Technion
Israel Institute
of Technology

DBD Plasma Flow Control on Wind Turbine Blades

David Greenblatt

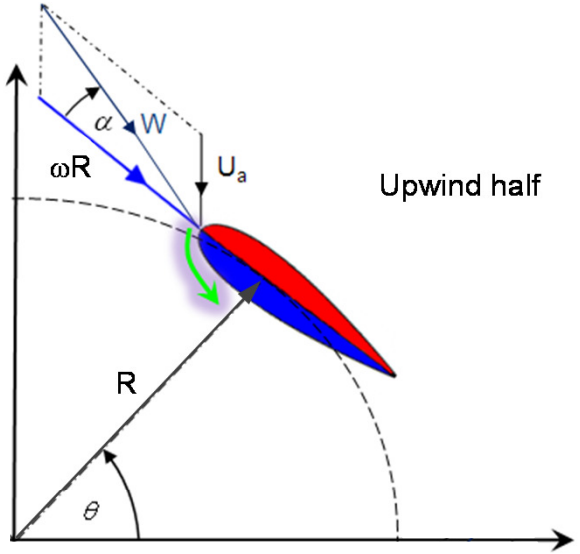
Faculty of Mechanical Engineering
Technion – Israel Institute of Technology

Acknowledgements
Mitchell Entrepreneurial Program
Carl E. Schustak Energy Research and Development Fund

VAWTs & Dynamic Stall



Eastern Wind Power's Sky Farm™ 50 kW VAWT



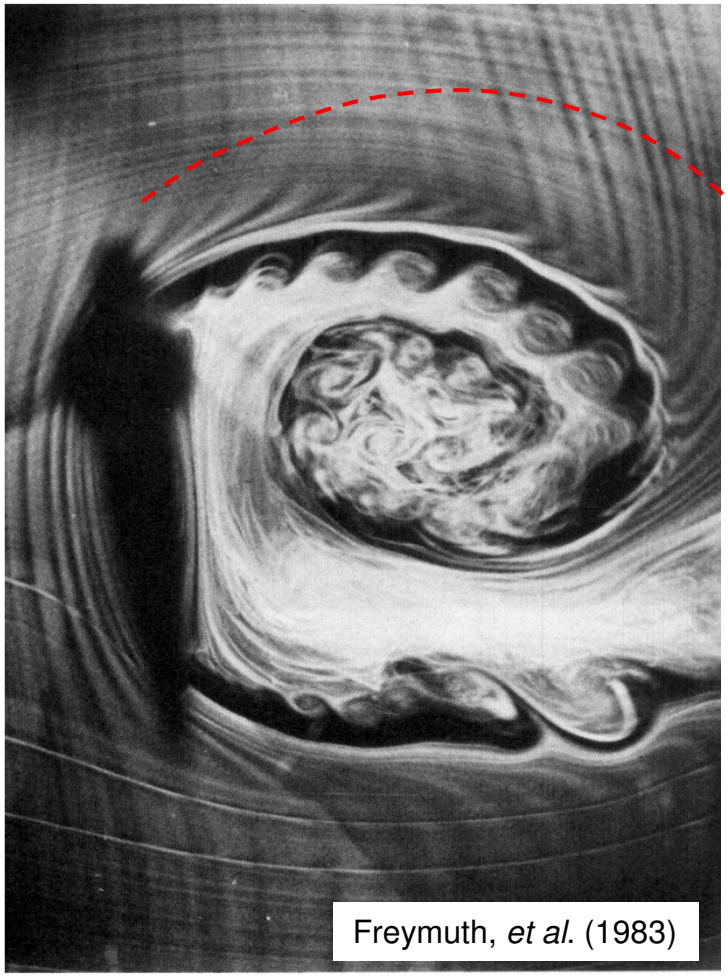
Objective

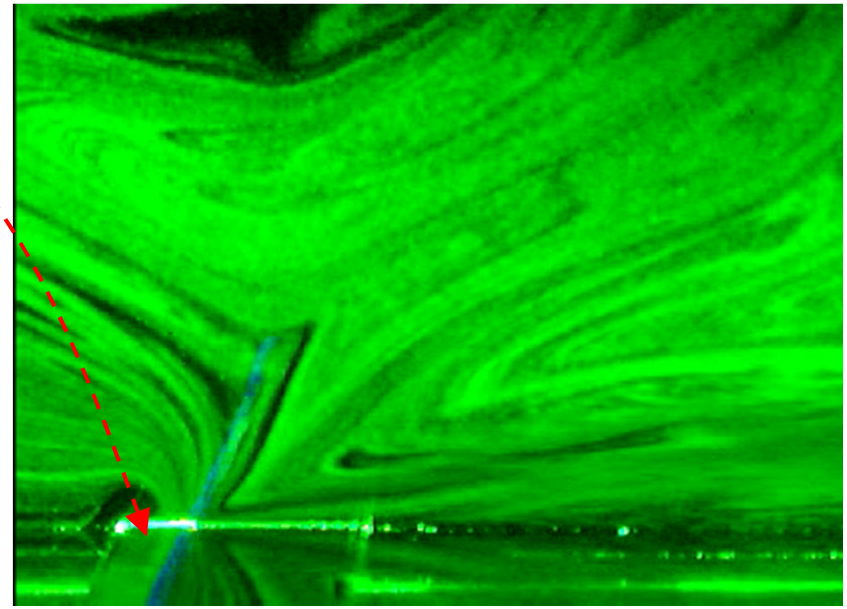
Develop a DBD plasma-based dynamic stall control system on VAWTs:

How far have we come?

- Open loop control – proof-of-concept (Schulman, Müller-Vahl)
- Feed Forward control – power efficiency (Ben-Harav)
- Upwind/downwind switching – towards implementation (Lautman)
- Hysteresis feedback control – unsteady wind speed (Eshel)

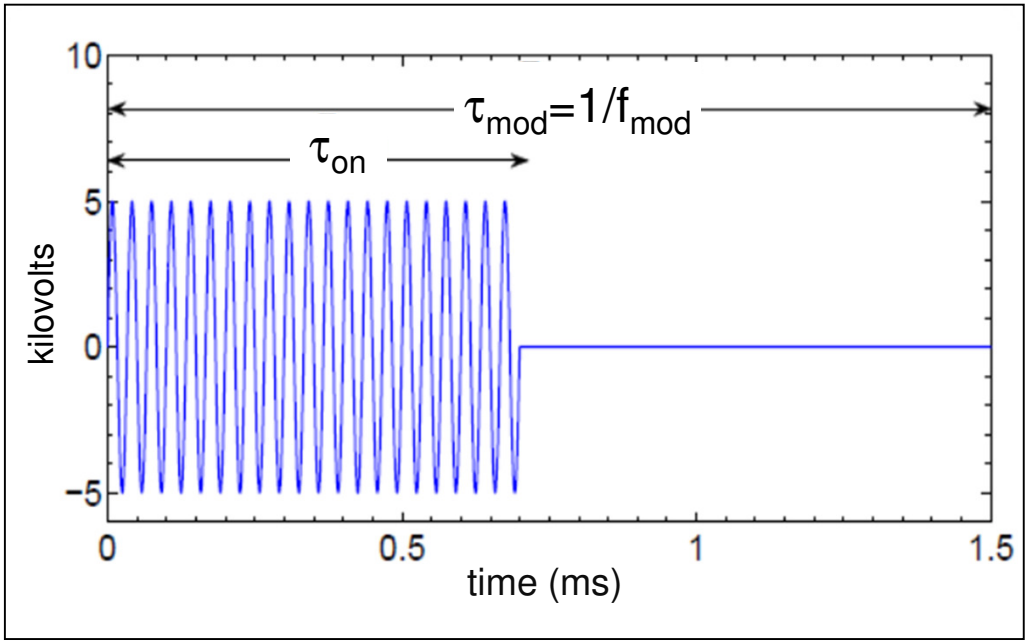
Dynamic Stall & Pulsed DBD Plasma Control

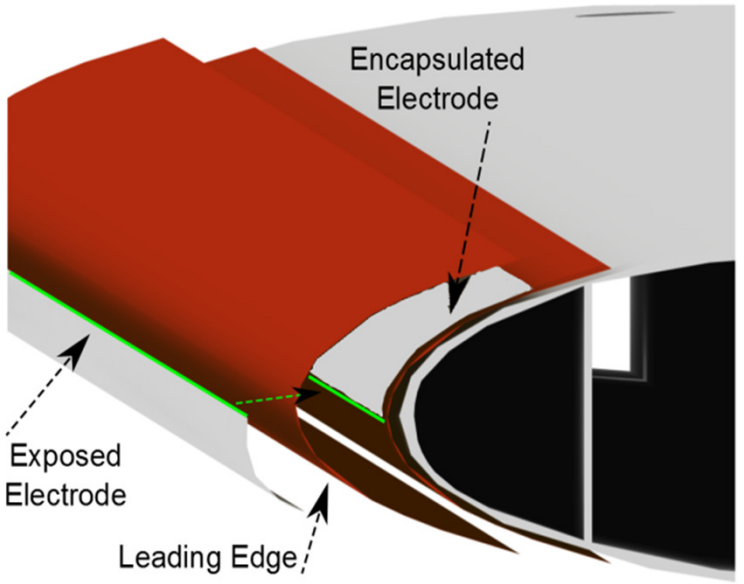




DBD Plasma is “pulsed” at the shear-layer instability frequency

One-sided actuator & parameters





Reduced Frequency

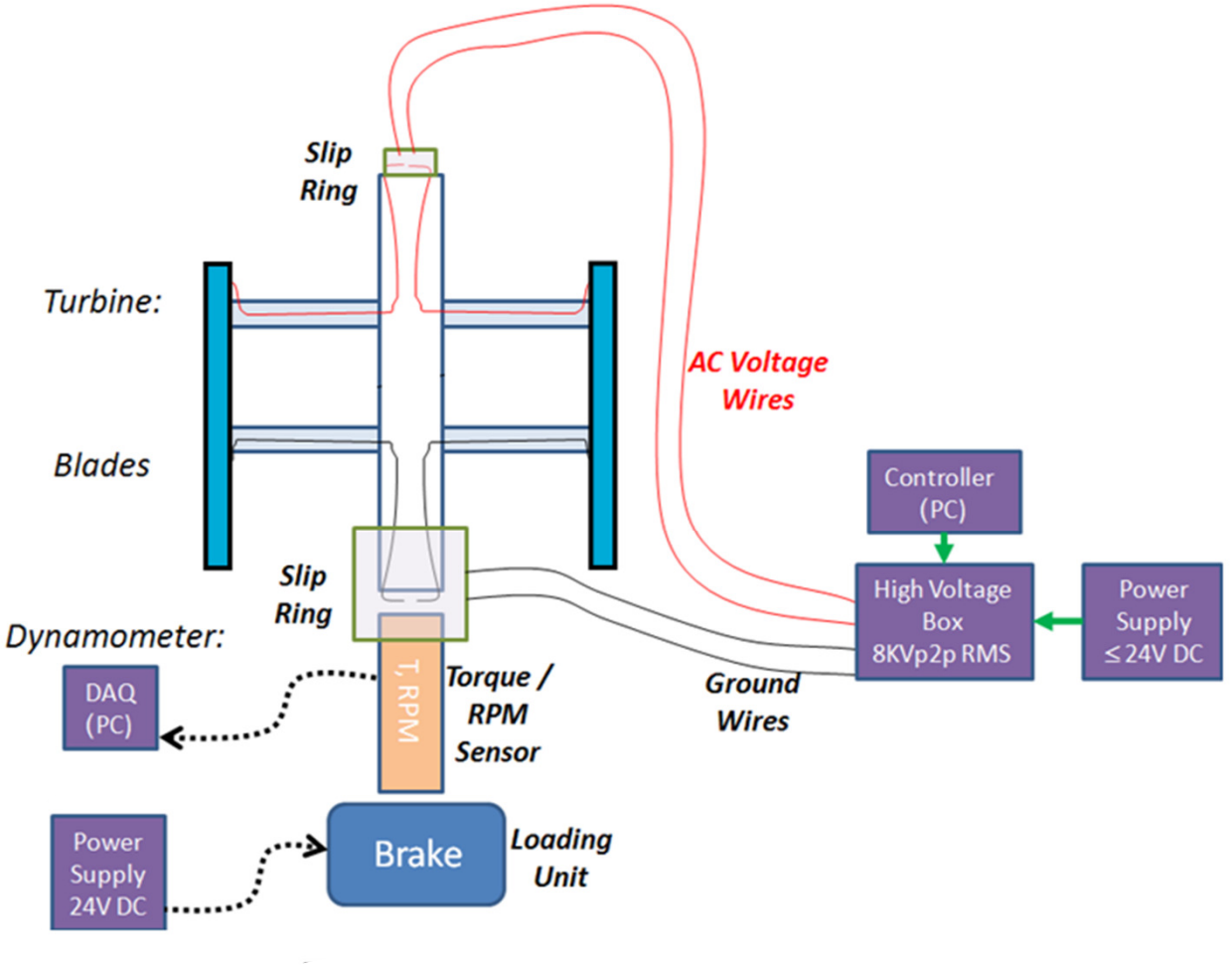
$F^+ = f_{mod}c/W$

Pulsation duty cycle

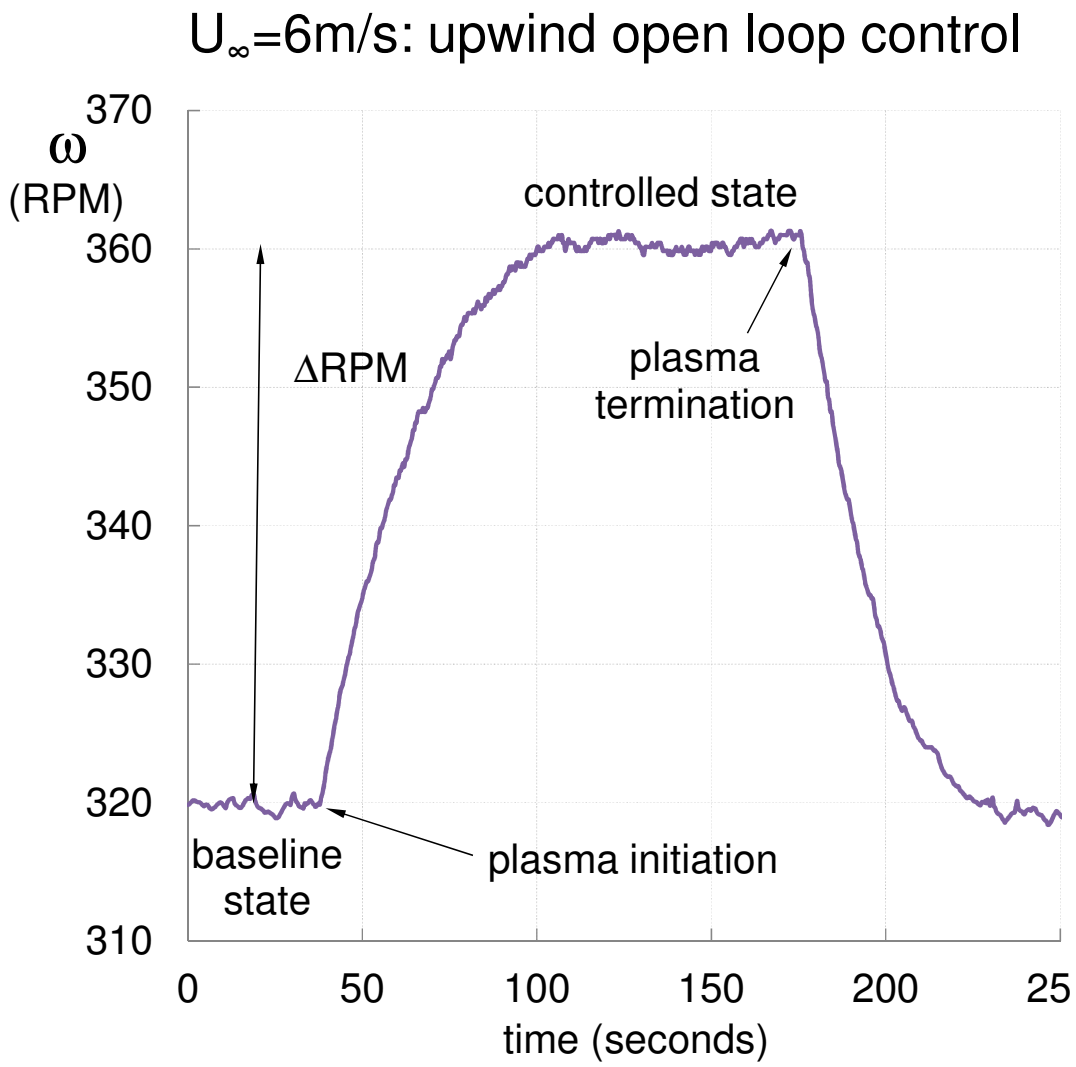
$DC = \tau_{on}/\tau_{mod}$

Wind tunnel mounted turbine model





Upwind open-loop control & performance metrics



Turbine power

$$P = T_{brake} \times \omega$$

Power change

$$\Delta P = T_{brake} \times \Delta\omega$$

Power coefficient

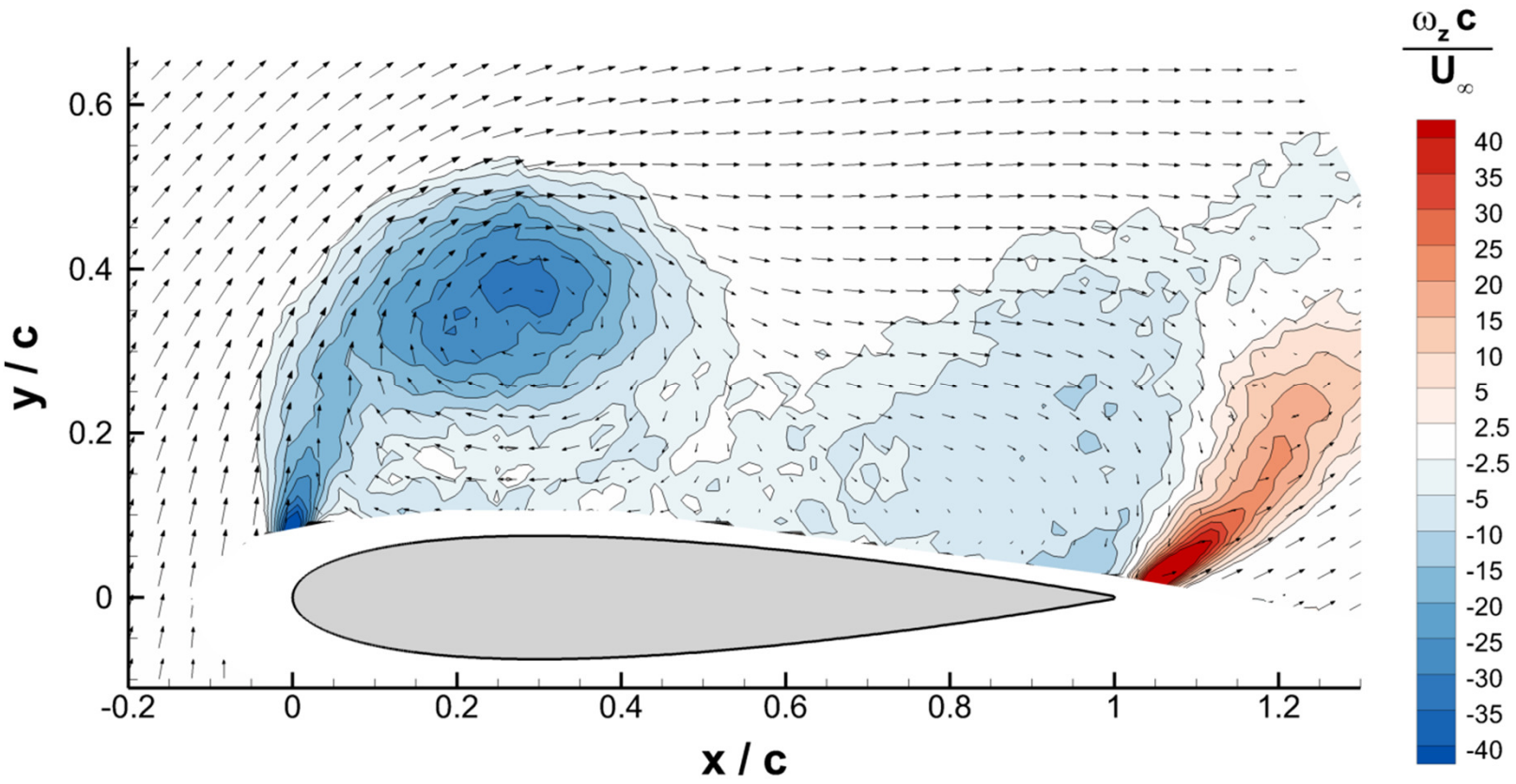
$$C_p = P/q_\infty U_\infty A$$

Speed ratio

$$\lambda = \omega R/U_\infty$$

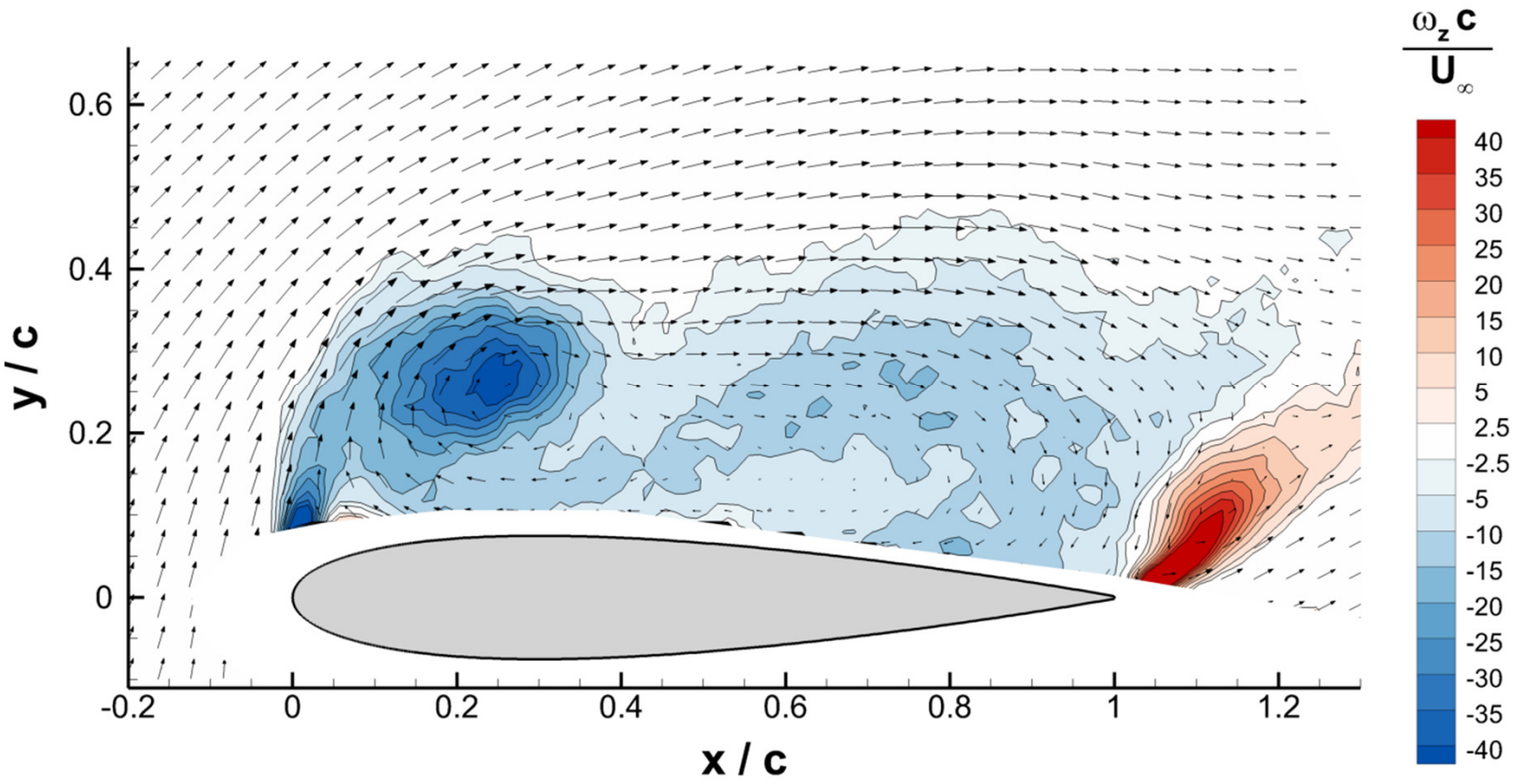
PIV data: low $\lambda \equiv \omega R/U_\infty = 1.4$

baseline: $\theta = 120°$



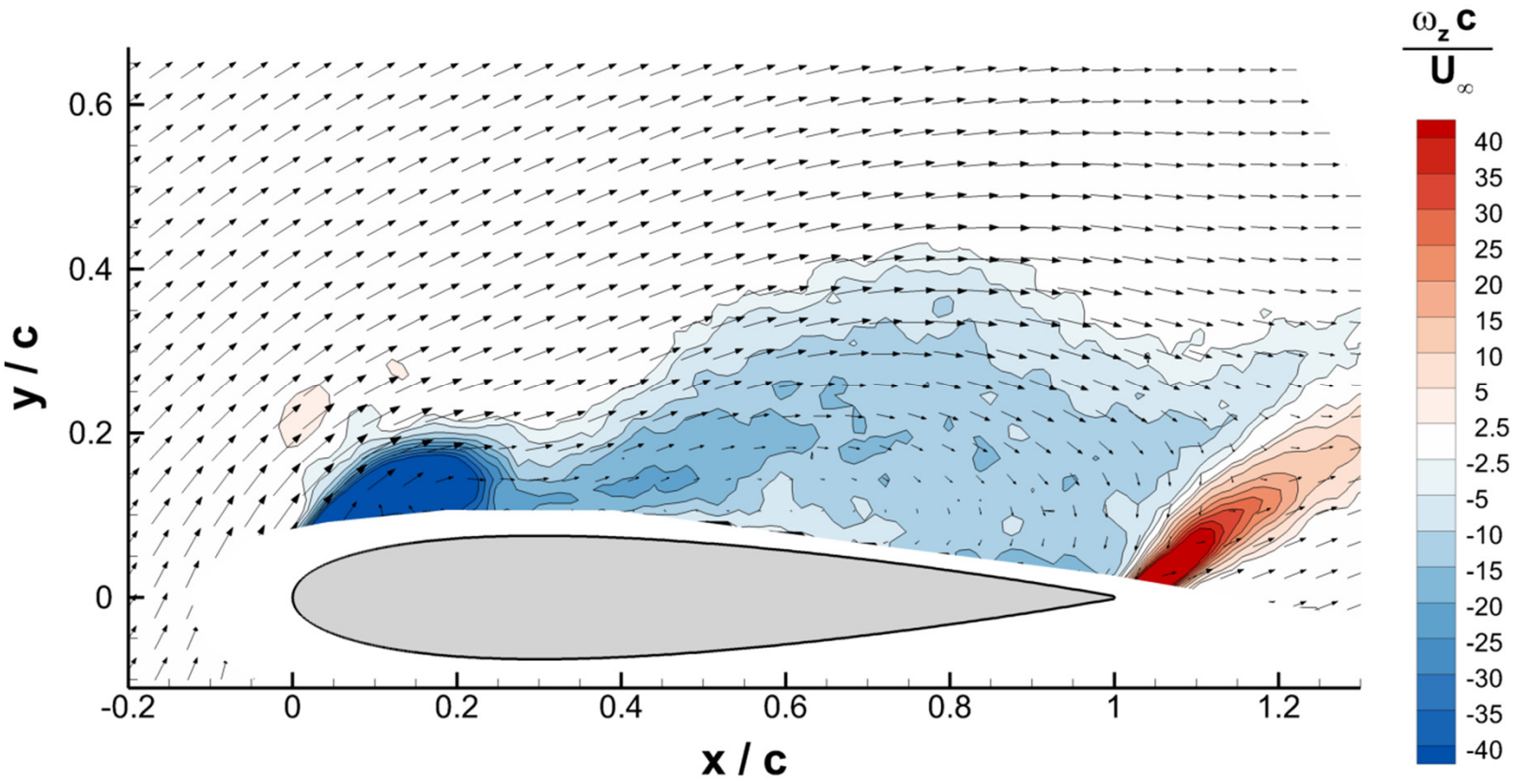
PIV data: low $\lambda \equiv \omega R/U_\infty = 1.4$

plasma: $\theta = 120°$



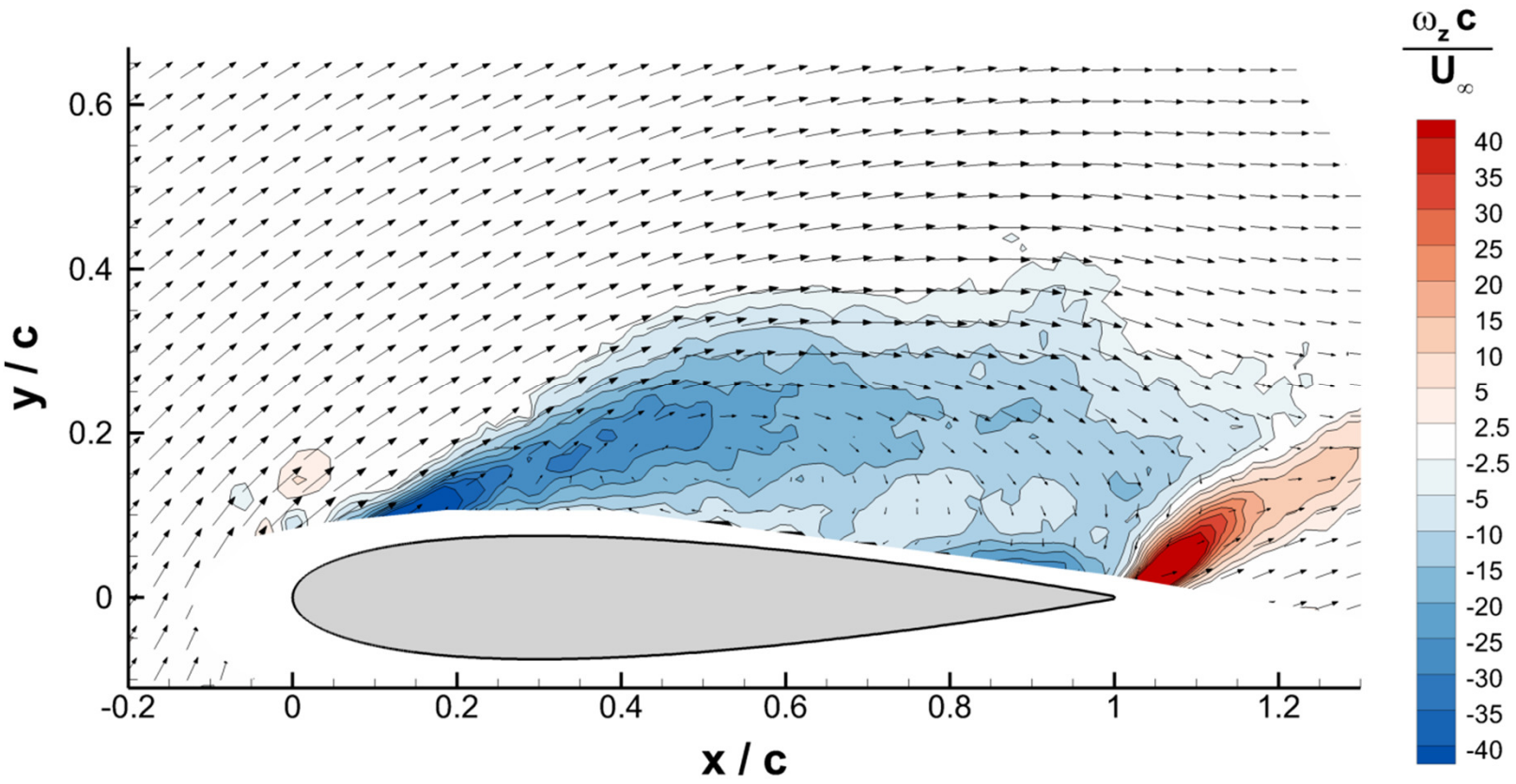
PIV data: low $\lambda \equiv \omega R/U_\infty = 1.7$

baseline: $\theta = 120°$

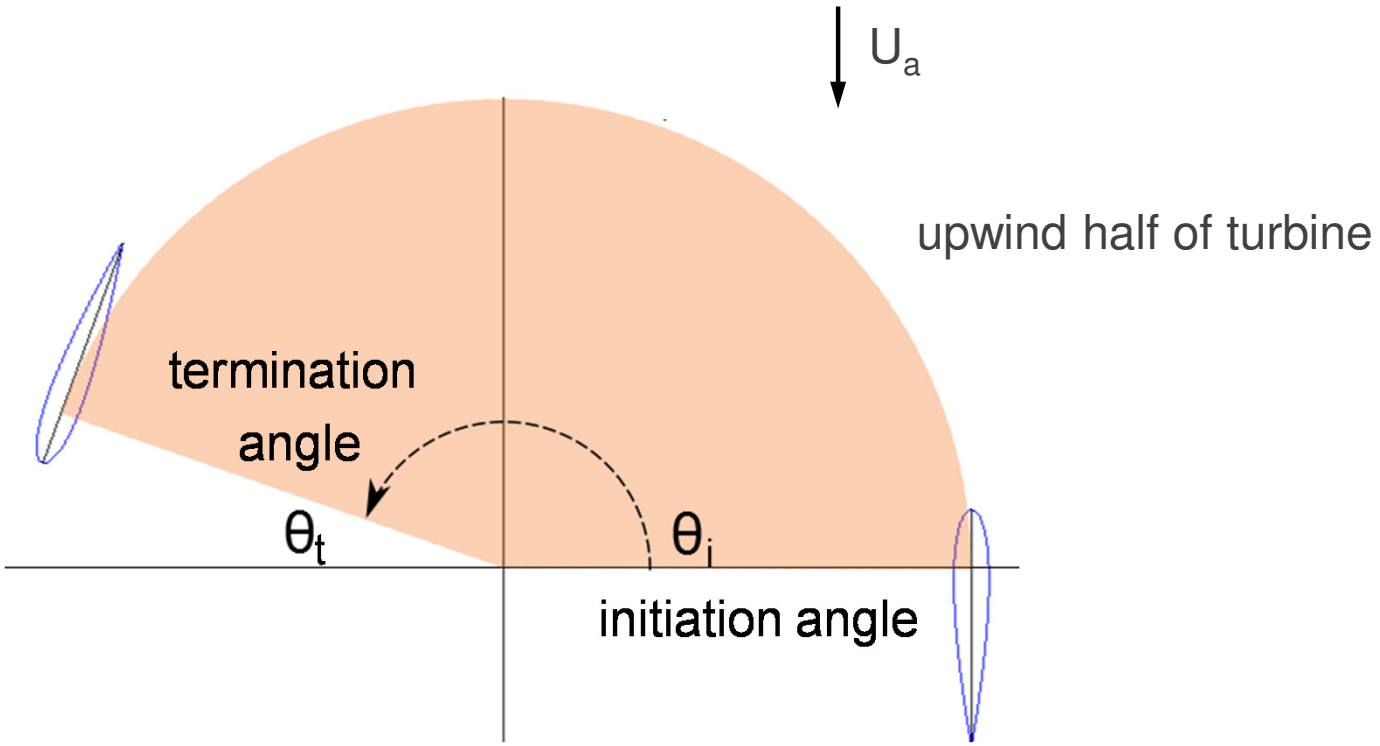


PIV data: low $\lambda \equiv \omega R/U_\infty = 1.7$

plasma: $\theta = 120°$



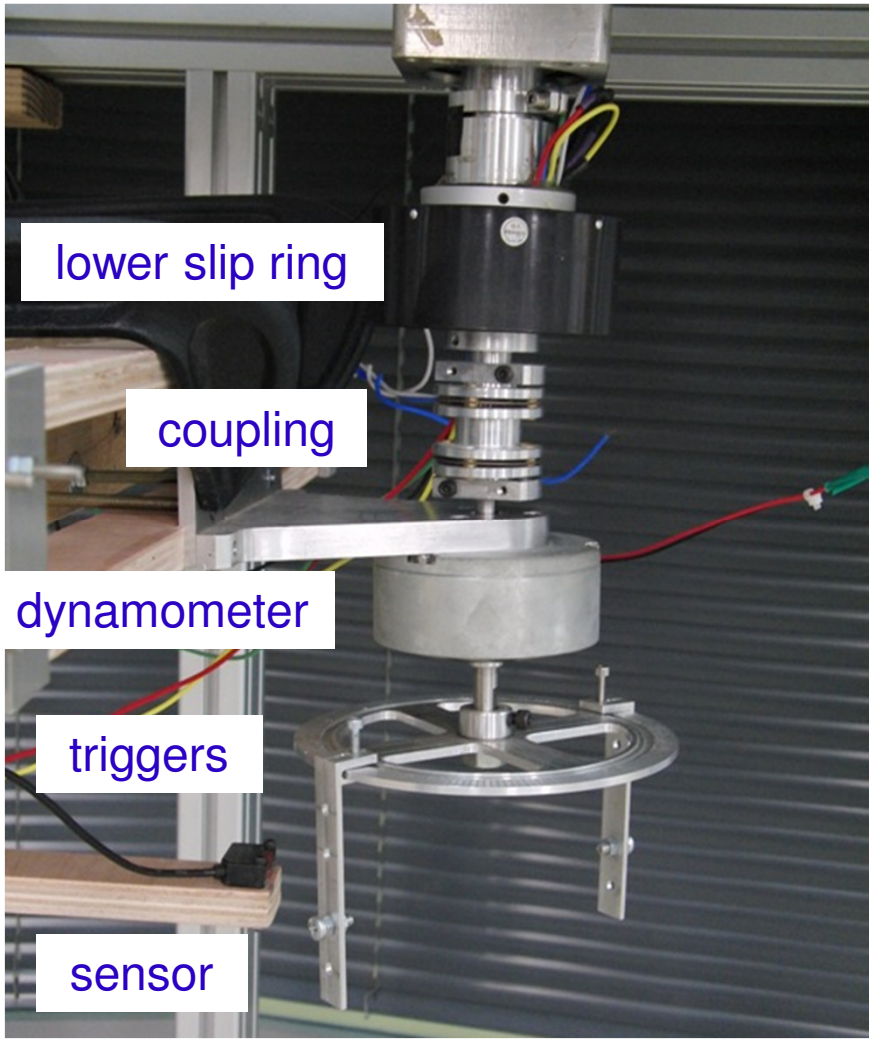
Feed forward plasma initiation & termination



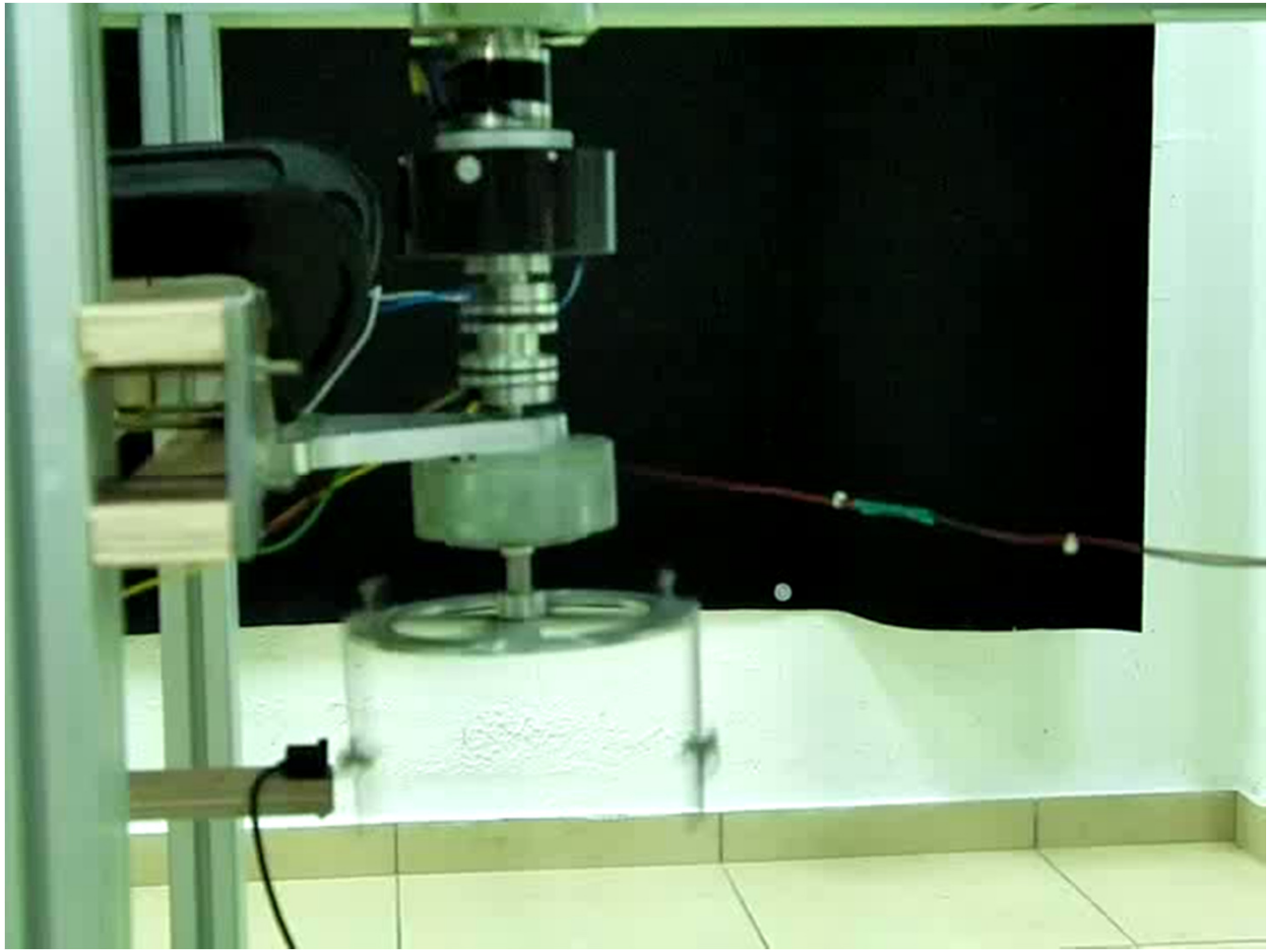
$$DC_{act} = (\theta_t - \theta_i) / 180°$$

Power into actuators: $P_{in} = P_{100\%} \times DC \times DC_{act}$

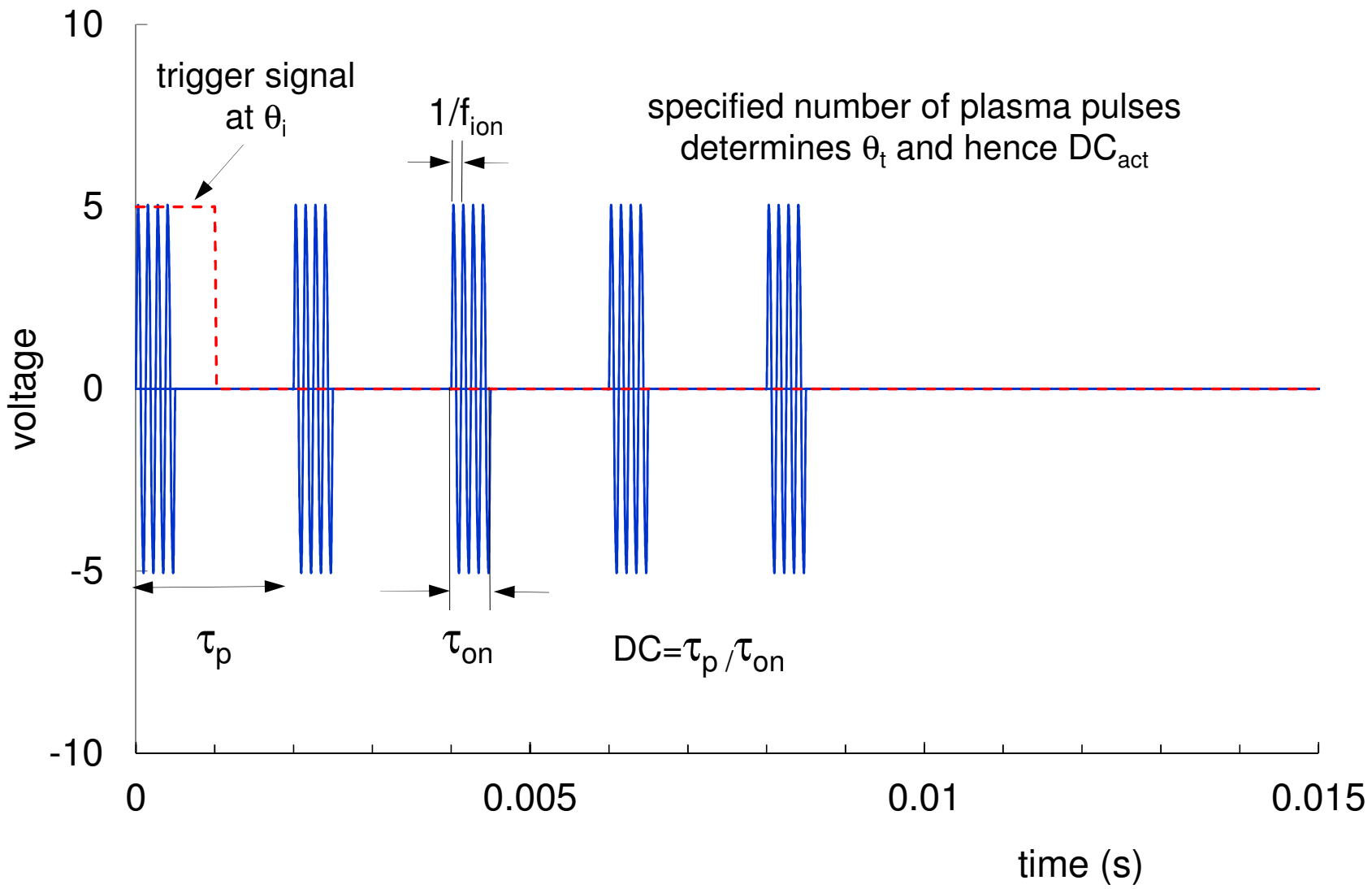
Feed-Forward Sensing & Variation



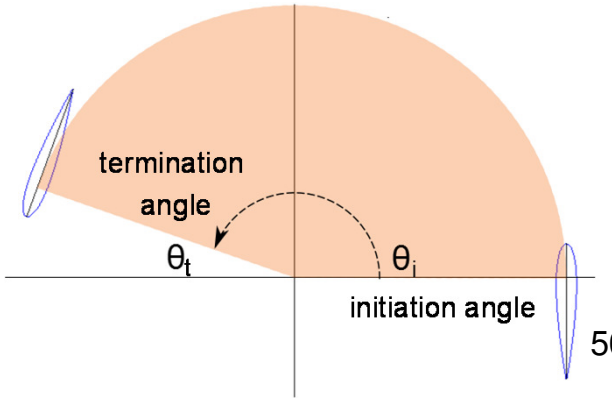
Feed-Forward Sensing & Variation



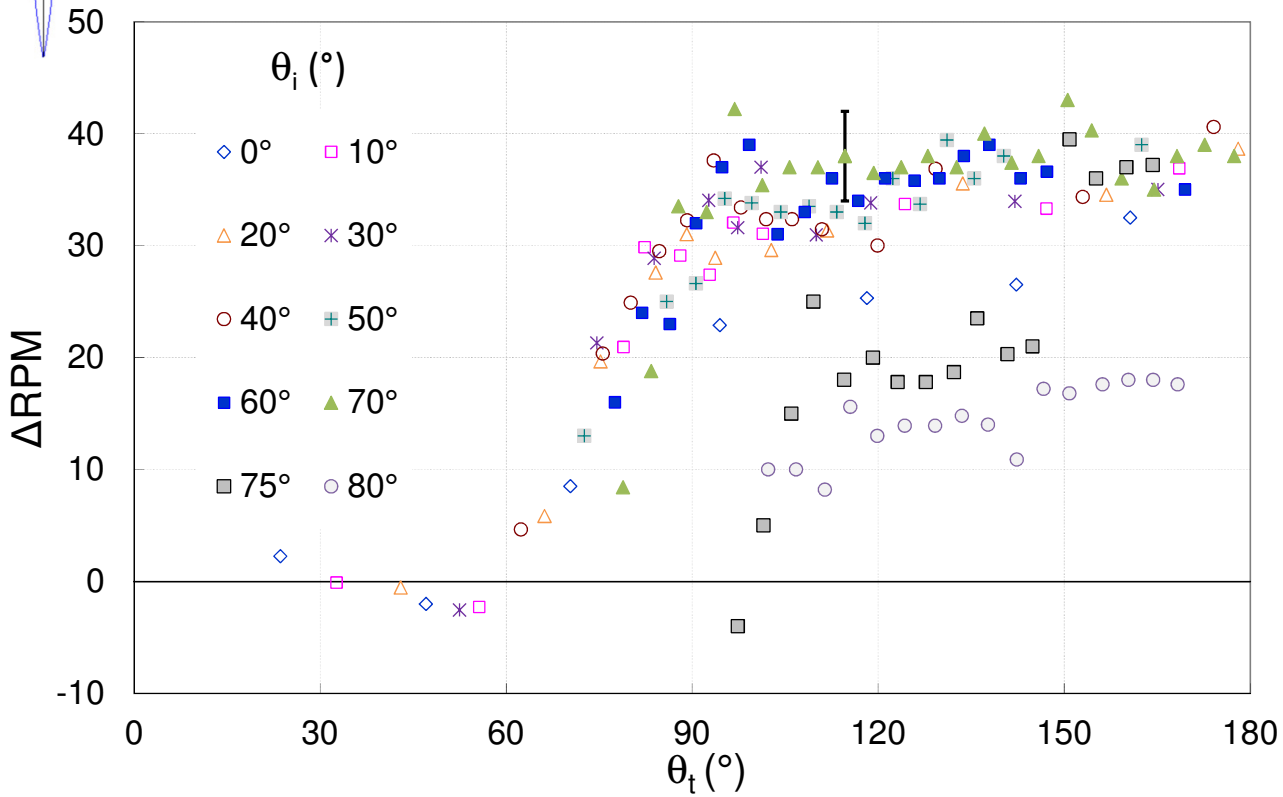
Feed-Forward pulsation triggering



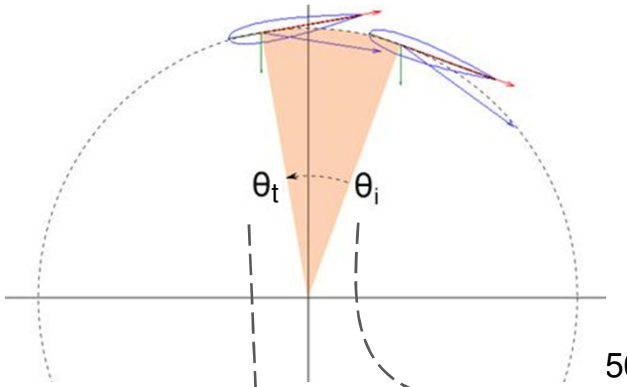
Actuation duty cycle



f_{mod}=500Hz, DC=20%, U_∞=7m/s, λ=1.4

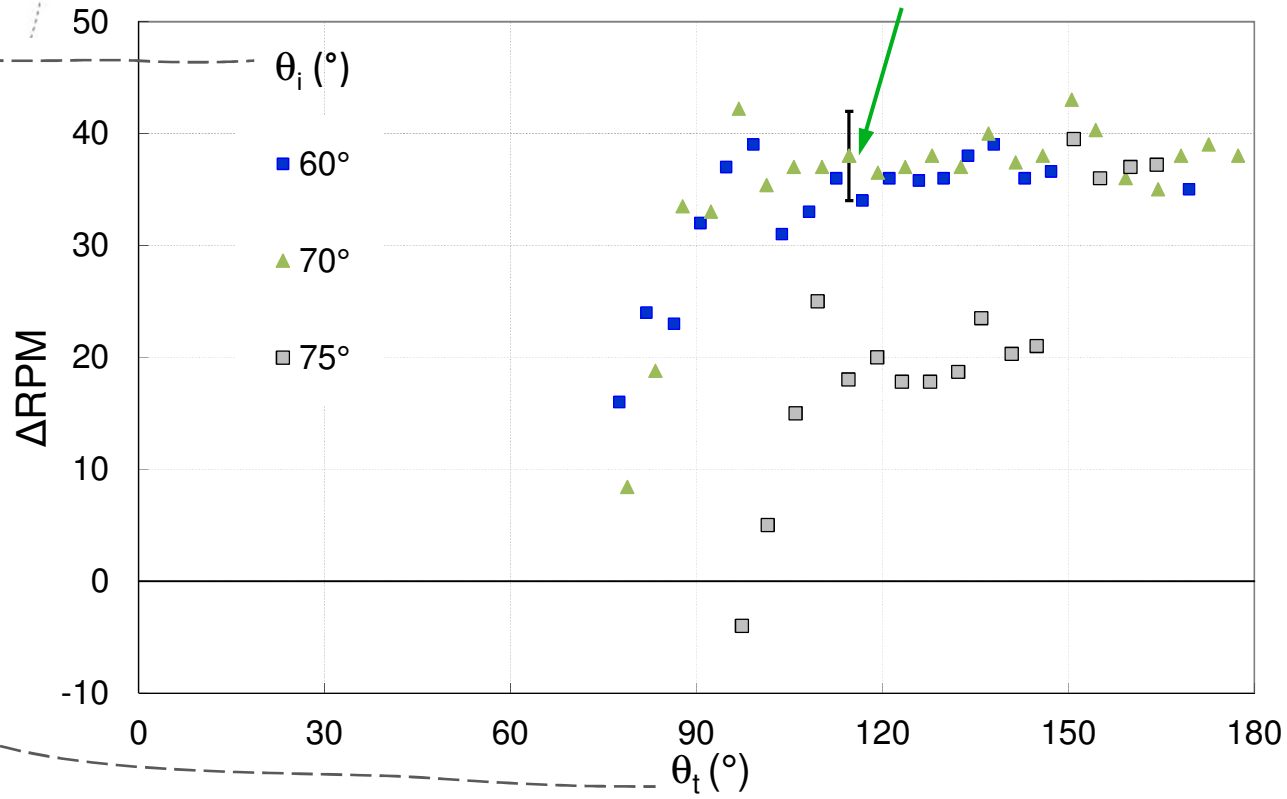


Actuation duty cycle



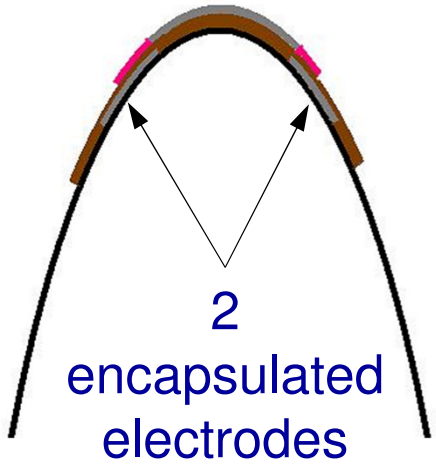
f_{mod}=500Hz, DC=20%, U_∞=7m/s, λ=1.4

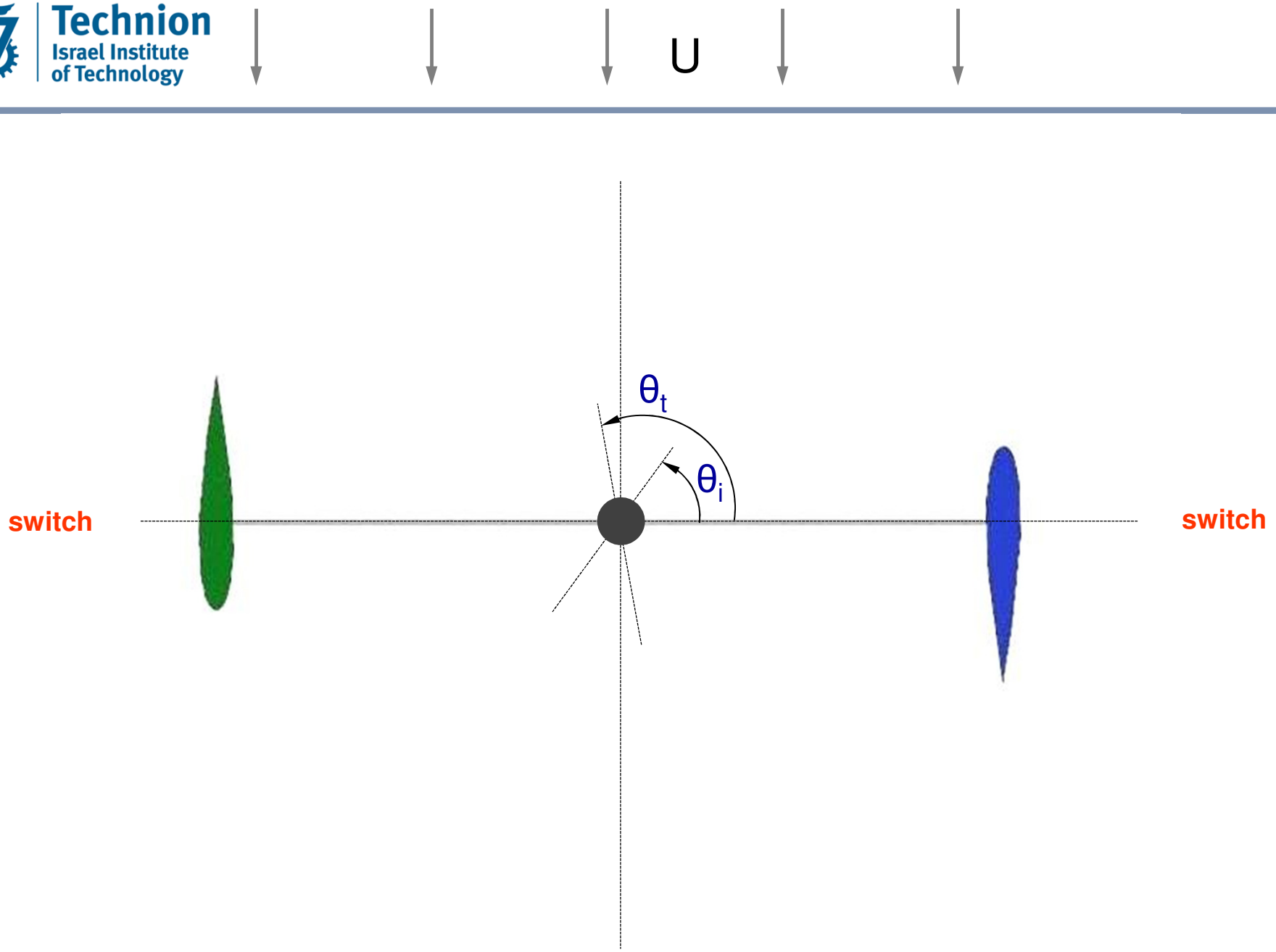
actuation duty cycle~17%



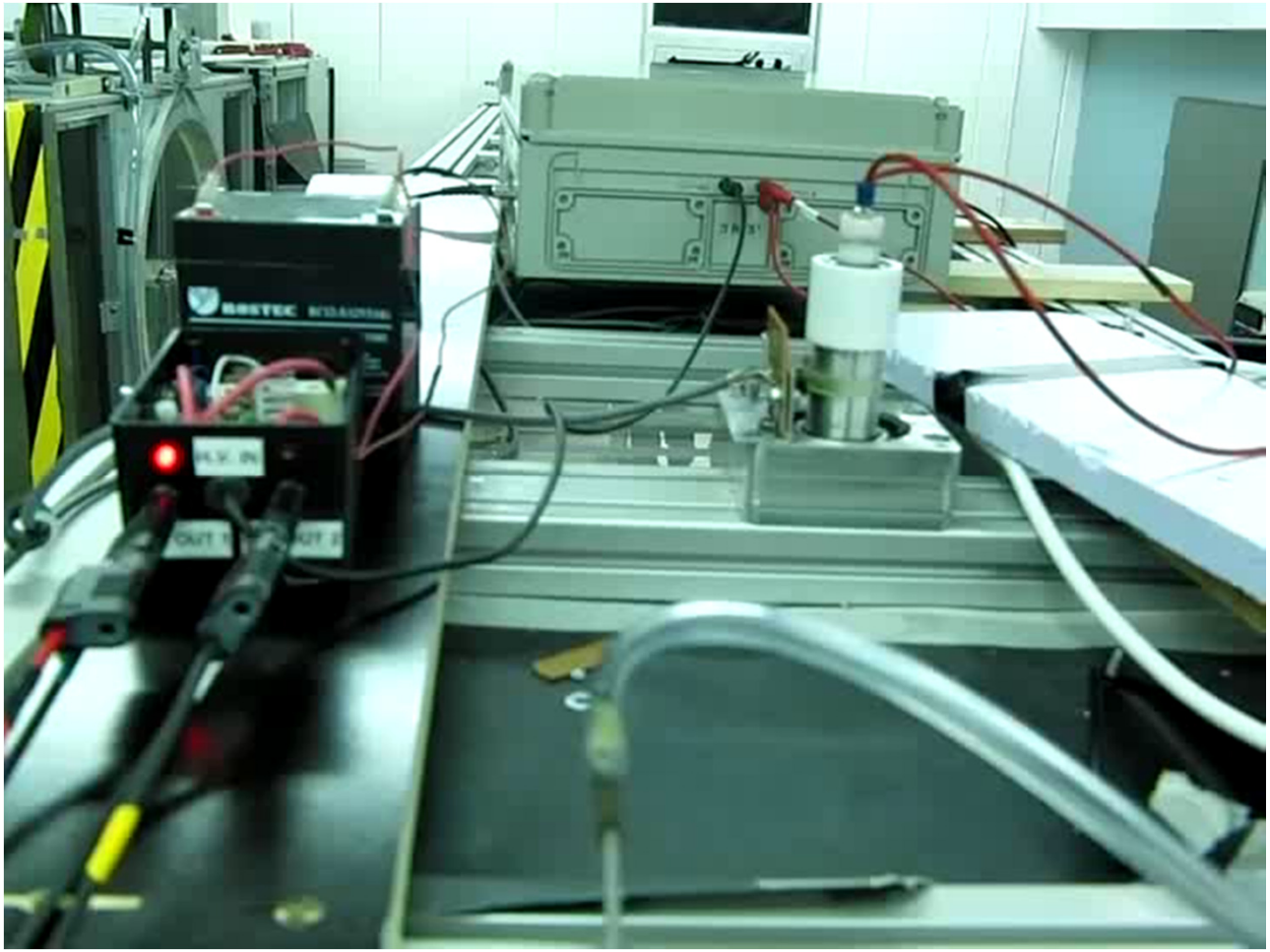
10% net power increase!

Switching Earthed Electrodes

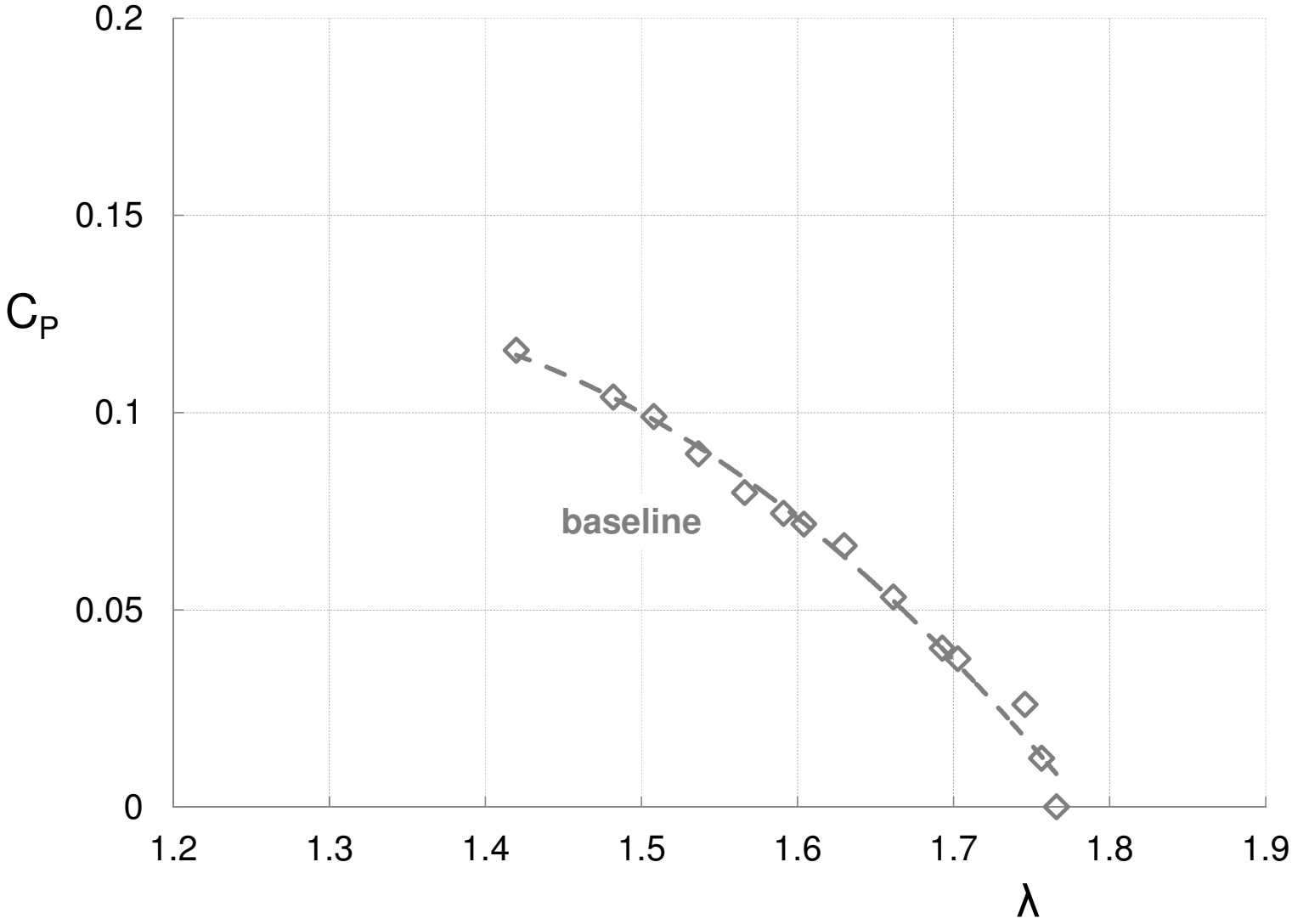



U
switch
θ_t
θ_i
switch

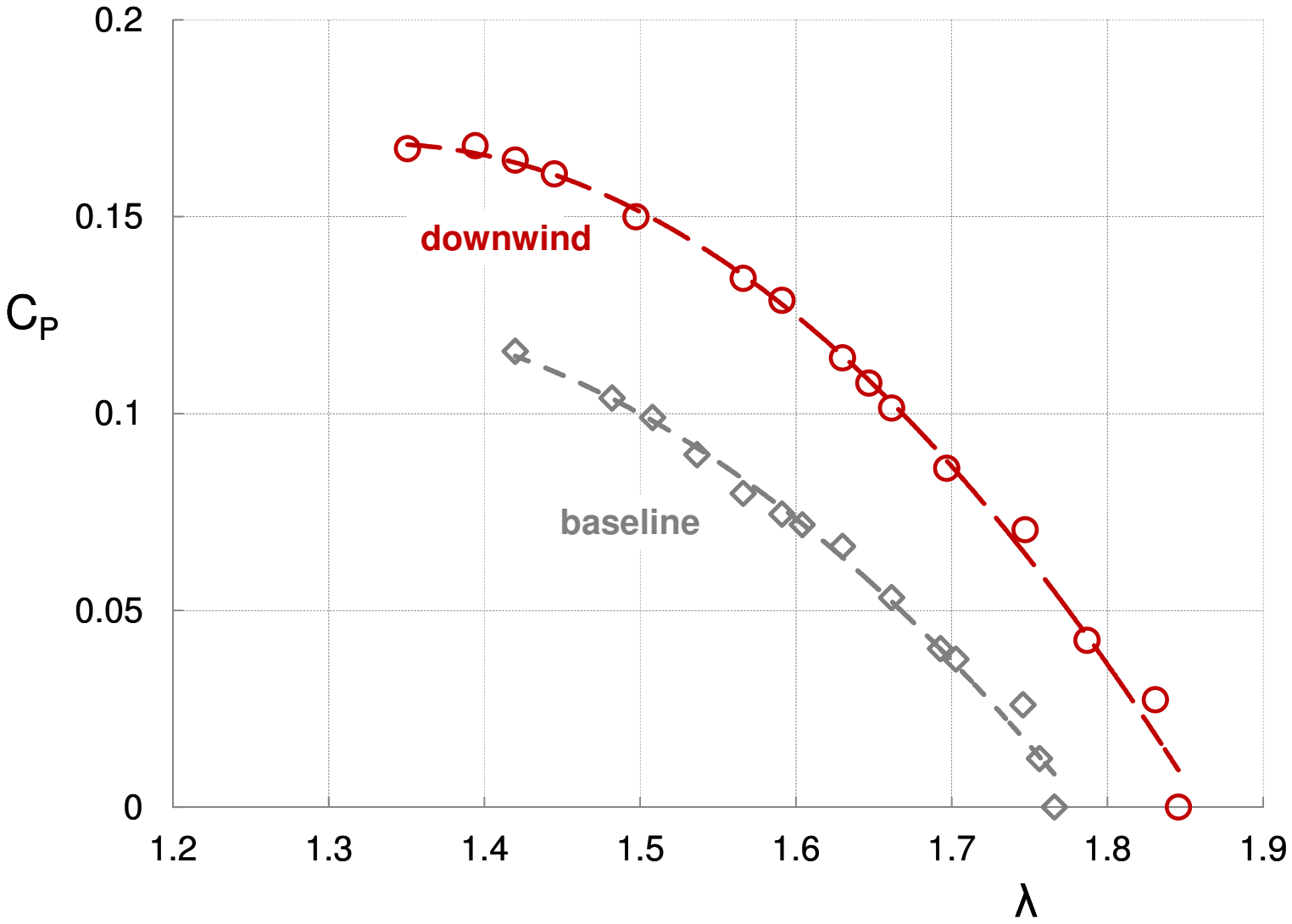
Switching Earthed Electrodes



Switching Results: 6m/s wind speed

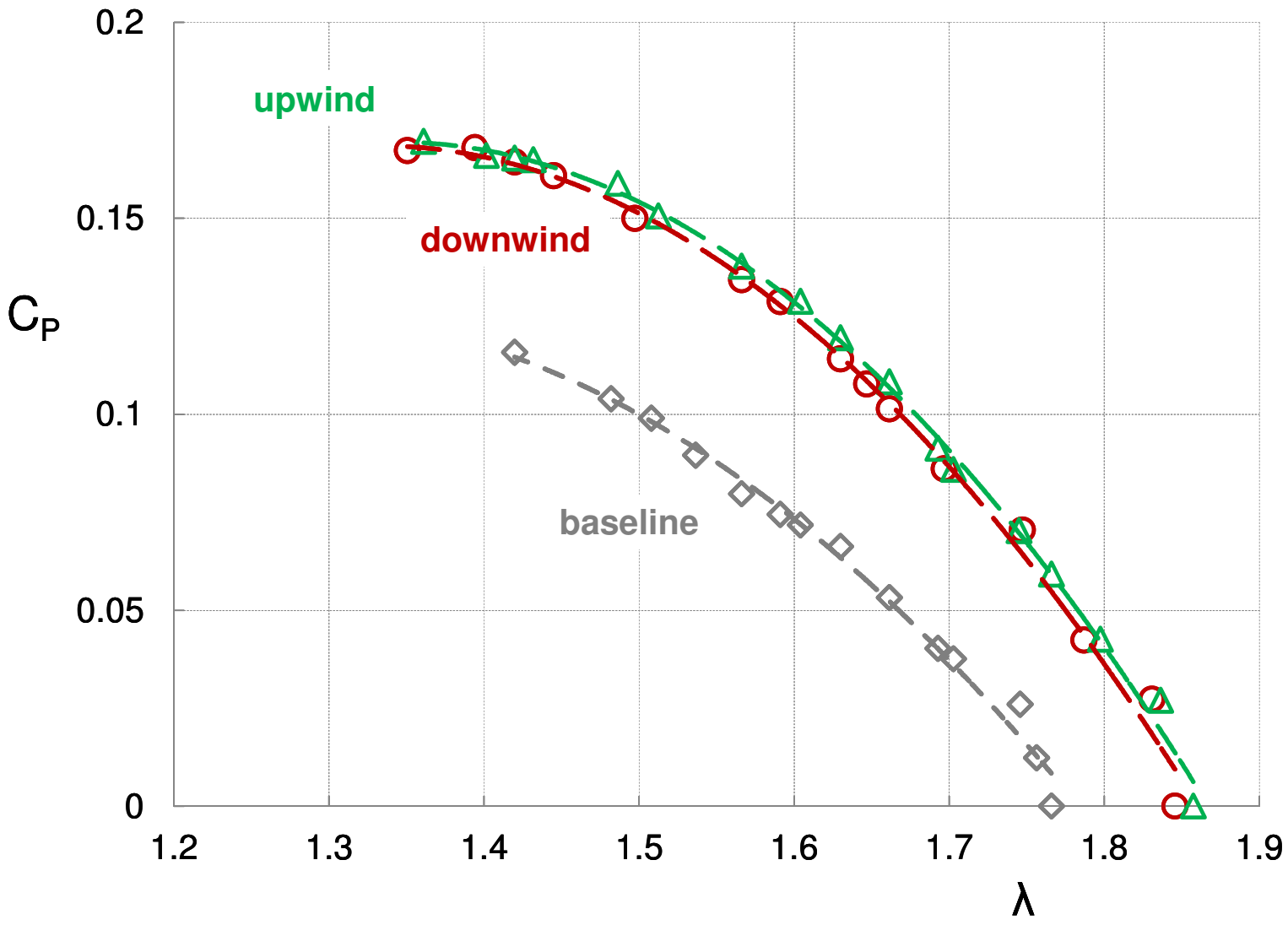


Switching Results: 6m/s wind speed

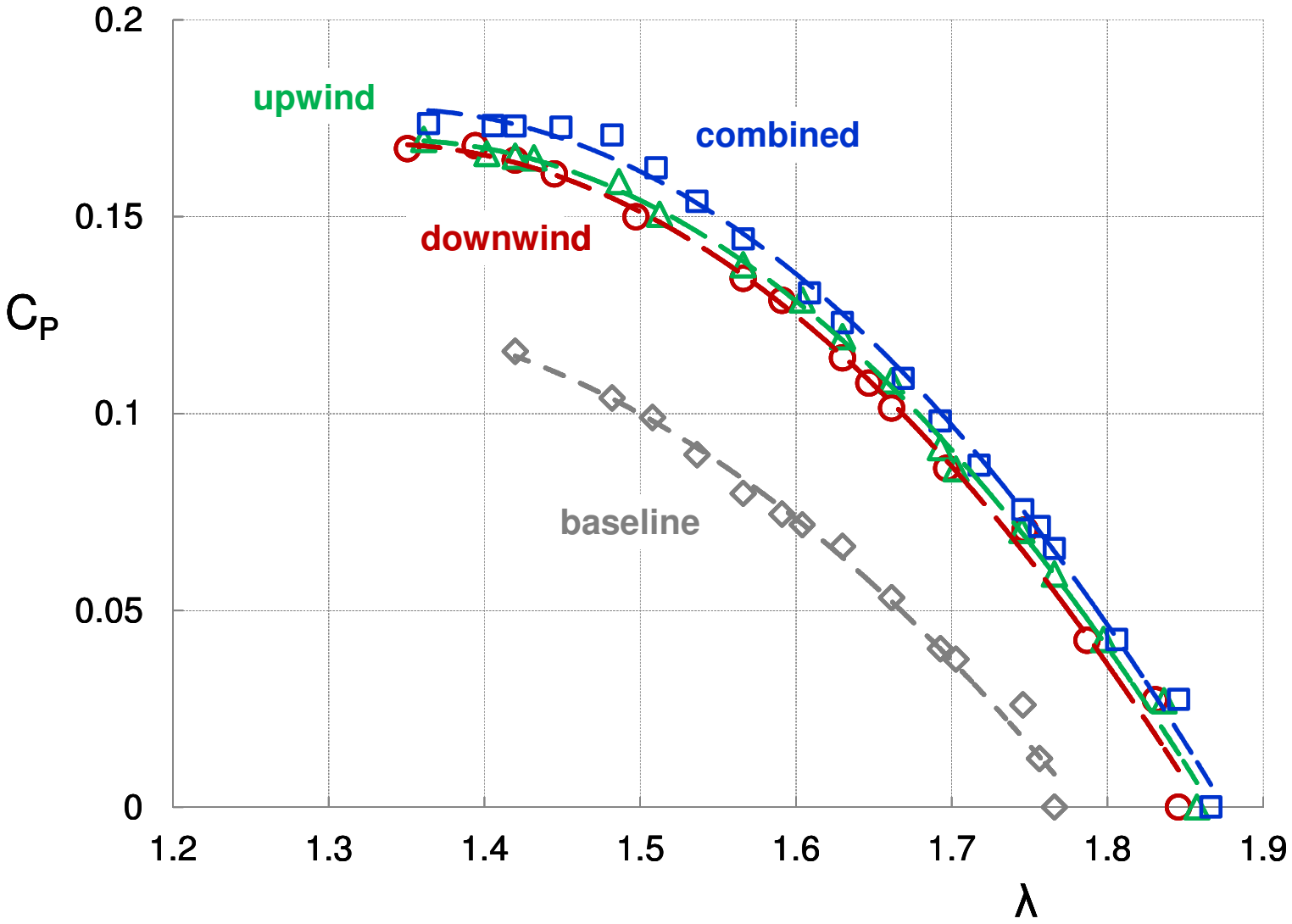


Technion
Israel Institute
of Technology

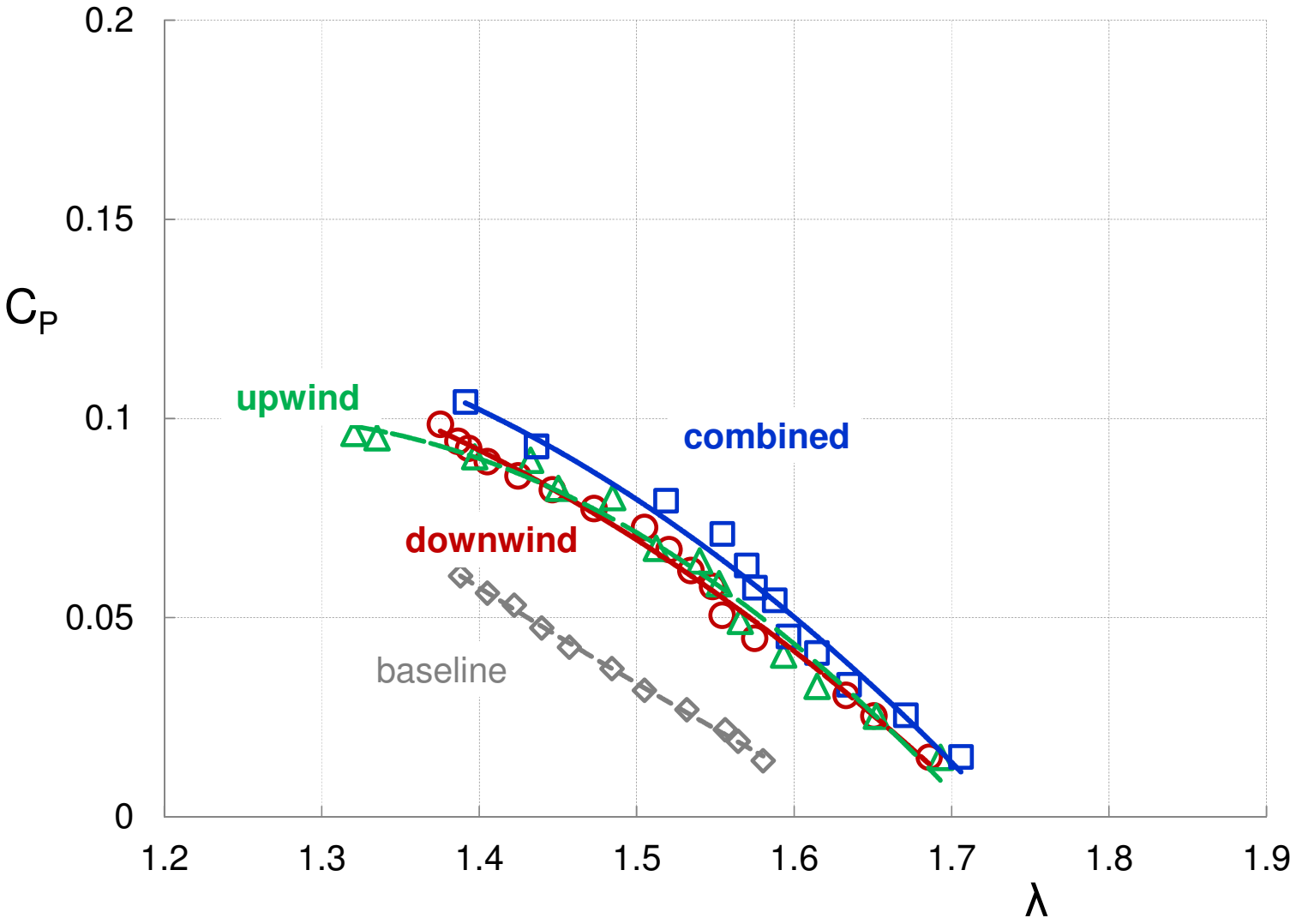
Switching Results: 6m/s wind speed



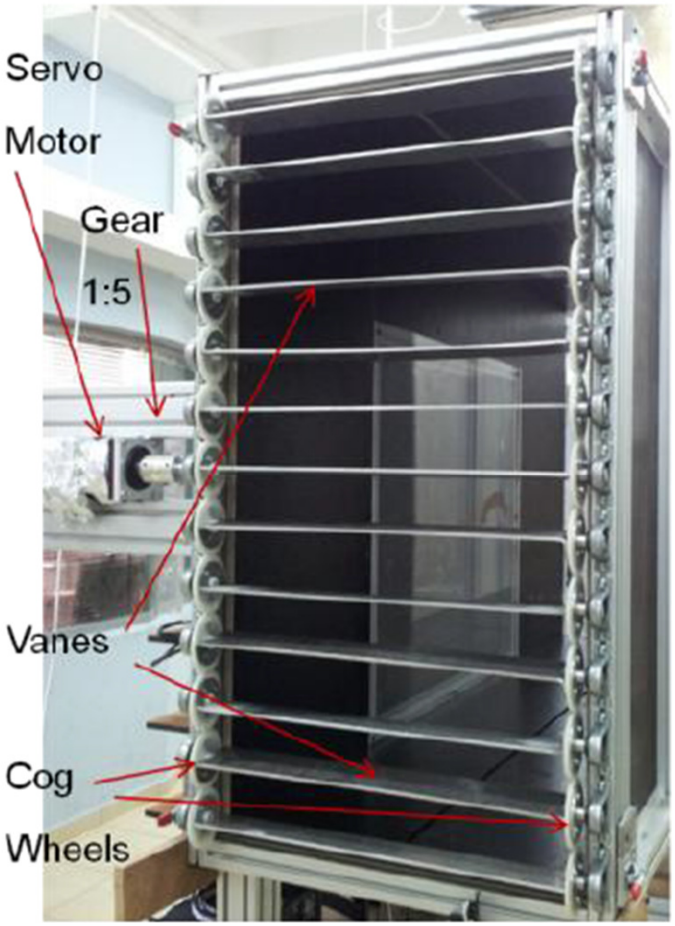
Switching Results: 6m/s wind speed

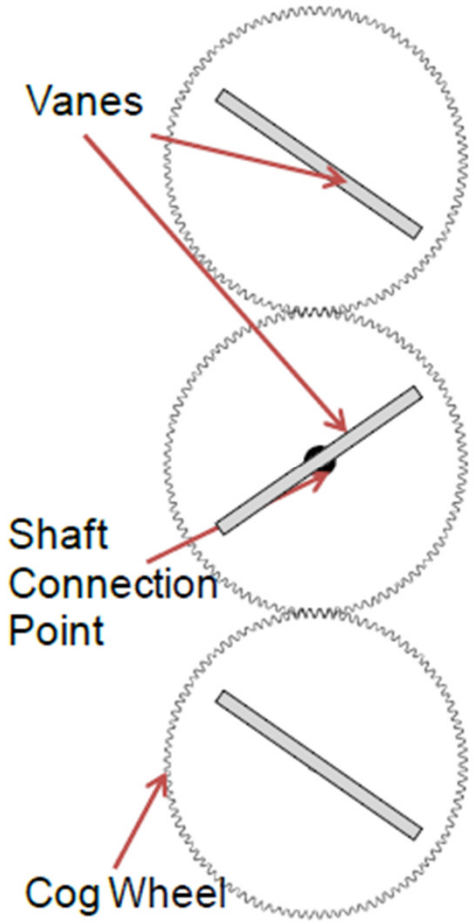


Switching Results: 5m/s wind speed



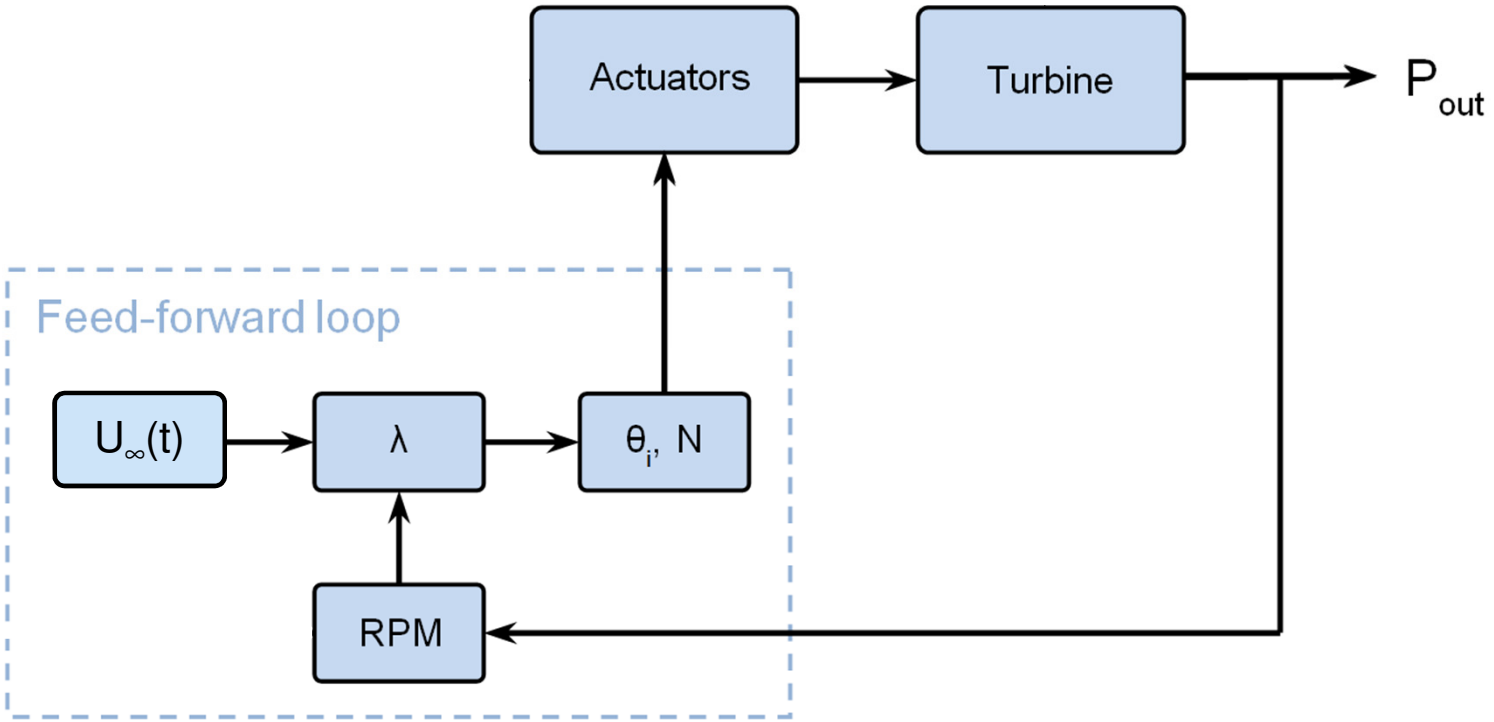
Achieving unsteady wind for closed-loop control



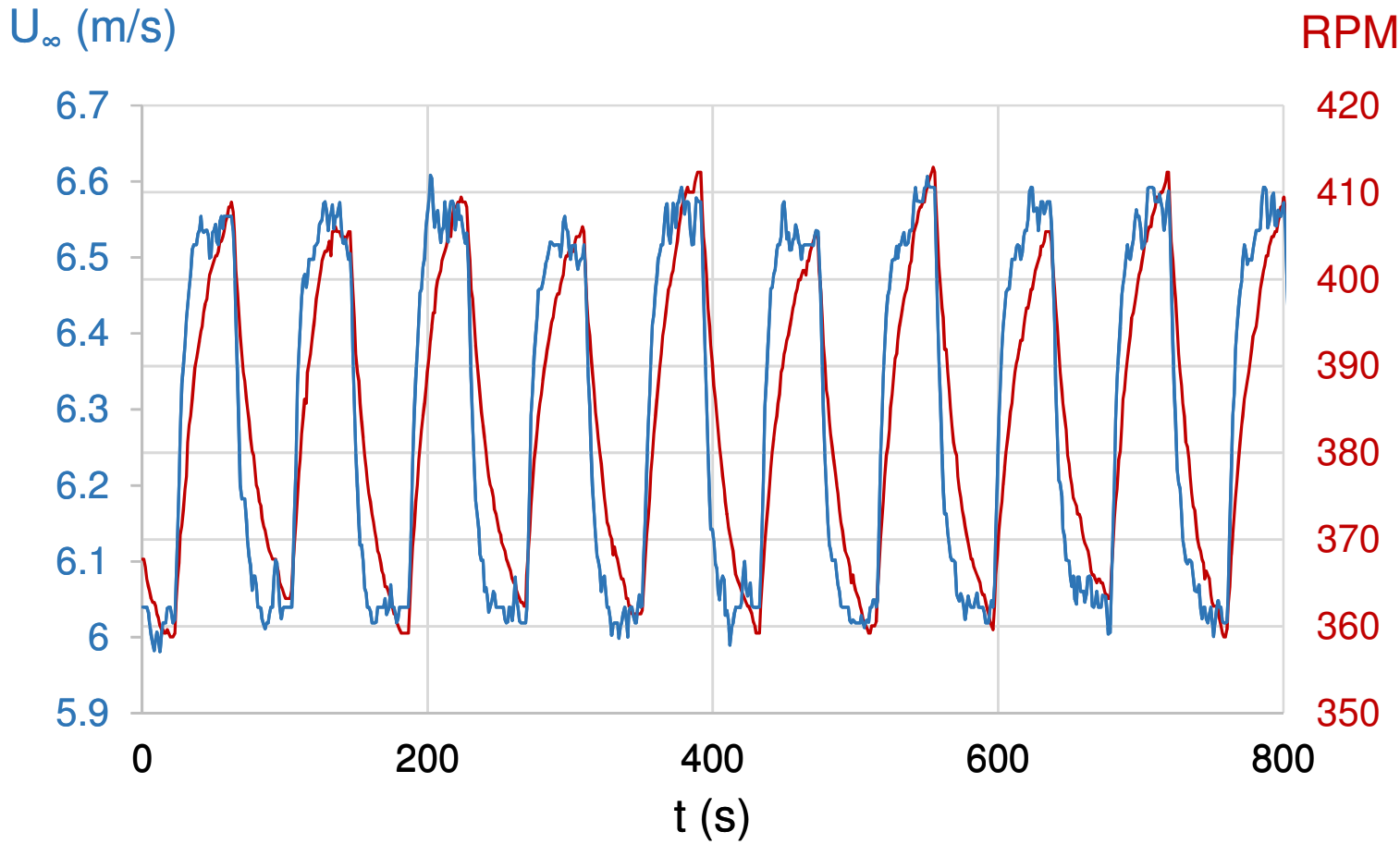


Feed-forward loop nested in a feedback loop

Objective: constant turbine power P_{set} (or ω_{set})
in the presence of varying wind speed

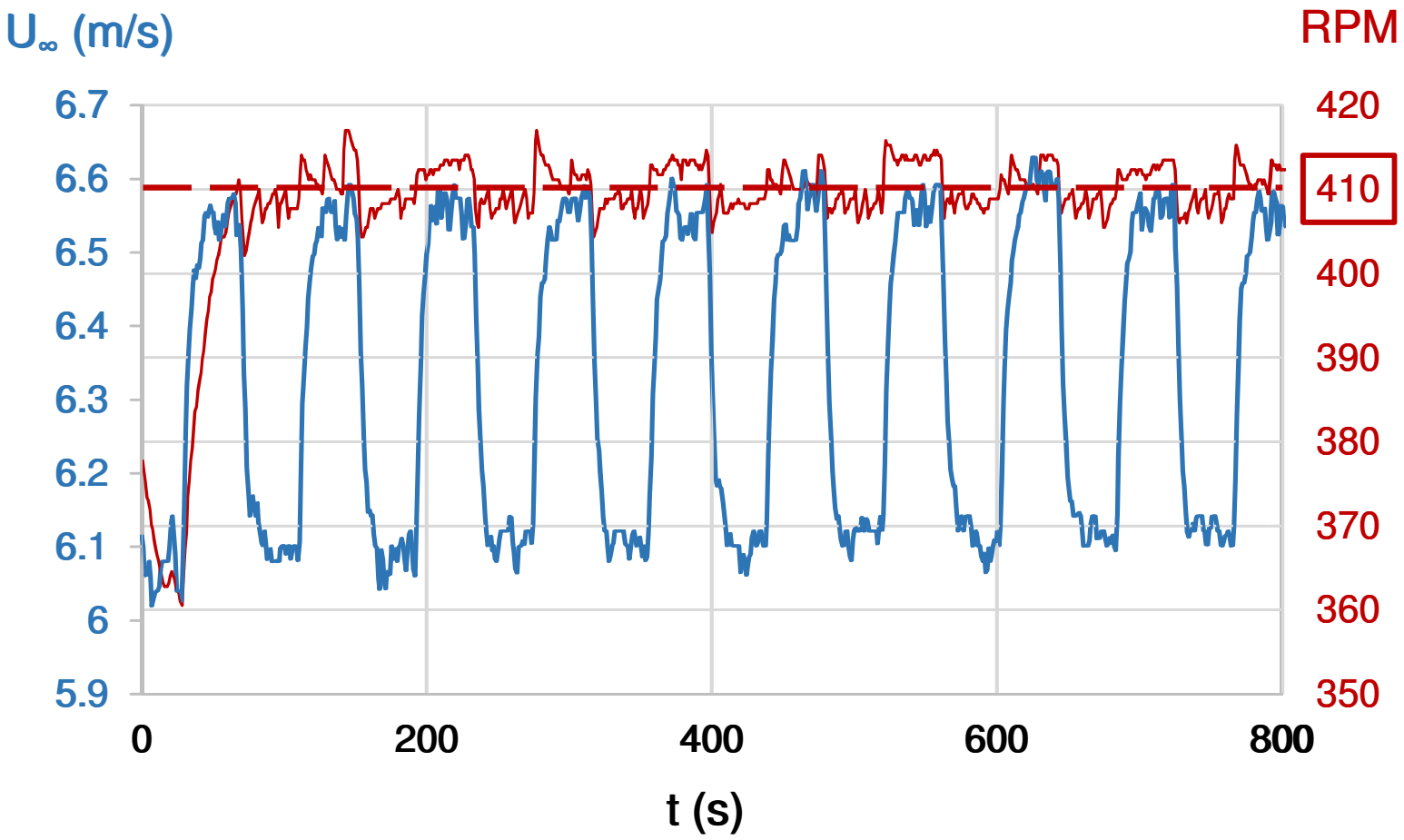


Baseline turbine under varying wind speed



Technion
Israel Institute
of Technology

Controlled turbine under varying wind speed



Technion
Israel Institute
of Technology

Plans for the future

- Increase actuator forcing and configuration
- Refine and improve closed-loop control
- Open-jet turbine testing
- Consider the effect of skew
- Implement and field test on a kilowatt scale turbine

Technion
Israel Institute
of Technology

Thank you for your attention!

