RC Helicopter lift force increase in hover mode by NS-SDBD plasma actuators

Andrey Starikovskiy[1], Nikita Persikov[2], Richard Miles[1]
[1]*Princeton University, Princeton, NJ 08544, USA*
E-mail: astariko@princeton.edu, miles@princeton.edu

[2]*Rutgers University, NJ 08901, USA*
E-mail: npersikov1@gmail.com

Keywords: NS discharge, plasma actuation, helicopter blade, lift force

NS-SDBD plasma devices have shown a sufficient control authority for conditions corresponded to helicopter retreating blade stall (RBS), which is characterized by free stream velocities on the order of 100 m/s (Mach 0.30) and Reynolds numbers on the order of 10^6 [1-5]. The goal of the current work is an experimental demonstration of efficiency of NS-SDBD for the lift force increase in a hover mode of the helicopter.

The main difference between the results of this work and previous studies is the use of rotating blades, which leads to the appearance of a longitudinal component of the flow velocity along the blade. Rotation of the blades also leads to a large difference in flow velocity near the root of the blade and near its tip, which makes it difficult to optimize the frequency of the actuator. The work also used a constant power drive to rotate the rotor – that is, the total effect of the actuator was composed of both an increase in the lift force coefficient when the flow was attached, and a change in the drag force coefficient, which led to a change in the rotational speed of the blades. Thus, the experiment was as close as possible to the operating conditions of the real helicopter rotor in the hover mode.

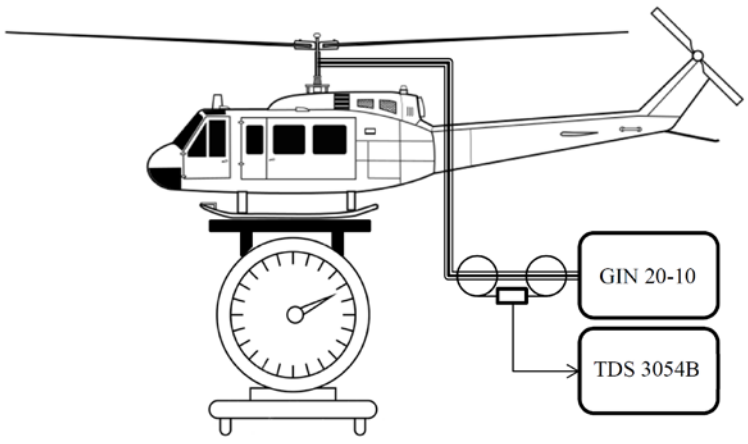

Figure 1. Experiment schematics.

For the experiment, a standard radio-controlled helicopter model was used. The model had 1860-mm blade span and was powered by 4.5 kW electrical motor (Fig.1). The model was additionally equipped with an electrical system which allows delivering NS high-voltage pulses from the pulser to rotating blades. The pulses had amplitude of 20 kV and frequency from 200 Hz to 2 kHz. The asymmetric plasma actuators were flash-mounted on the leading edge of the blades.

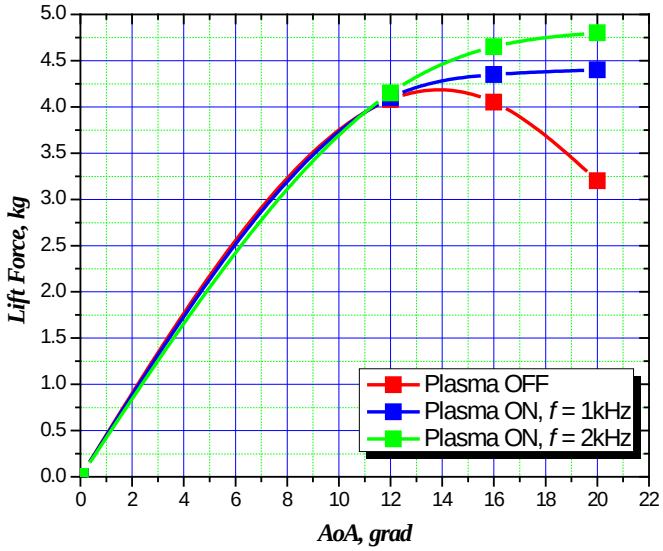

Figure 2. Lift force dependence on angle of attack.

Figure 2 shows the results of the lift force measurements in the hover mode for different angles of attack in three cases: without actuation; actuation at f = 1 kHz; and actuation at f = 2 kHz. Without actuation the blades achieve the maximal lift force at $\alpha = 12^0$. Further increase of the angle of attack leads to the flow separation and the lift force decrease (Figure 5). When actuator is on, we observed a significant lift force increase at high angle of attack – up to 7% for actuation frequency of 1 kHz, and up to 20% for actuation frequency of 2 kHz. It means that we can significantly increase the payload and/or extend the flight envelope of the helicopter using plasma actuation.

Acknowledgements
This work was supported in part by ARO research program "Control of Static and Dynamic Stall in a Wide Range of Mach Numbers by Plasma Actuators with Combined Energy/Momentum Action".

References
[1] Starikovskiy A., Aleksandrov N.. Nonequilibrium Plasma Aerodynamics. In: Aeronautics and Astronautics. Ed by: Max Mulder. ISBN 978-953-307-473-3. 2011.
[2] 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.
[3] 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
[4] 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)
[5] 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)