced frequency of 0.02, stall mitigation is demonstrated for angles of attack up to 32 degrees and increase in lift of up to 20%. The common issue of Retreating Blade Stall (RBS), as experienced in helicopters, was also considered in this study by experimenting with a reverse flow over an airfoil. Increases in lift are demonstrated for separated flows with Reynolds numbers up to 7×10^5 and reduced frequencies $k \leq 0.05$, with angles of attack up to 32 degrees. Increases in lift with plasma control are demonstrated to be up to 55% for reversed flow. Changes in drag with plasma actuation for all tests are within 10% in the stall regime.

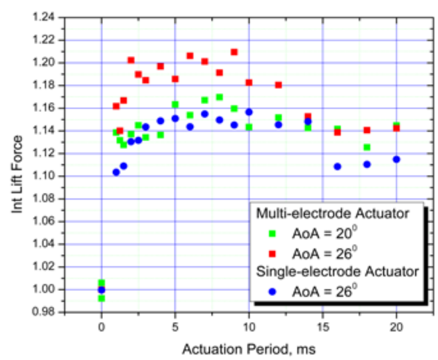
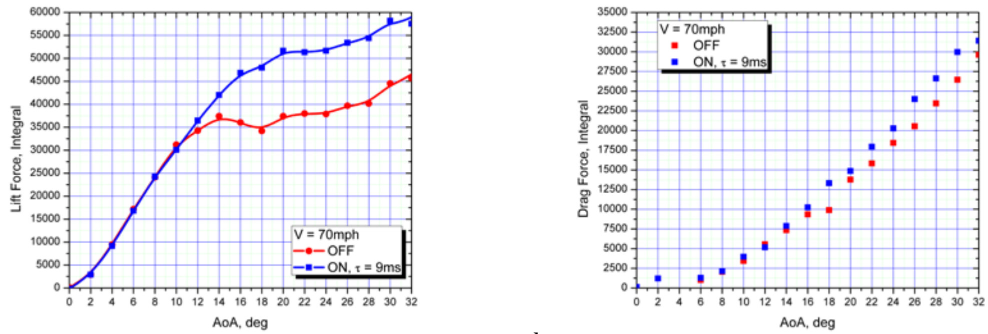


Figure 1. Integral of the lift force over the pitching cycle for single-electrode and multi-electrode configurations. V = 31 m/s.

Figure 1 demonstrates the lift force integral over the pitching cycle for two different electrode geometries. Single-electrode geometry corresponds to the initial configuration with a single discharge located at the leading edge of the airfoil. Multi-electrode configuration utilizes the same electrode on the leading edge of the airfoil with 4 additional electrodes equally distributed along the upper surface of the airfoil. The multi-electrode configuration was designed to enhance the authority of the plasma actuator due to the multiple vortices production during the separation development. It is clear from the Figure 1 that the multi-electrode actuation allows additional lift force increase in compare to the case of the single-electrode actuator. In a multi-electrode configuration the airfoil at AoA= 20^0 demonstrates the same lift force increase as the airfoil with a single-electrode actuator at AoA $=26^0$ (Figure 1).



a b

Figure 2. Integral of the lift (a) and drag (b) force over the pitching cycle for reverse flow configuration. V = 31 m/s. Actuation period τ = 9 ms.

Integral of the lift and drag force over the pitching cycle for reverse flow configuration is shown in the Figure 2. NS SDBD actuation with a discharge frequency of f ~ 110 Hz allows an integral lift force increase up to 1.4 times (Figure 2,a), with almost the same drag force (Figure 2,b).

Five free stream velocities were tested in the reverse configuration: U_∞ = 40mph, 70mph, 100mph, 120mph, and 150mph (Figure 2). Similar trends are observed for the pitching dynamics as with the normal flow configuration. These trends include the linearity of lift force increase until separation occurs, then an unsteady period of boundary layer separation above the critical angle of attack, and a hysteresis between the separation angle and reconnection angle. It should be noted these flows are all quasi-steady, with reduced frequencies $k \leq 0.05$. Integral lift over a single pitching period increases near-monotonically with plasma actuation. Increases in lift are observed to be as large as 55%, while changes in drag are typically below 10% in the stall regime.

Acknowledgments

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References

[1] Miles R.B., Plasma Flow Control, Fundamentals, Modeling, and Applications,” von Karman Institute for Fluid Dynamics , Rhode Saint-Genese, Belgium VKI LS 2011-02, ISBN-13 978-2-87516-014-0 (2011)

[2] Starikovskiy A., Aleksandrov N.. Nonequilibrium Plasma Aerodynamics. In: Aeronautics and Astronautics. Ed by: Max Mulder. ISBN 978-953-307-473-3. 2011.

[3] Opaits D.F., Roupassov D.V., Starikovskaia S.M., Starikovskii A.Yu., Zavialov I.N., Saddoughi S.G.,“*Plasma Control of Boundary Layer Using Low-Temperature Non-equilibrium Plasma of Gas Discharge*”. 43-rd AIAA Aerospace Sciences Meeting and Exhibit, 2005. Reno, Nevada, USA, paper AIAA 2005-1180, 2005.

[4] Nikipelov A., Nudnova M., Roupassov D., Starikovskiy A. “Acoustic Noise and Flow Separation Control by Plasma Actuator”. AIAA-2009-695. 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 5-8, 2009

[5] Starikovskii A.Yu., Nikipelov A.A., Nudnova M.M., Roupassov D.V. “SDBD plasma actuator with nanosecond pulse-periodic discharge,” Plasma Sources Sci. Technol. 18 (2009)

[6] Aleksandrov N.L., Kindysheva S.V., Nudnova M.M. and Starikovskiy A.Yu. “Mechanism of ultra-fast heating in a nonequilibrium weakly-ionized air discharge plasma in high electric fields”. J. Phys. D: Appl. Phys. 43 (2010) 255201 (19pp)