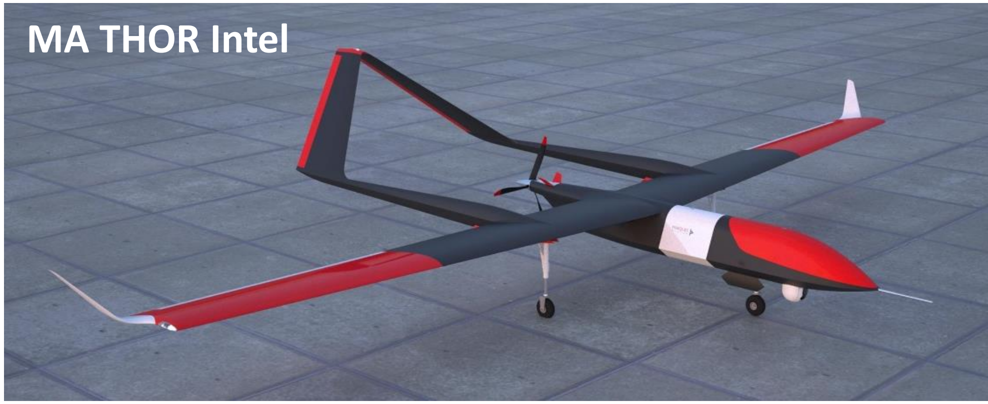
The Marques Aviation Unmanned Aircraft: *Trends in Design and Innovation*

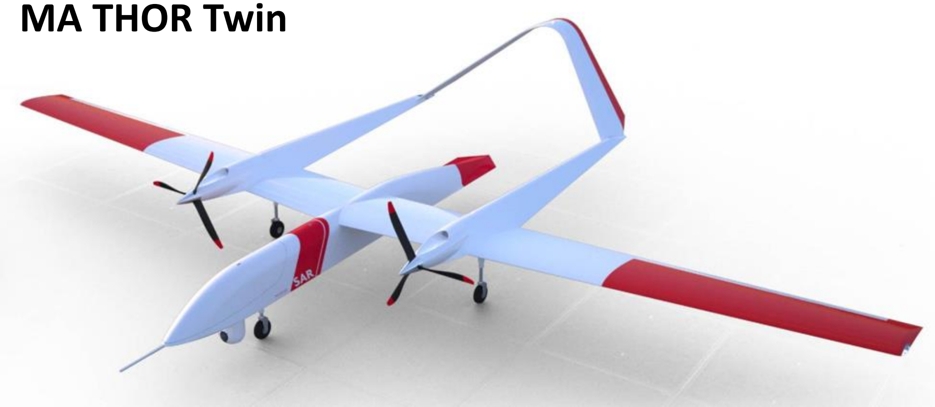
Dr Pascual Marqués
Marques Aviation Ltd - UK

Industry Academia Collaboration: Technology for Development
6-8 April 2015 - Cairo International Convention Centre

MA THOR Unmanned Aircraft



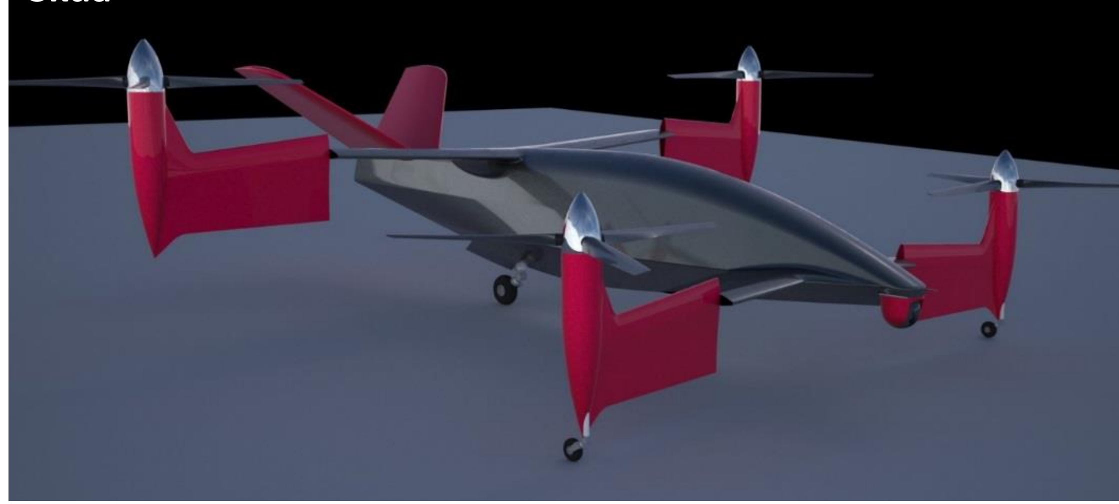
MA THOR Twin



MARQUES™
AVIATION

MA THOR Unmanned Aircraft

Skua



Heli

Trends in Design & Innovation

Innovation network

International collaboration

Next-generation unmanned aircraft

- Airborne Anti-Stealth Technology
- Robotic Natural Binocular Vision
- Ergonomic Design of GCS
- Aeroelasticity and Energy Harvesting
- Solar Energy
- Sense and Avoid Technology
- Plasma Actuation - Flow Control

Airborne Anti-Stealth Technology

- Detection of low observable aircraft.
- Aircraft's cross section.
- Conventional aircraft visible.
- Stealth aircraft shows as large bird.
- Triangulation.
  Network of radar systems.

El Diwiny (2014); El Diwiny *et al.* (2014)

Six types of stealth techniques:

- Radar Absorbent Surface (RAS)
- Radar Absorbent Material (RAM)
- Infra-red (IR) Signature
- Electromagnetic Signature
- Acoustic Signature
- Plasma Stealth

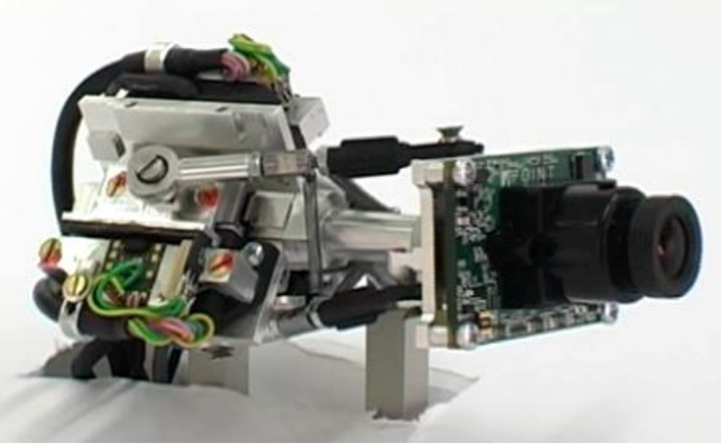
New method of detecting low observable aircraft:

Microwaves similar to cell phone towers.
Increasing electric permittivity.
Augmented material impedance.
Increased reflection coefficient.

Robotic Natural Binocular Vision

- Stereoscopically arranged cameras.
- Special attention and alertness.
- Pilot naturally immersed in flight scene.
- Realistic perception of depth.
- Virtual Reality Head Mounted Display
- Change in pilot’s operational routine.
- Use during manual navigation, landing on unknown ship deck, hovering between buildings, flying through mountains.

1. Two cameras. Mounted parallel. Eye distance of the pilot.
2. Gimbal mount to mimic eye and head movements
3. VR-HMD requires eye and head tracking.



Sönke Dierks
Director of Aircraft Design at Marques Aviation.

MARQUES™
AVIATION

Ergonomic Design of GCS

Design standards and capabilities for GCS.

Research initiatives, regulatory guidance, and GCS design challenges.

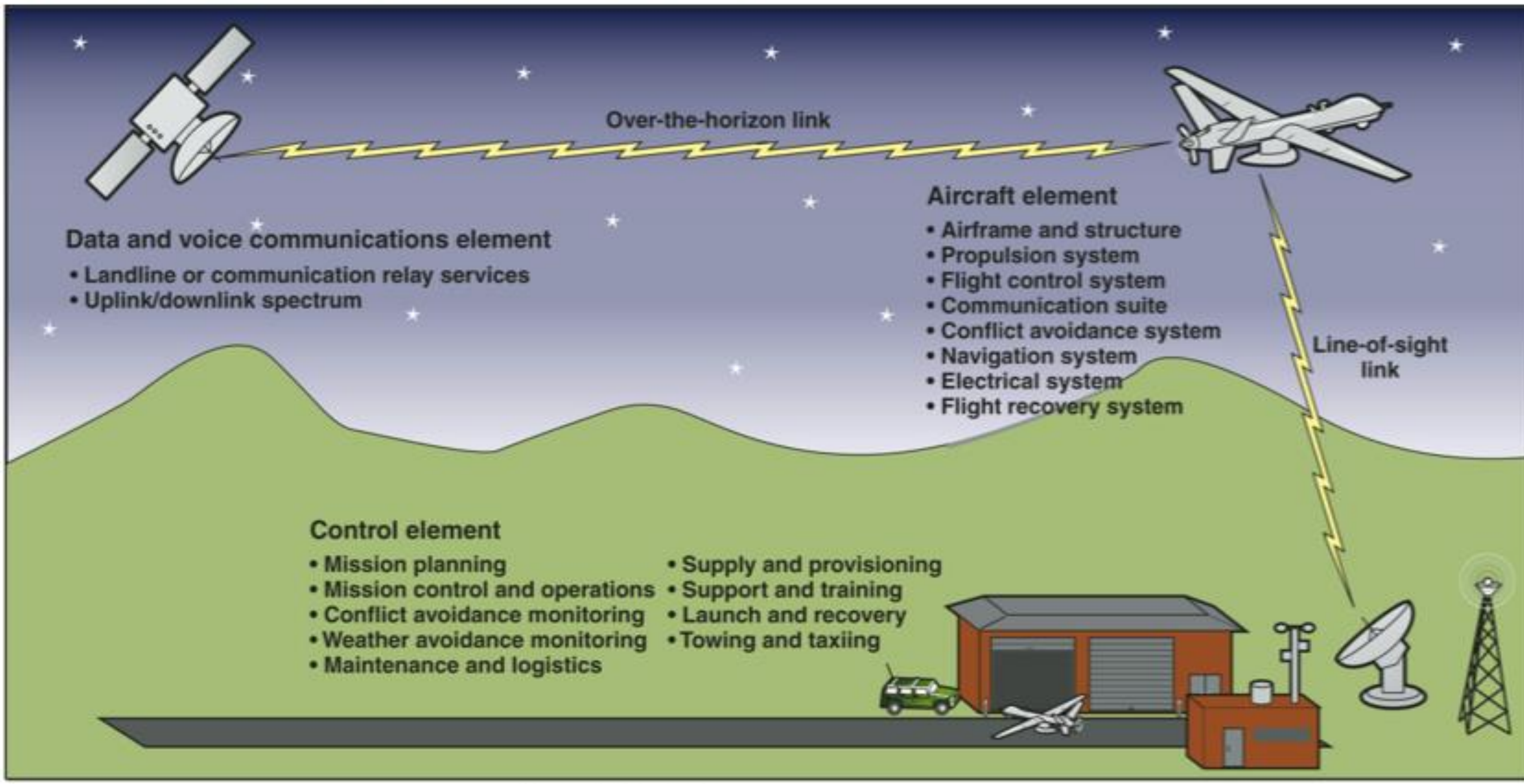
GCS designs to support safe and non-disruptive UAS operations in the relevant airspace.

MA THOR series in the small-medium and medium-altitude long-endurance (MALE) categories.

Mid-sized UASs have more complex human-machine interfaces than small UAVs.

Ergonomic Design of GCS

Figure 1: Conceptual Rendering of Unmanned Aircraft System



Sources: GAO and NASA.

Ergonomic Design of GCS

Important factor in UAS safety and performance.

GCS interfaces the pilot with the aircraft, and the aircraft's environment.

GCS design must meet demanding, high-workload conditions and provide rapid response to anomalies in flight.

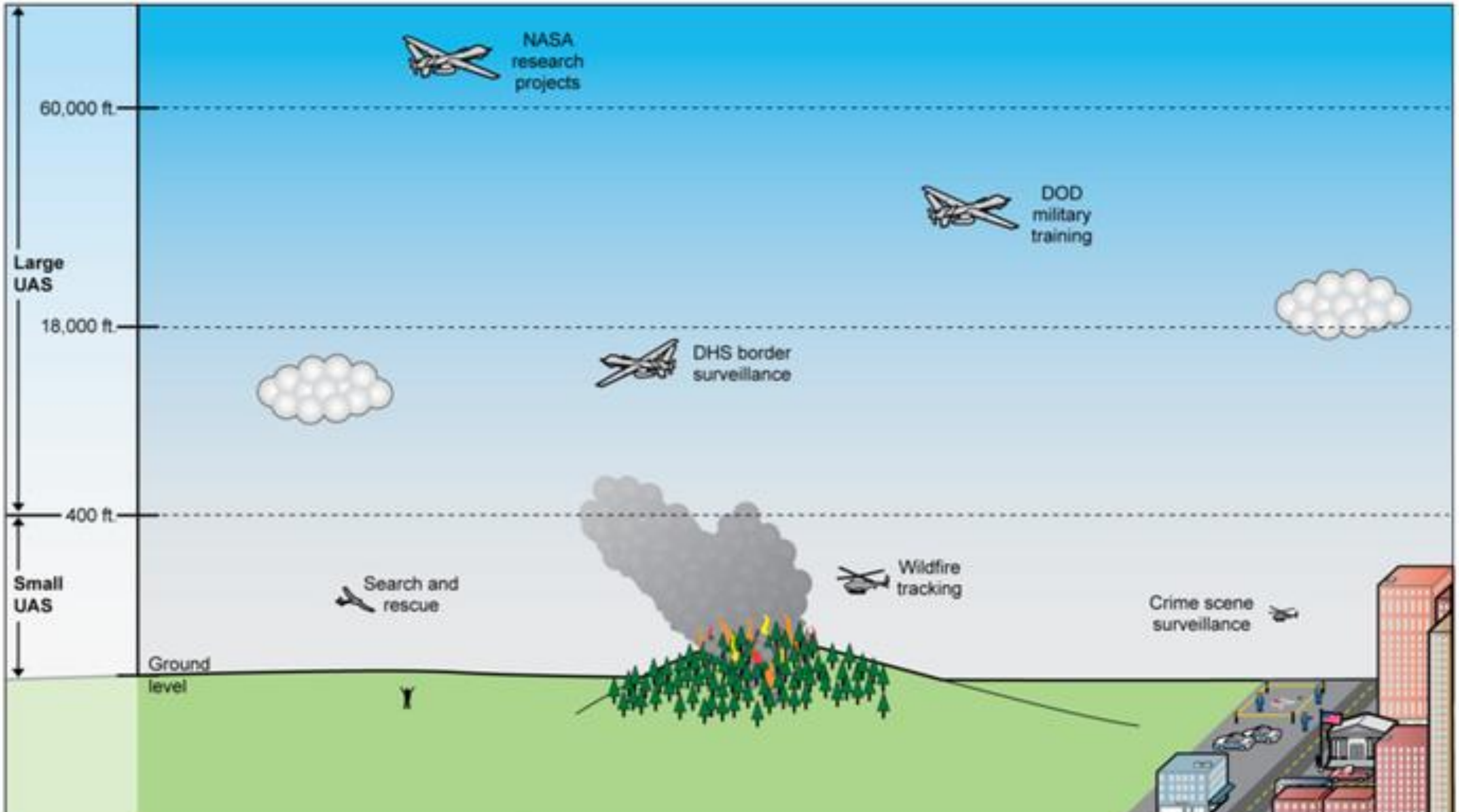
Ergonomic Design of GCS

GCS should display information for the UAV pilot to:

1) Control flight and monitor status.
2) Navigate the aircraft.
3) Communicate.
4) Avoid aircraft, unauthorized airspace, people, and terrain.
5) Manage contingencies based on changing system status and environmental information.

Ergonomic Design of GCS

Figure 2: Examples of Current Uses for UAS and their Altitudes of Operation



Source: GAO.

Ergonomic Design of GCS

Pilot requires access to standard aircraft information:

Position, heading, speed, altitude, attitude, and traffic to ensure separation minima and traffic flow efficiency.

Pilot errors prevented if more information and control actions are available to the pilot or in-built into a **complex layered interface architecture**.

GCS designs should integrate large amounts of **information**, a variety of **direct access control** actions, and facilitate **attention management**.

MARQUES™ AVIATION

Aeroelasticity & Energy Harvesting

- Attractive technology for next-generation UAVs.
- Harvest both **vibration** and **solar** energy using smart materials.
- Piezoelectric patches harvest energy from **wing vibrations** induced by wing aeroelasticity and from **rigid body motions** of the aircraft.

Marques Aviation R&I

Optimization of piezoelectric vibration and photovoltaic solar harvesters and incorporation into the design of the **MA THOR SolarLight** aircraft to actively harvest vibration and solar energy.

Aeroelasticity & Energy Harvesting

Commercially available piezoelectric fiber sensors:

- Macrofiber Composite (MFC) - NASA Langley Research Center.
- Piezoelectric Fiber Composite (PFC) - Advanced Cerametrics, Inc.

Flexible piezoelectric fibers in wing locations of high strain without the risk of brittle fracture.

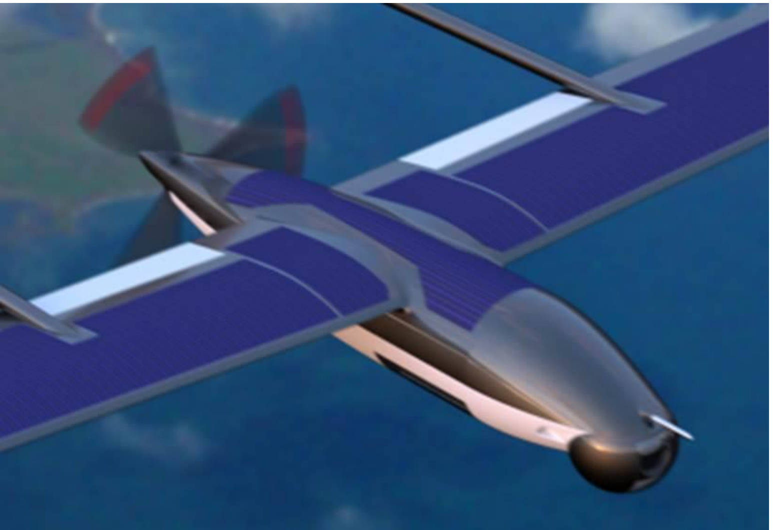
Long wing span of MA THOR SolarLight. Suitable environment for piezoelectric vibration harvesting.

1. Characterize the vibration frequency and displacement.
2. Design piezoelectric fibers mechanically tuned to the specific vibration frequencies.
3. Provide sufficient power to feed the aircraft subsystems.

Solar Energy

MA THOR SolarLight

- Endurance: 24 hours flight.
- Solar panels collect energy during the day for immediate use.
- Store extra energy for flight at night using high energy density batteries.



Superior aircraft endurance without the need to refuel.

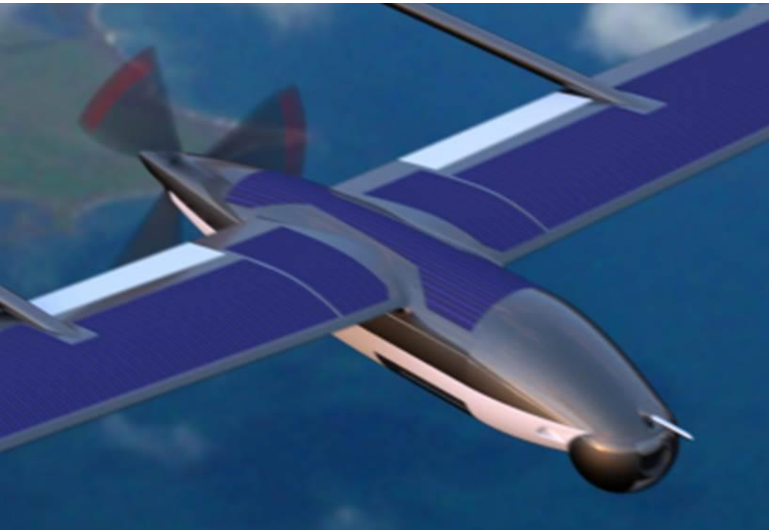
Technical and economic feasibility:

- Solar power UAVs more expensive to build and research due to the advanced solar technology.
- More fuel-efficient and less maintenance than fueled UAVs.
- Economical in the long term.
- Protect the environment.

Solar Energy

Solar array: Cells with highest power to weight ratio.

Flexible cells: Bend over the wing and fuselage without altering aerodynamic configuration.



- Sunpower A-300 cells.
- Cell efficiency ~ 20%.
- 840 W/m^2 Global Radiation.
- Motor work voltage ~ 18.5V.
- Each solar cell ~ 0.59V at maximum power (close loop).
- Solar cells in serial = 0.59V times number of cells in serial.
- Possible loss of aerodynamic efficiency when using solar cells, in the interest of solar cell efficiency.

Solar Energy

T_{LK}	Sky Condition
1	Pure sky
2	Very clear sky
3	Clear sky
5	Summer with water vapour
7	Polluted urban industrial

Table 1: Typical values for the Linke turbidity factor

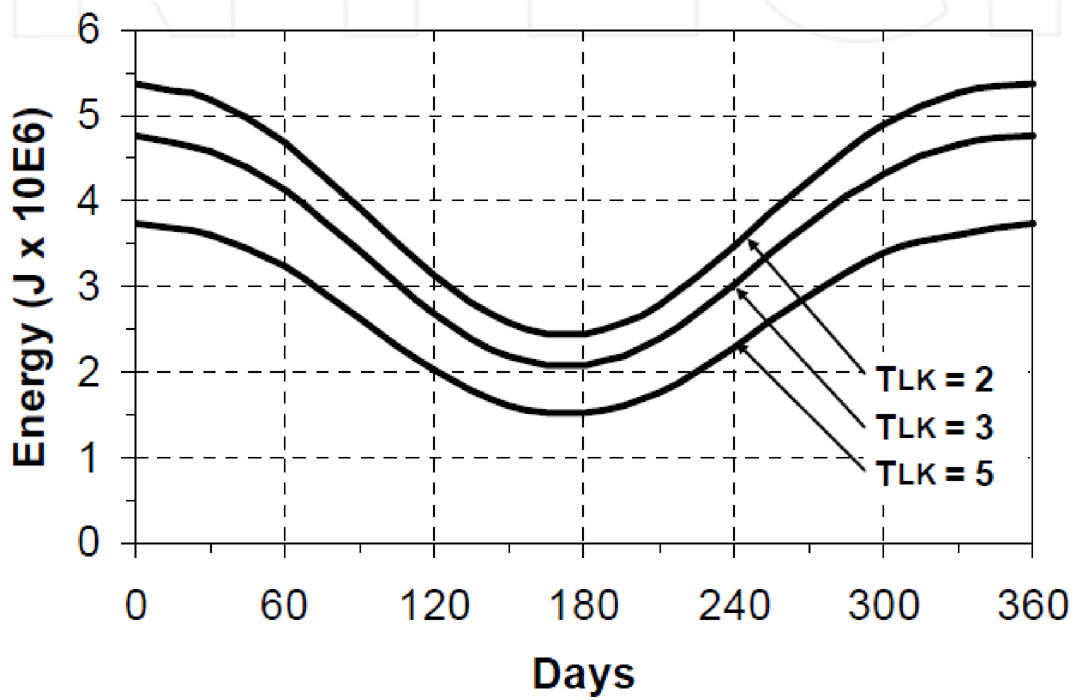


Fig. 1: Available solar energy per day which can be collected by a 1 m^2 photovoltaic array with a 16% efficiency for various values of Linke turbidity factor.

(Day 1 is summer solstice in southern hemisphere)

Meyer *et al.* (2009)

Solar Energy

Photo voltaic (PV) cells
Lithium polymer (Li-Po) batteries
Super capacitors (SC)
Hydrogen fuel (FC) cells

Energy density (Wh/kg)
Energy unit cost (Wh/$)
Lifespan (years)

Meyer *et al.* (2009)

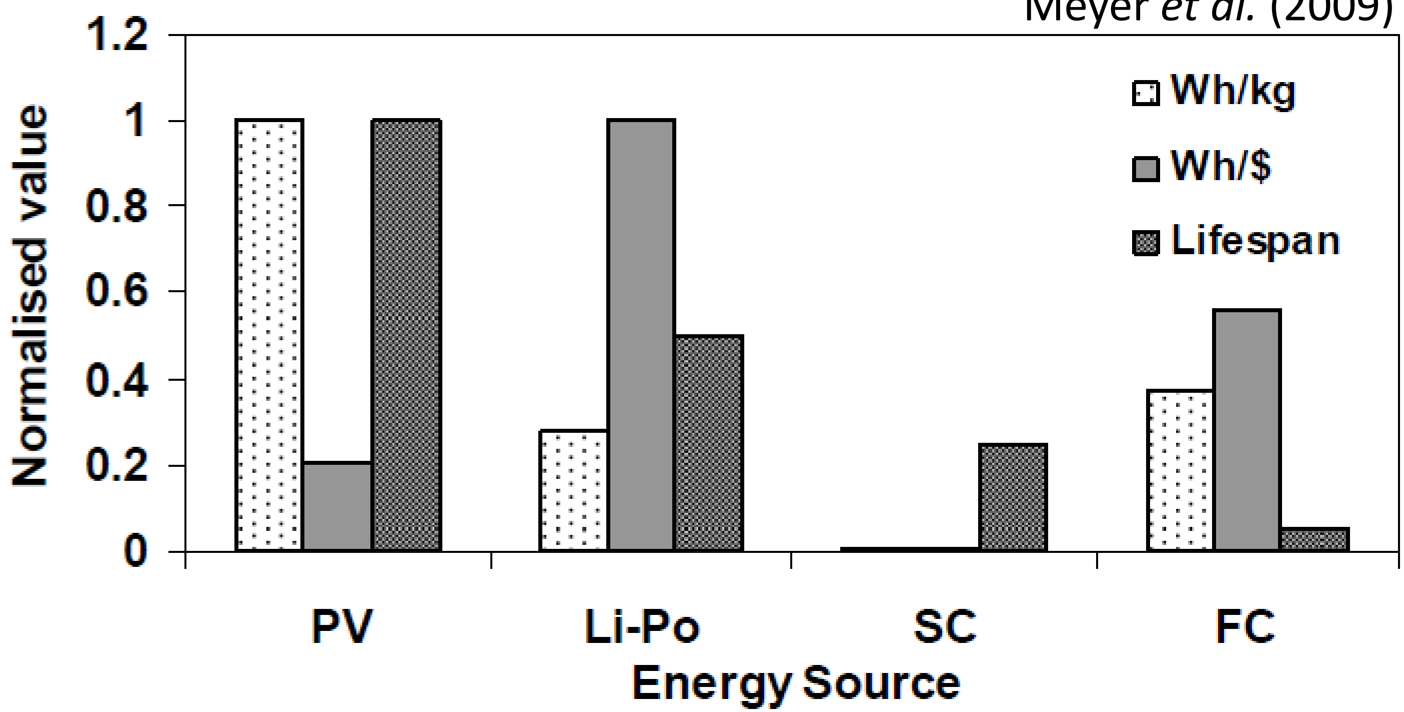


Fig. 2: Normalised comparison of the key performance parameters for the energy sources considered.

Solar Energy

MARQUES™ AVIATION

Table 2: Applicable energy source for various UAV application requirements

Flight Duration (h)	Power Source Weight (kg)	Required Power (W)	Solution 1	Solution 2
2	5	40	PV	Li-Po
10	4	20	Li-Po	FC
12	10	150	FC	PV-Li-Po
21	10	200	PV-Li-Po	None
24	20	200	FC	PV-Li-Po

Photo voltaic (PV) cells
Lithium polymer (Li-Po) batteries
Super capacitors (SC)
Hydrogen fuel (FC) cells

Meyer *et al.* (2009)

Sense & Avoid Technology

Collision avoidance:

Emerging theme for UAS operation in civil airspace.

Several sensor technologies integrated to address full range of collision hazards.

U.S. National Airspace System (NAS)

Several technologies to ensure risk of collision for manned aircraft is within acceptable Target Level of Safety (TLOS).

Layered approach:

1. Airspace structure and procedures.
2. Strategic separation services.
3. Radar separation services.
4. Traffic collision and avoidance systems (TCAS).
5. See and avoid.

Concurrent failures at multiple layers required to cause a system failure and ensuing a mid-air collision.

Sense & Avoid Technology

Collision avoidance:

- Unmanned systems - collision avoidance is complex.
- Collision avoidance in civil airspace relies upon human judgment.
- Unmanned aircraft - autonomous collision avoidance capability.

UAS collision avoidance technology

Must function in:

Instrument Meteorological (IMC) and Visual Meteorological Conditions (VMC).

Day and night.

Must detect:

Aircraft and other airborne vehicles.

Aircraft with and without a transponder.

Sensors

Acquire range, azimuth and elevation of nearby targets.

Sense & Avoid Technology

Surveillance for collision avoidance:

Two methods

1. Cooperative sensors.
A target transponds information and gives its position.

2. Non-cooperative sensors.
Sense a target indirectly. Passively sensing a property of the target, or actively deploying energy to locate the target.

Surveillance methods that sense a **cooperative** target work well for manned aircraft operating in controlled airspace in which all aircraft carry a Mode A/C altitude-encoding transponder.

Cooperative surveillance does not permit sensing of non-transponding aircraft.

Non-cooperative sensing methods.
Target sensed by:

1. **Passively** acquiring information about the target (e.g., optical camera, acoustic sensor).
2. **Actively** deploying energy to intercept the target (e.g., radar emitting an electronic pulse, or laser range finder which emits infrared light to detect reflections).

Sense & Avoid Technology

Surveillance for collision avoidance:

Two methods

1. Passive sensors.

Optical cameras. Smaller and lighter-weight systems.

2. Active sensors.

Laser range finder. Use a fair amount of energy. Bigger and heavier.

Passive sensors

- Do no need high power sources to transmit energy.
- Provide good field of regard and high resolution.
- Very high processing is required for high resolution image.
- Optical solutions provide accurate information on azimuth and elevation angles, however range is not measured directly.

Sense & Avoid Technology

Surveillance for collision avoidance:

Two methods

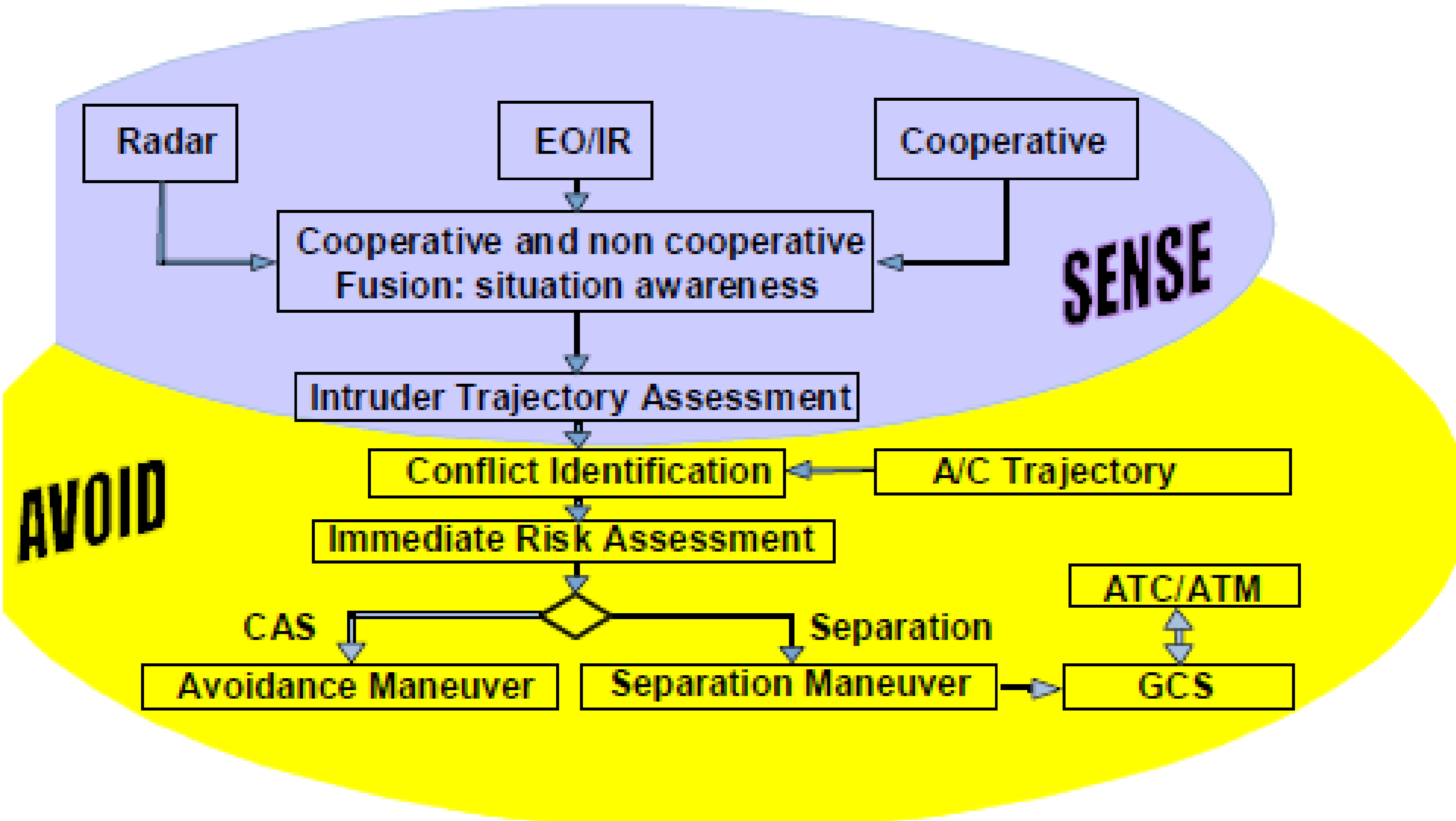
1. Passive sensors
2. Active sensors

Active sensors

- Accurate range information.
- Limited capability to provide angle resolution. Field of regard is very small (laser range finder point) or large (radar or acoustic omni-directional ping).
- Mechanical scanning, steering, or processing can enhance distance measurements, but added weight.
- Non-cooperative sensors operate over a much shorter range than cooperative sensors, and in line of sight only.
- Non-cooperative sensors applicable to the very short time frames of the "see and avoid" level of collision avoidance.

Sense & Avoid Technology

Summary



Plasma Actuation – Flow Control

Plasma actuators for flow control divided into two groups depending on kind of plasma generated:

Non-thermal plasma | **Thermal plasma**

Thermal plasma actuators

Generate an equilibrium discharge.

Locally increase pressure and temperature of surrounding gas.

Plasma Synthetic Jet (PSJ) actuators generate a spark discharge inside a small cavity with pinhole exit at wall.

Pressure increase inside the cavity induces a wall-normal jet that acts on the boundary layer as a vortex generator.

Non-thermal plasma

Dielectric Barrier Discharge (DBD) or Corona Discharge.

Non-equilibrium surface discharge induces a force parallel to the wall (ionic wind) inside the boundary layer.

Control of airflow around flat plates, cylinders and airfoils.

Plasma Actuation – Flow Control

Rudderless Flight Control

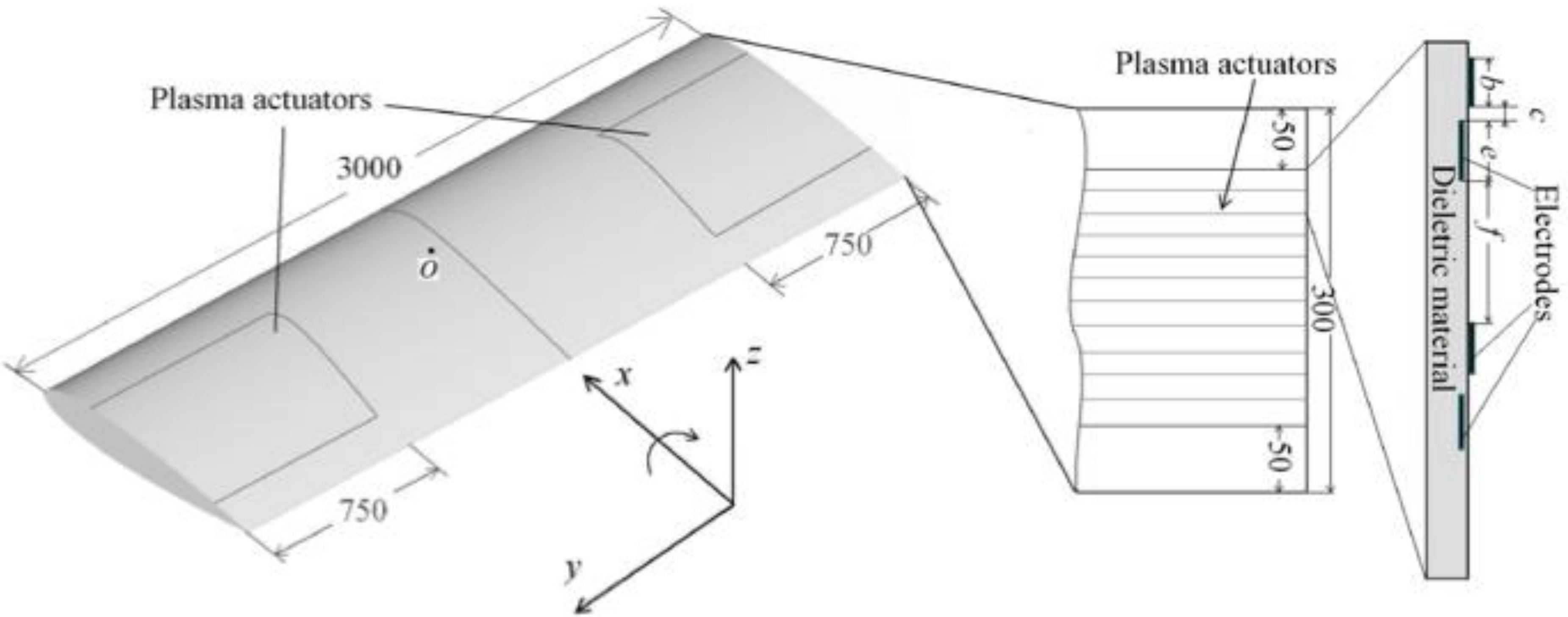


Fig. 7. DBD plasma actuators on an NACA 0015 airfoil to achieve rudderless flight control.

MARQUES™ AVIATION

Plasma Actuation – Flow Control

Plasma actuators control airflows to reduce environmental impact of aircraft.

Reduce aircraft fuel consumption by delaying boundary-layer transition on wings (preserve laminar flow) to reduce skin friction drag.

Steady actuation | **Unsteady actuation**

Steady actuation

Used to modify the mean velocity profile to make the boundary layer more stable.

E.g., Steady suction.

Unsteady actuation

Used to act (or counteract) on the instabilities growing within the boundary layer - Tollmien-Schlichting (TS) waves - which lead to turbulence for low disturbance level airflow.

Active Wave Cancellation (AWC).

E.g., DBD plasma actuator delays transition on an airfoil by either steady or unsteady actuation.

Imparts momentum to boundary layer.

Plasma Actuation – Flow Control

Single dielectric barrier discharge (SDBD) plasma actuators

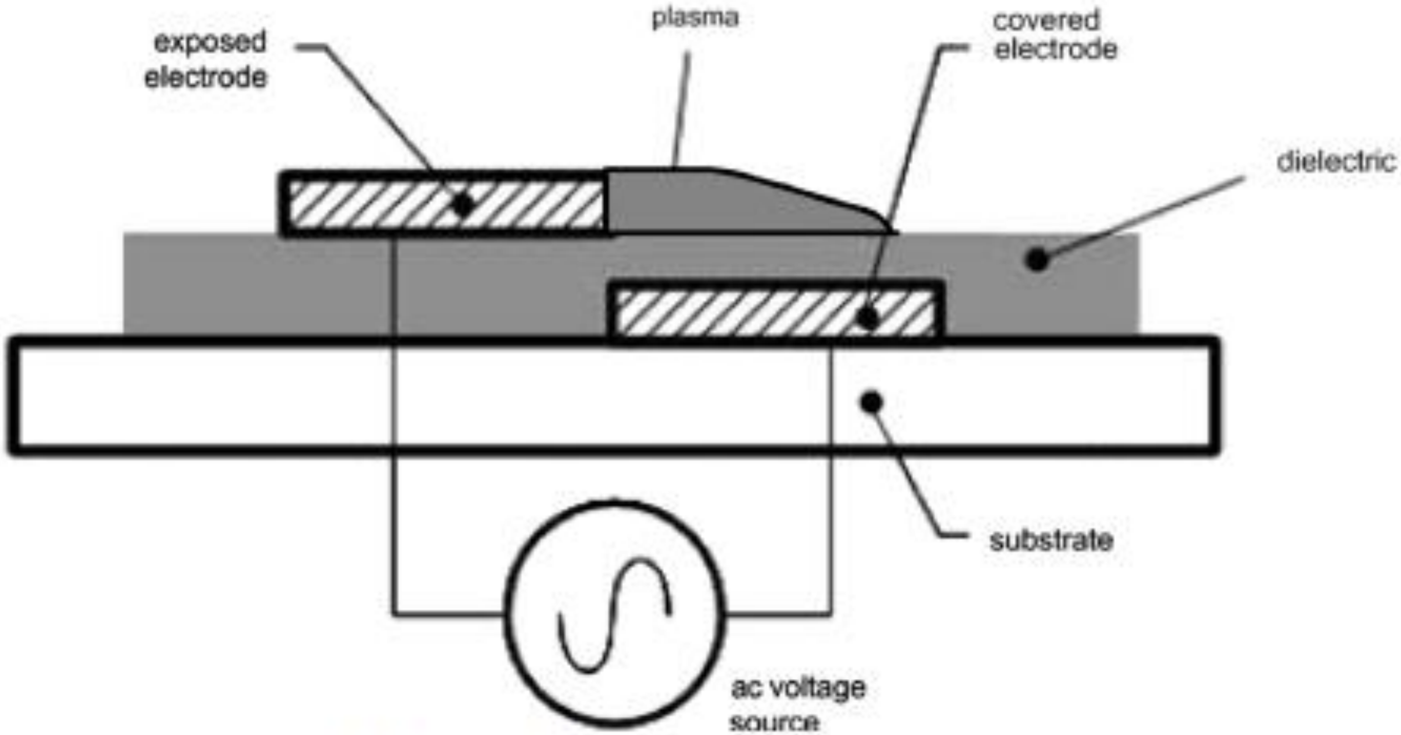


Fig. 1 Schematic of the SDBD plasma actuator.

Thomas *et al.* (2013)

Plasma Actuation – Flow Control

Optimization of DBD plasma actuators for active aerodynamic flow control.

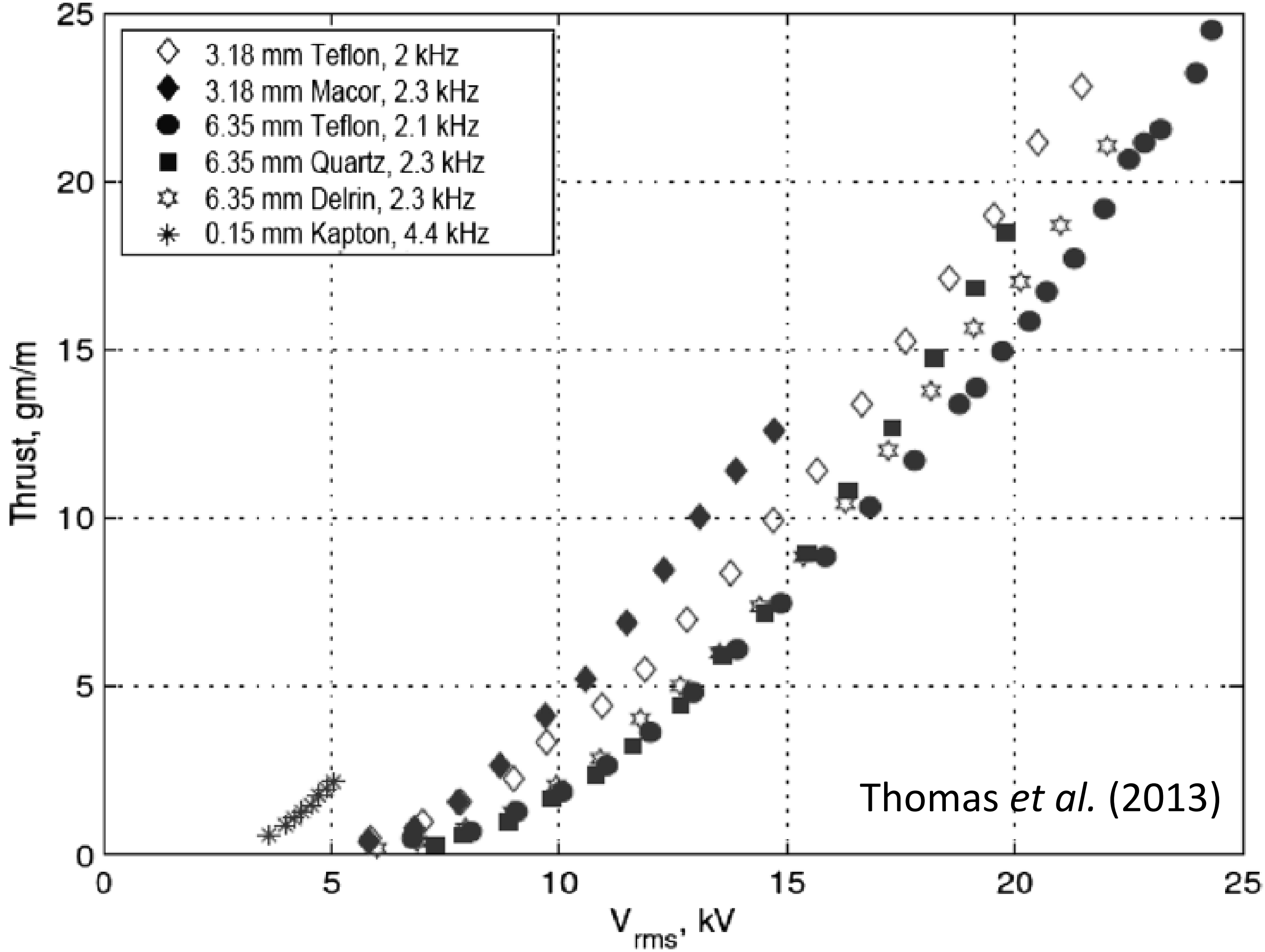
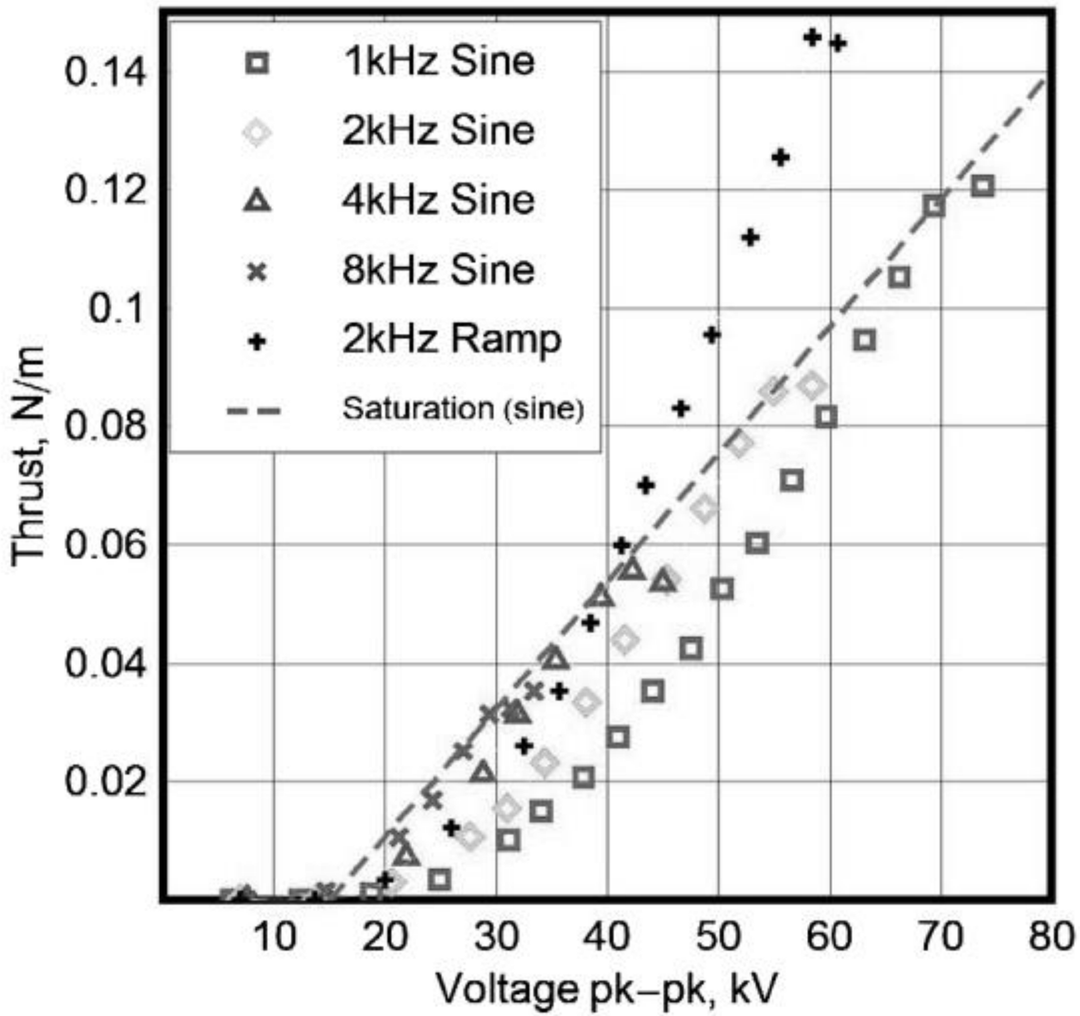


Fig. 4: Thrust per unit span/g versus rms applied voltage for various dielectric materials.

Plasma Actuation – Flow Control



Optimization of DBD plasma actuators for active aerodynamic flow control.

Fig. 7 Actuator thrust as a function of applied voltage for different frequencies (6.35-mm thick quartz).

Thomas *et al.* (2013)

Plasma Actuation – Flow Control

Effect of multiple actuators in series and covered electrode width.
Higher force using multiple actuators in series.
Experiments with actuator arrays of up to 3 actuators.
Geometry for multiple actuator arrangement.
Width of exposed electrodes: 12.7 mm
Width of the covered electrode: 12.7 and 50.8 mm

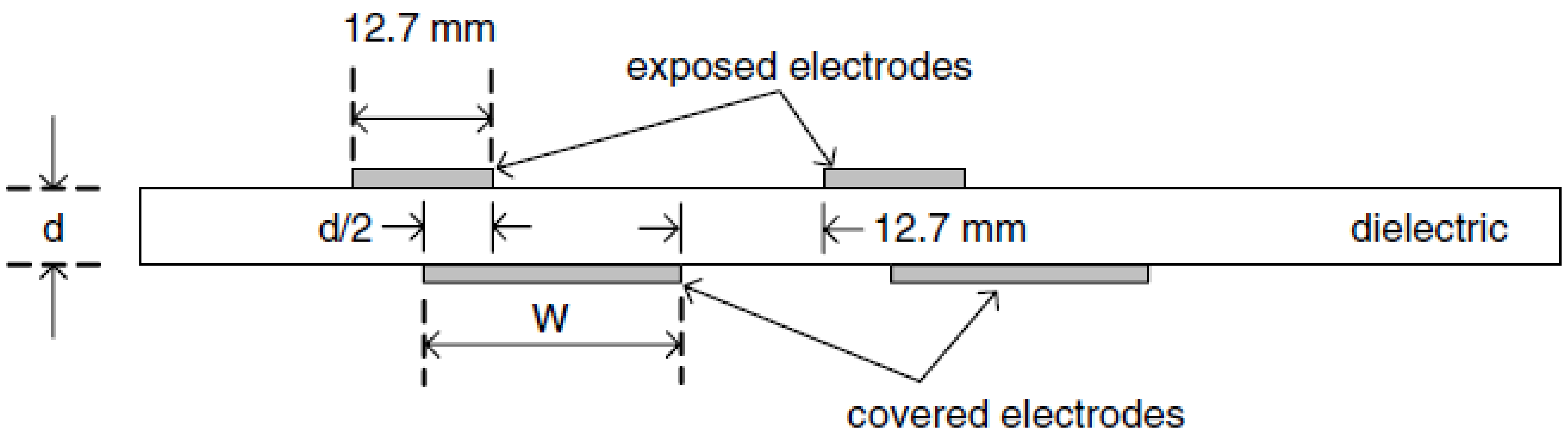
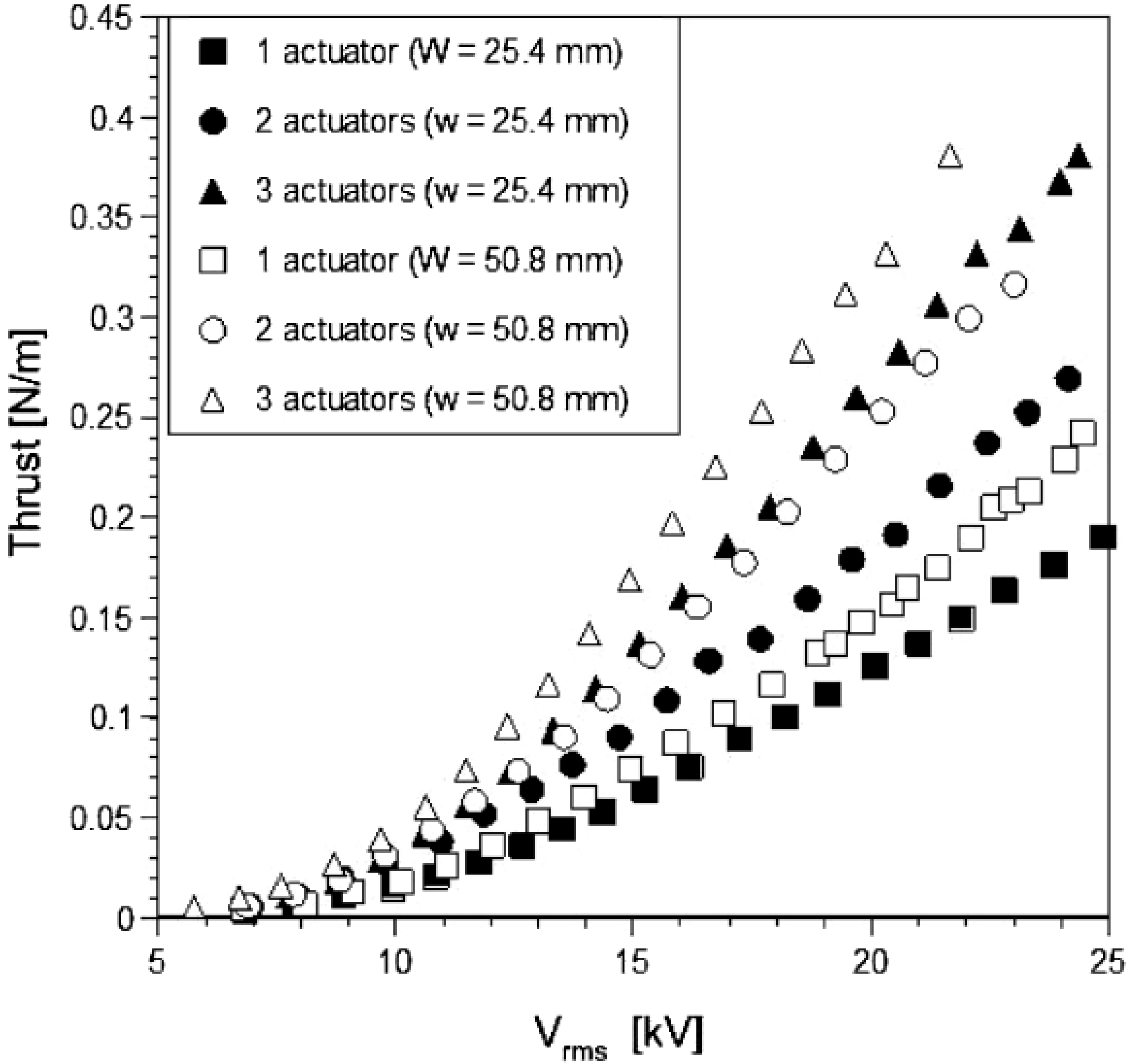


Fig. 11: Schematic of the geometry used to measure thrust from multiple actuators.

Thomas *et al.* (2013)

Plasma Actuation – Flow Control



Experiments with actuator arrays of up to 3 actuators.

Width of exposed electrodes: 12.7 mm

Width of the covered electrode: 12.7 and 50.8 mm

Fig. 12: Thrust for multiple actuator configurations.

Thomas *et al.* (2013)

Plasma Actuation – Flow Control

Measured thrust per unit span as a function of applied ac peak-to-peak voltage.

Actuators with **straight** and **optimized serrated edge**.

Benefit of using serrated exposed electrode.

Increase in thrust compared to actuator with straight electrode.

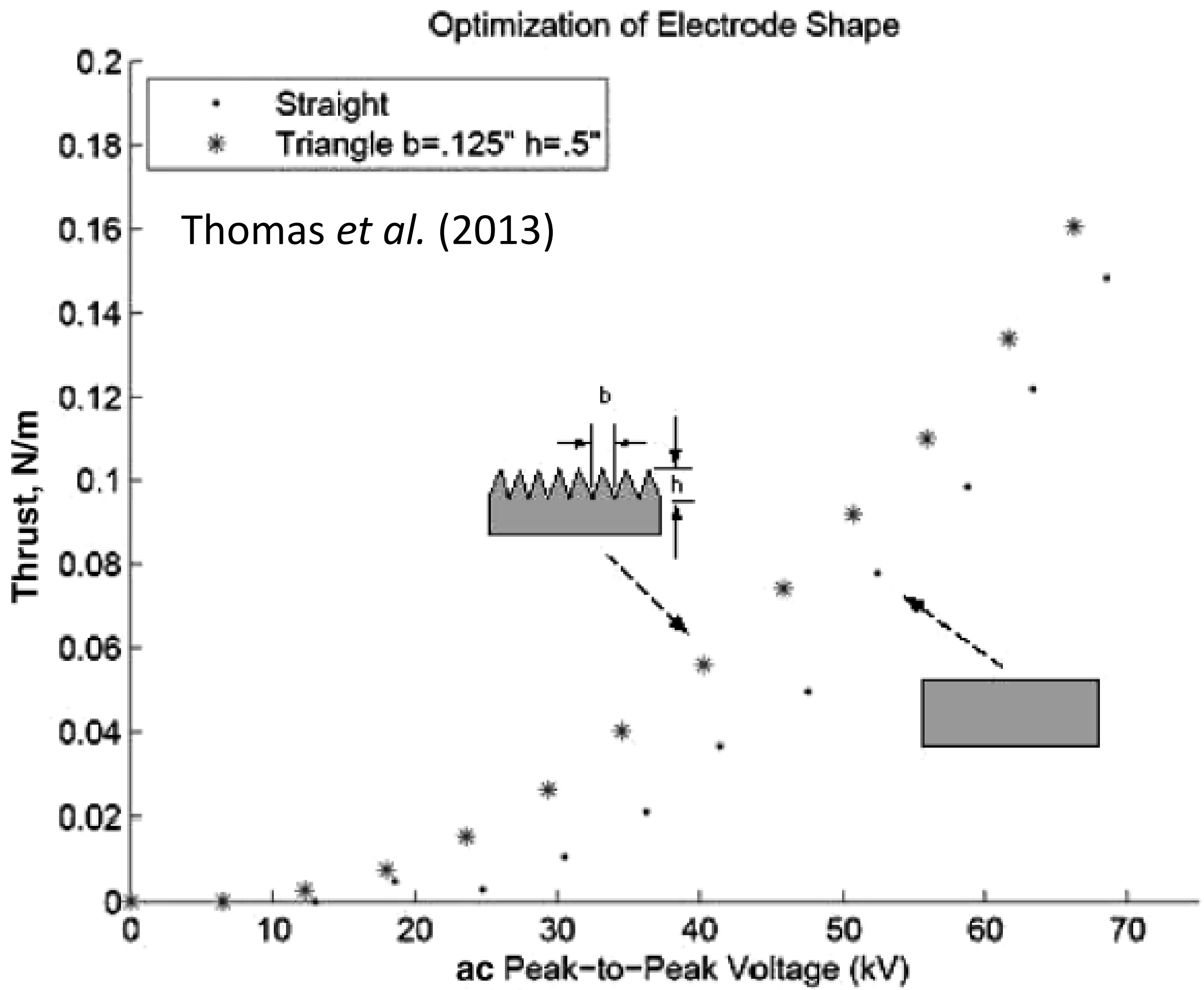


Fig. 18: Thrust per unit span for actuators with straight and optimum serrated electrodes.

Plasma Actuation – Flow Control

Optimization of DBD plasma actuators for active aerodynamic flow control (Thomas *et al.*, 2013).

Conclusions

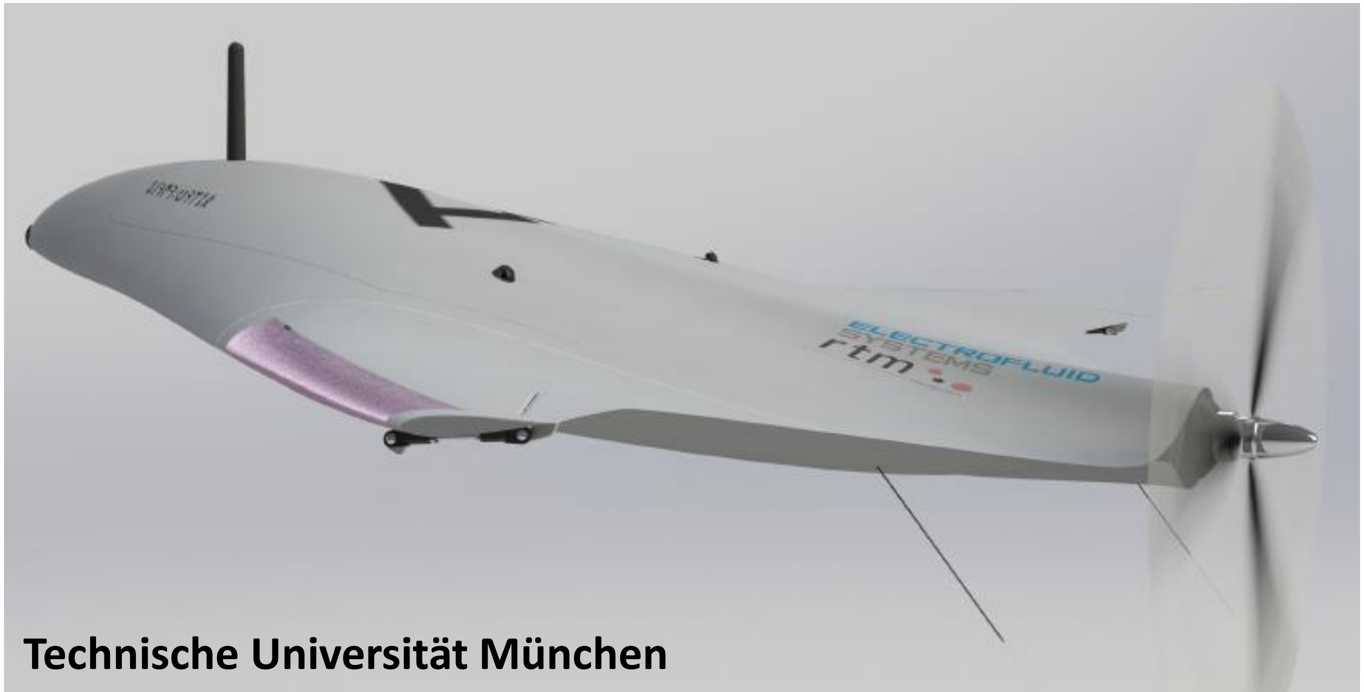
1) **Maximum force** produced by SDBD plasma actuator **limited by formation of streamers** in the plasma.
2) Higher saturation force obtained by lowering the applied **ac frequency**.
3) For low to moderate operating voltages, the force is found to follow a power law and is proportional to the applied voltage to the **3.5 power**.
4) SDBD plasma actuators using an exposed electrode with the downstream edge **serrated** provide a considerable increase in force over actuators with a conventional straight-edge electrode.
5) For both the single actuator and the multiple actuator arrays, achieving optimum body force requires that the covered electrode **width is sufficient** that the plasma forming region is not artificially constrained at the highest applied voltages.
6) For multiple actuator arrays, the total force increases with the **number of actuators** but does not sum linearly.
7) Plasma flow control achieved in wind-tunnel tests of a full aircraft configuration. Lift enhancement and drag reduction demonstrated at **wing Reynolds numbers of 1.2 x 10^6.**

Plasma Actuation – Flow Control

Plasma Flyer

The World‘s First Plasma Flow Controlled Flying Wing

Control of flow separations at low speeds.
Realize flight control without mechanical flap deflections.
Flight maneuvers at high angles of attack and low speeds.



Plasma Actuation – Flow Control

MARQUES™ AVIATION

Boundary Layer Transition Control using DBD Plasma Actuators

Experimental setup
Subsonic open-return wind tunnel – Onera Toulouse.

Low turbulence level
0.5 x 10^{-3} < Tu < 0.5 x 10^{-2}

For free-stream velocities: 5 - 75 m/s.

Two-dimensional model of symmetric profile.
Chord length c = 0.35 m

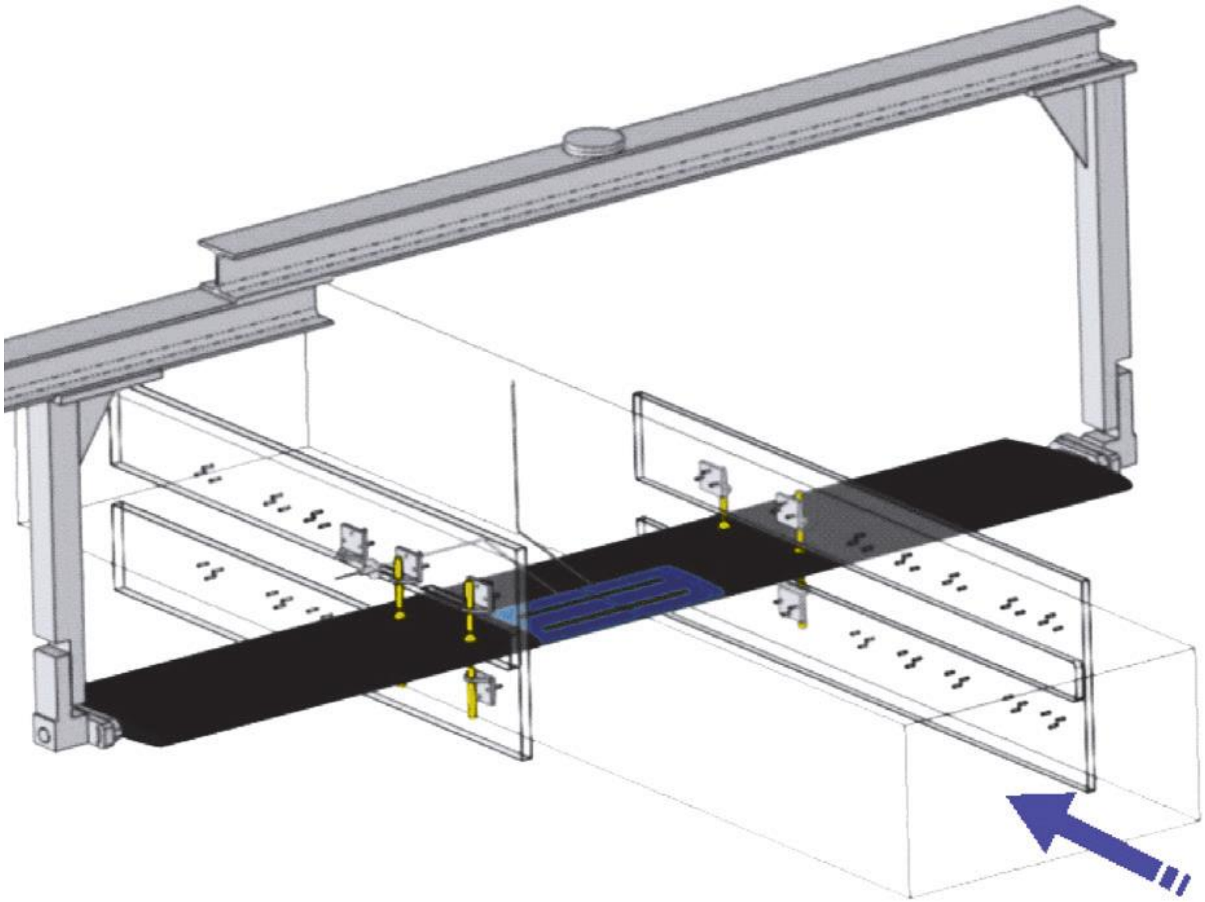
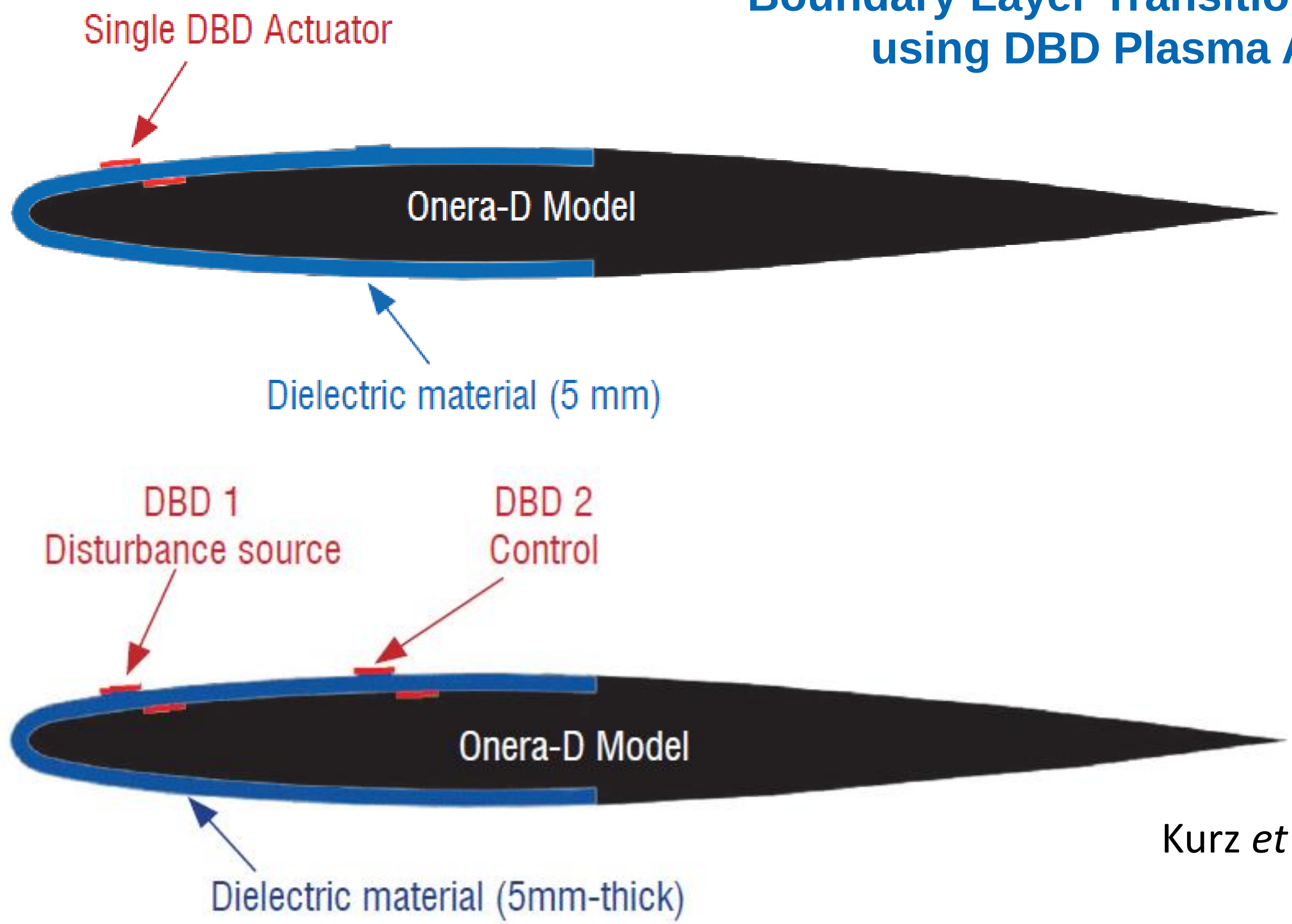


Fig. 1: Two-dimensional model of the Onera-D airfoil mounted inside the wind tunnel

Kurz *et al.* (2013)

Plasma Actuation – Flow Control

Boundary Layer Transition Control using DBD Plasma Actuators



Kurz *et al.* (2013)

Fig. 2: Cross-sectional view of the Onera-D wing model equipped with one DBD actuator (top). Experimental set-up for Active Wave Cancellation (bottom).

Plasma Actuation – Flow Control

Boundary Layer Transition Control using DBD Plasma Actuators

Study of Kurz *et al.* (2013)

- DBD plasma actuators to **delay 2D boundary-layer transition**.
- Steady or unsteady actuation.
- Wind tunnel investigations.
- DBD actuator used in **steady mode** has a stabilizing effect on the boundary layer.
- Modification of the mean velocity profiles, impeded amplification of the disturbances, and delayed transition.
- Maximum transition delay of 35% chord at low free-stream velocity (U_∞ = 7 m/s).
- **Unsteady force** produced by DBD actuator achieves Active Wave Cancellation.
- Significant transition delay achieved by damping artificial TS waves for free-stream velocities up to U_∞ = 20 m/s.

Key References

- M. A. El Diwiny, "Implementation of anti-stealth technology using Fuzzy Logic inference for safe operation of unmanned aerial vehicle." 33rd Digital Avionics Systems Conference. Antlers Hilton. Colorado Springs, CO. 5th -9th October, 2014.
- B. C. Madden, and U. M. C. von Seelen, "PennEyes: a binocular active vision system." Technical Reports (CIS). University of Pennsylvania. Department of Computer & Information Science. December, 1995.
- T. Armstrong, "Aircraft structures take advantage of energy harvesting implementations." High Frequency Electronics. May, 2010. Pp. 50-58.
- A. Weider, H. Levy, I. Regev, L. Ankri, T. Goldenberg, Y. Ehrlich, *et al*., "SunSailor: solar powered UAV." Masters Thesis. Faculty of Aerospace Engineering. Technion IIT Haifa, Israel, 2014.
- A. R. Lacher, D. R. Maroney, and A. D. Zeitlin. "Unmanned aircraft collision avoidance–technology assessment and evaluation methods." The 7th Air Traffic Management Research & Development Seminar. Barcelona, Spain. 2007.
- F. O. Thomas, T. C. Corke, M. Iqbal, A. Kozlov, and D. Schatzman, "Optimization of dielectric barrier discharge plasma actuators for active aerodynamic flow control." AIAA JOURNAL. Vol. 47, No. 9, September 2009.
- A. Kurz, S. Grundmann, C. Tropea, M. Forte, A. Seraudie, O. Vermeersch, *et al*. "Boundary layer transition control using DBD plasma actuators." Aerospace Lab. Issue 6. AL06-02. June, 2013. Pp. 1-8.