NOVEL AIR-BREATHING PLASMA JET PROPULSION FOR SOLAR POWERED HIGH-ALTITUDE FLIGHT PLATFORMS

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4th EASN Association International
Workshop on Flight Physics &
Aircraft Design
27th – 29th October 2014
RWTH Aachen University

Outline

- Motivation
- *Electrohydrodynamic (EHD)* Pulsed Propulsion based on Sliding Corona Discharge with Ferroelectric Field Electron Emission
- *Magnetohydrodynamic (MHD)* Pulsed Propulsion based on Magneto-Plasma Flux Compression
- Combined Distributed *EHD-MHD* Fan Propulsion
- Conclusions and Outlook

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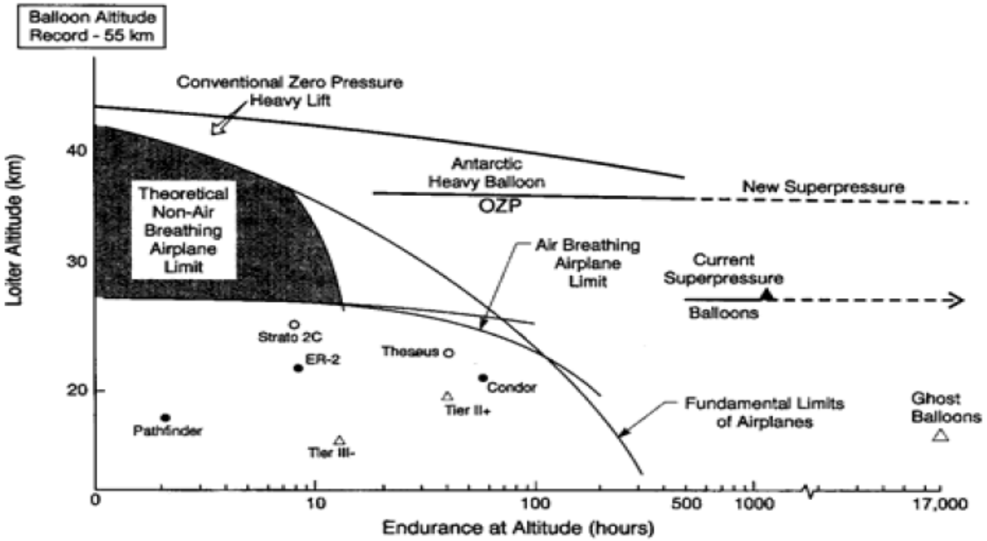
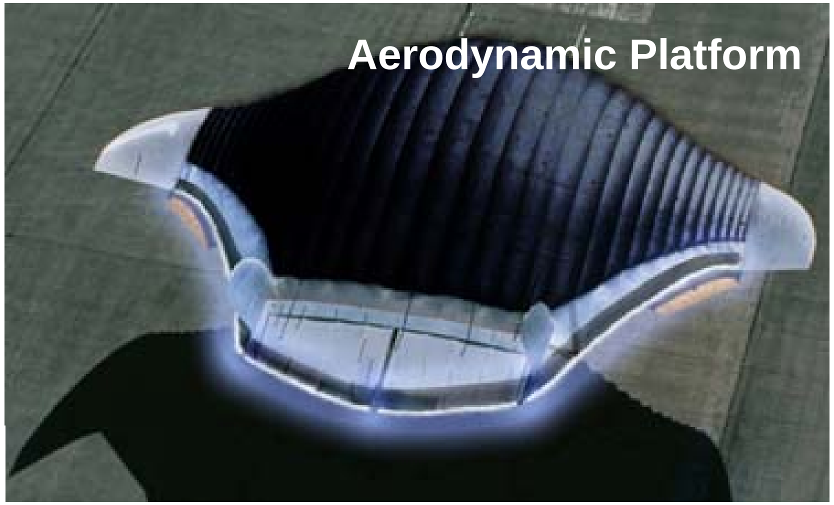
Motivation

- **Need for High-Altitude Geostationary Airships / Stratospheric Platforms (Stratollites) to Partly Replace Satellites**
- **Conventional Propeller Propulsion Systems Limited to 30 km with Decreasing Aerodynamic Efficiency at High Altitudes**





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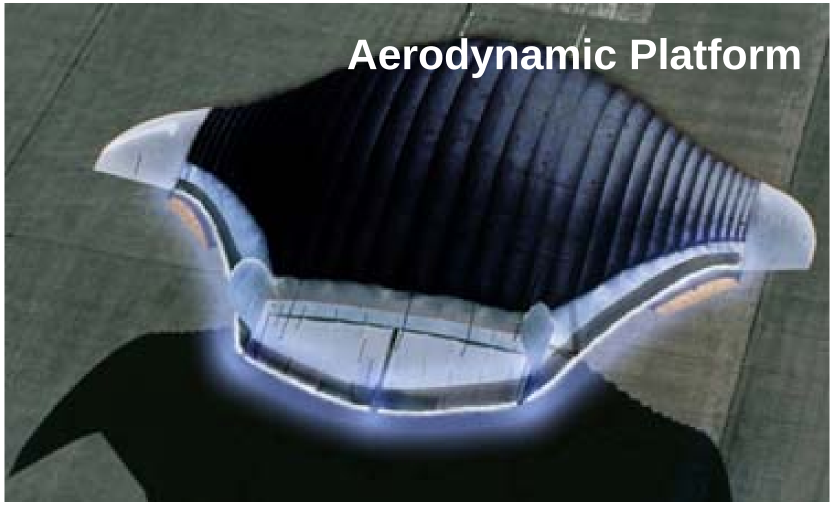
- Novel Air Plasma Jet Propulsion as Alternative for Propellers at Very High Altitudes (>20km up to 50 km Stratopause)
- World's First EHD Plasma Propulsion Demonstrated for Airships in 2005
- Spin-Off from MHD Fusion Research and Power Electronics to Develop High-Thrust Combined EHD/MHD Propulsion Systems



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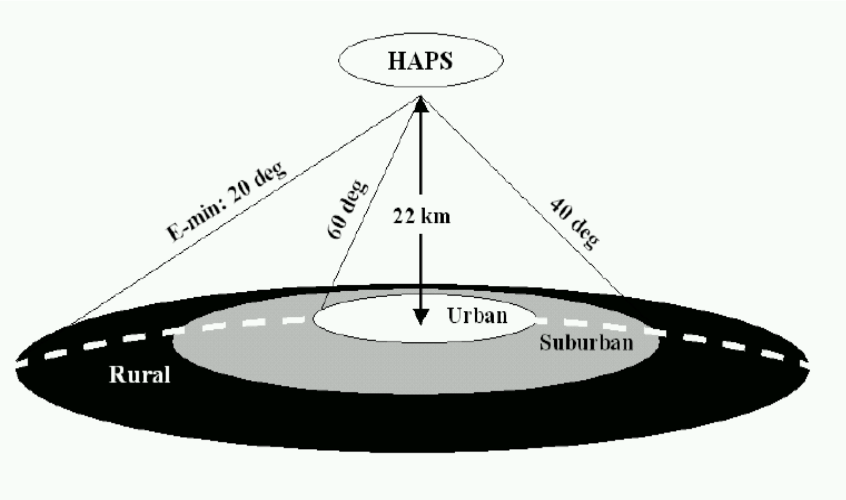

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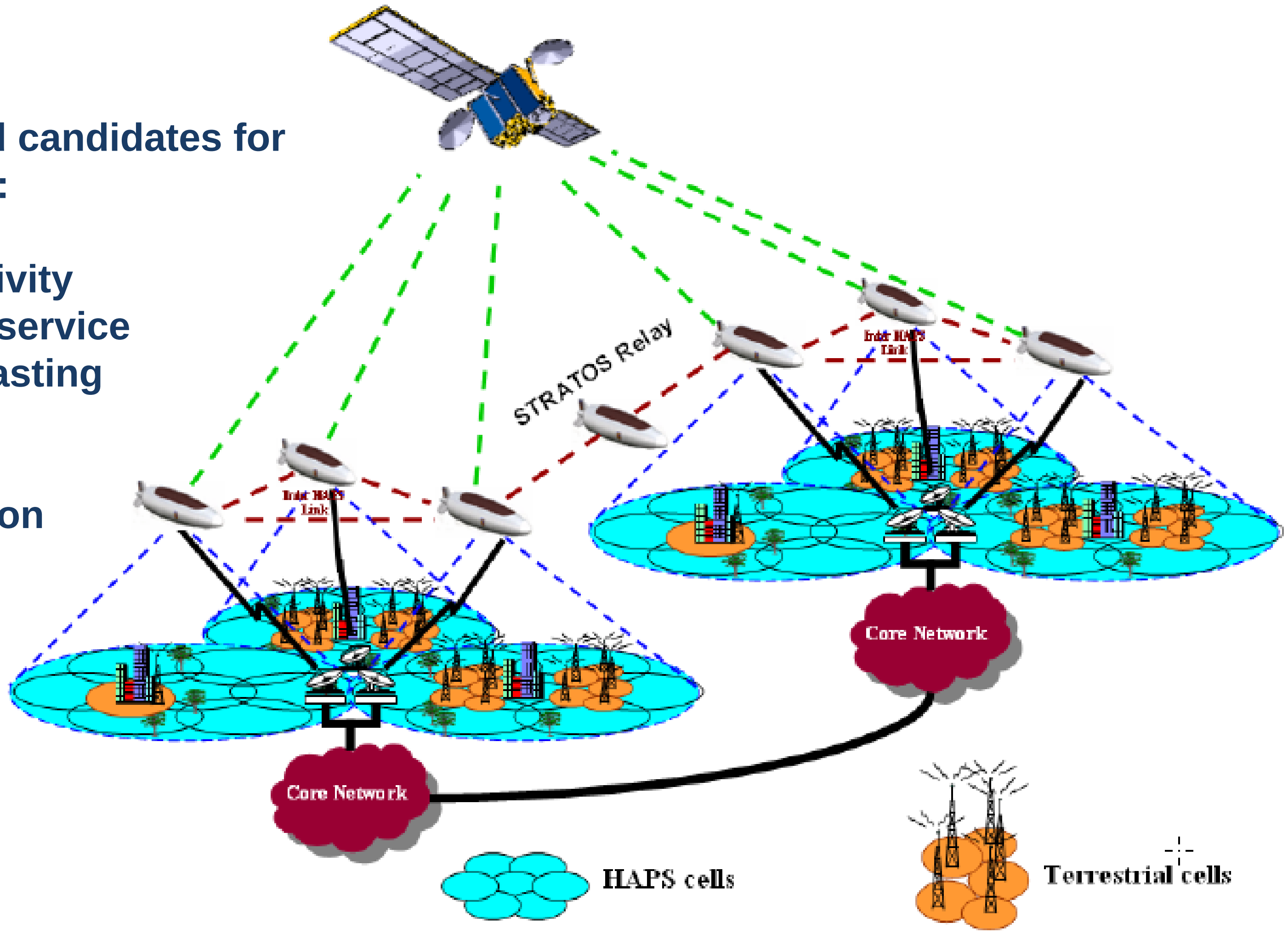
Regenerative payload candidates for stratospheric service:

- **Broadband connectivity**
- **3G/4G base-station service**
- **DAB/DVB-T Broadcasting**

Other potential non-telecommunication services such as remote sensing, navigation, and telemetry as add-on services



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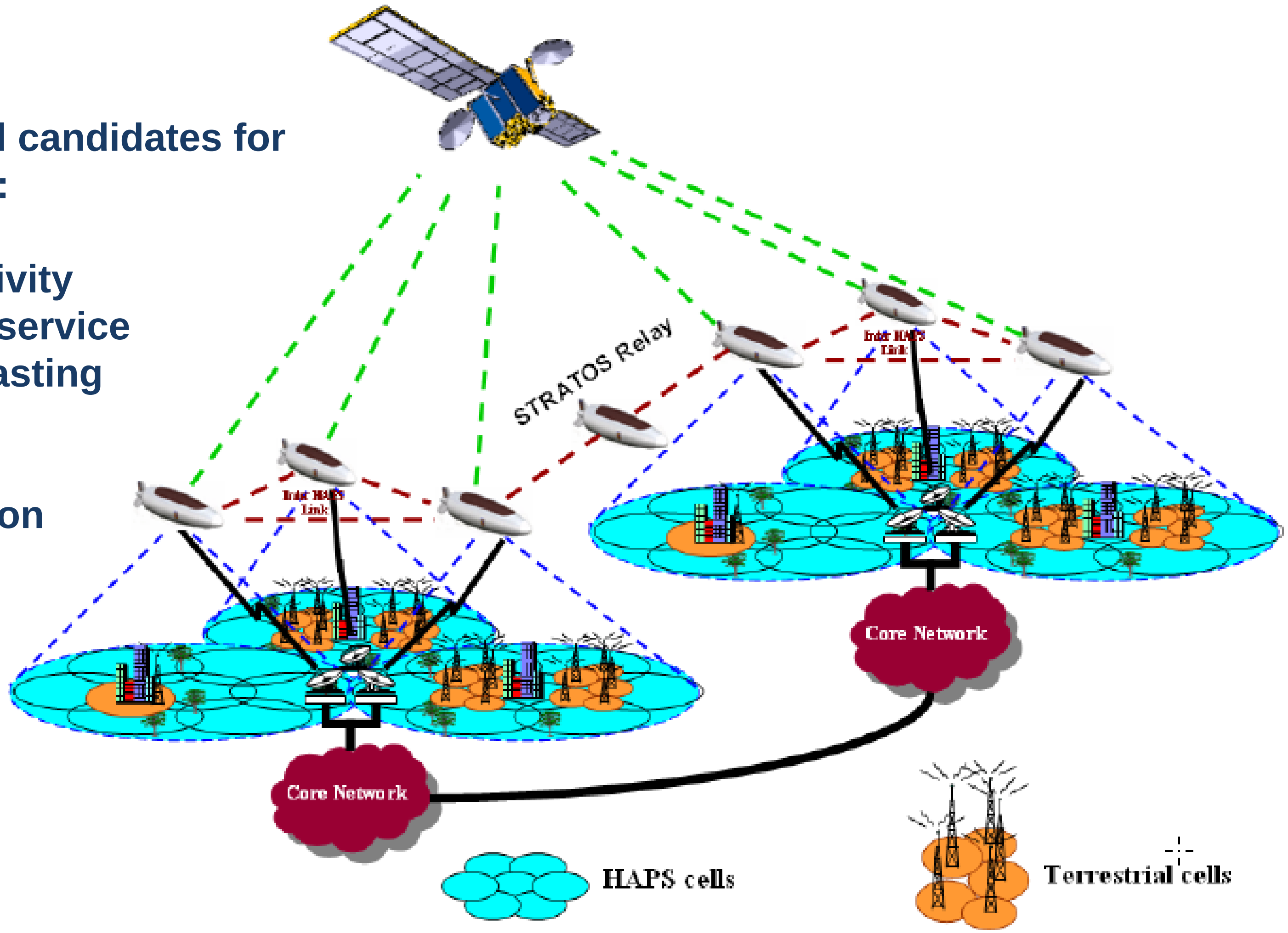

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Electrohydrodynamic (EHD) Pulsed Propulsion for High Altitude Solar Flyer based on Corona Discharge and Ferroelectric Field Electron Emission

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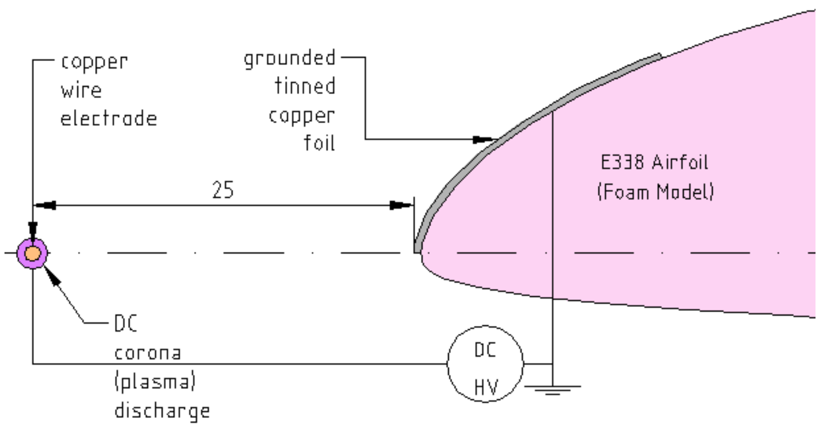
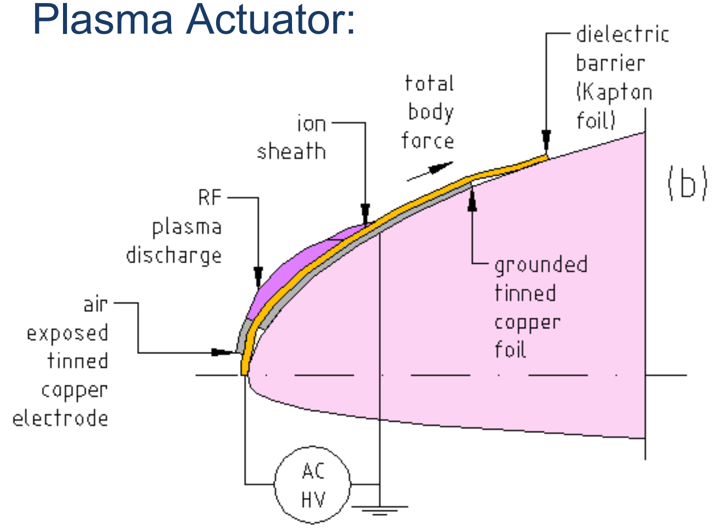
(a) Corona Discharge Plasma Actuator:



(b) Dielectric Barrier Discharge (DBD) Plasma Actuator:



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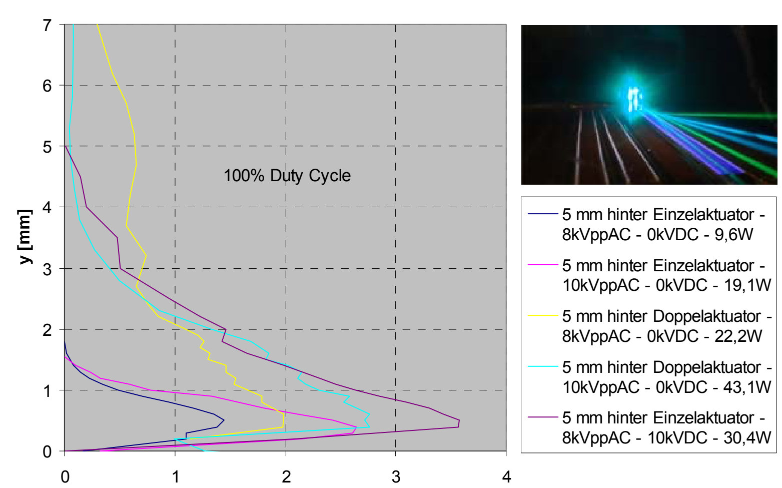
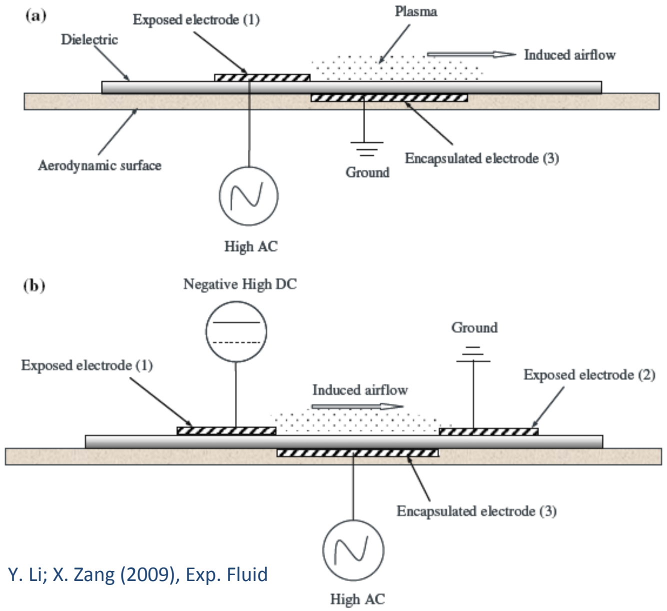
(c) Sliding Corona Discharge Plasma Actuator:



B. Göksel (2013)



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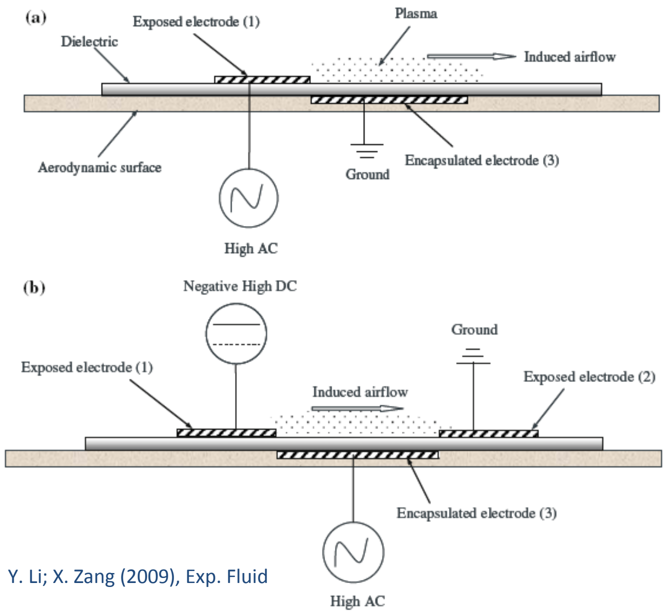

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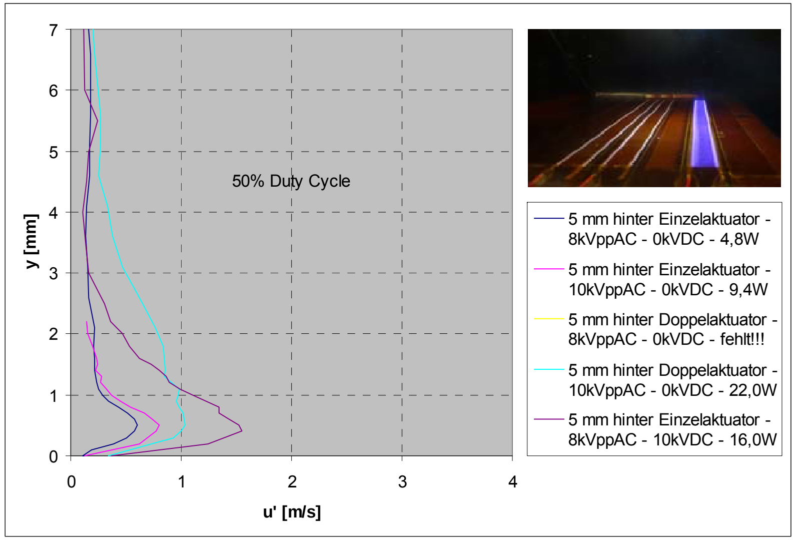

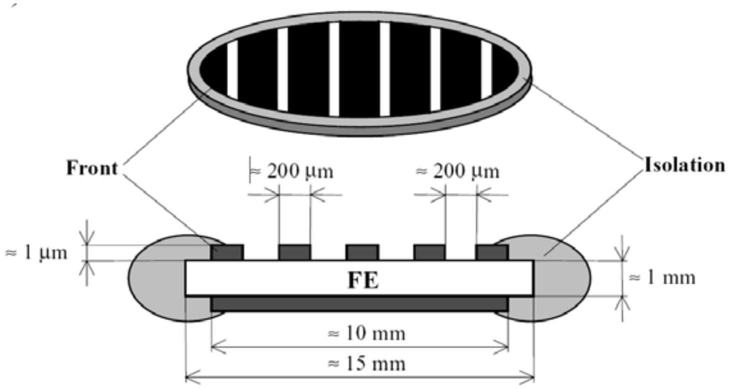

Heydari (1995)
TU Berlin

After a fast pole-changing of the spontaneous polarisation P_S within a few nanoseconds an intensive electron beam could be measured from ferroelectric barriers in a period of time up to 50 ns.

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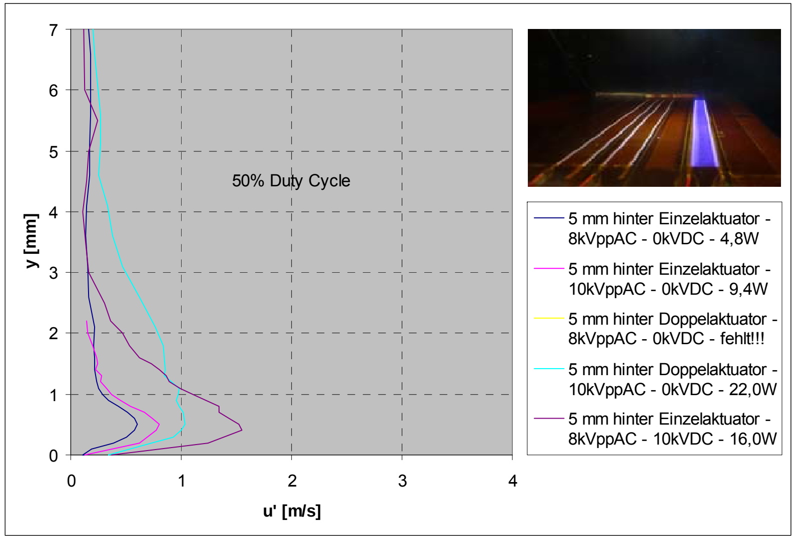

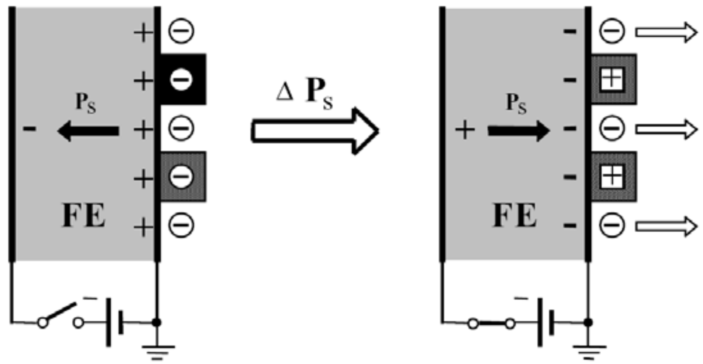

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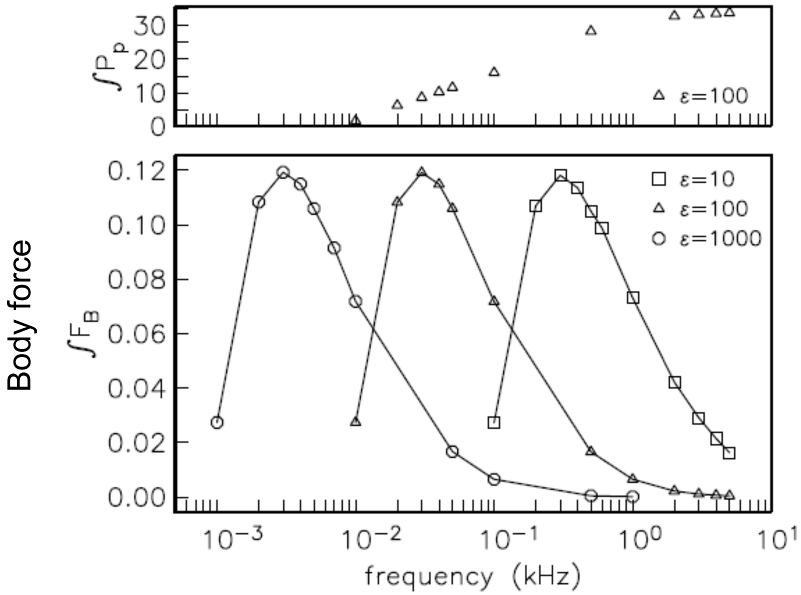

Corke et al. (2007)

Today everybody is working with a dielectric permittivity of 5 - 10 (Teflon, Kapton, Silicon Rubber) and kHz-frequencies. For the use of high-k materials based on ferroelectric dielectrics there is need for low Hz-frequency nanopulse excitation (see left)

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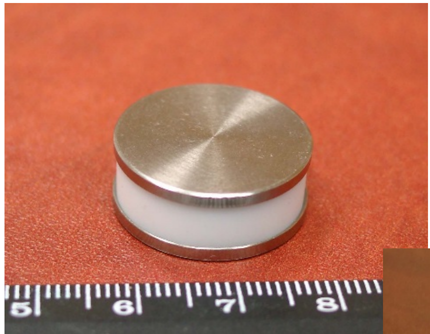

10 kV 600 A DSRD

Megaimpulse Ltd. from St. Petersburg developed highly efficient nanopulse high-voltage generators based on stacks of *Drift Step Recovery Diodes (DSRD)* which are very fast semiconductor opening switches for high-voltage pulses with 10 kV/ns rise rate.

Pulse amplitude up to 35 – 50 kV
Pulse front duration less than 4 ns
Pulse width (FWHM) 10 ns
Repetition rate up to 3 kHz

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7.5 m Length b-IONIC Airfish – World's First Airship Propelled with Plasma Engines

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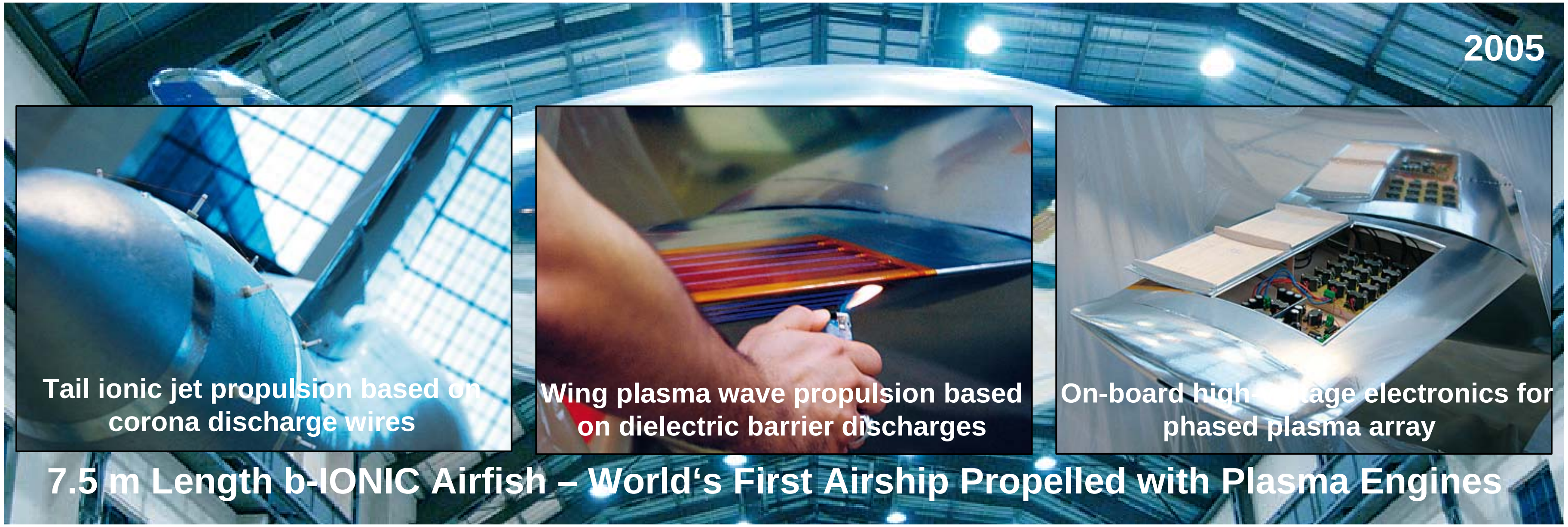

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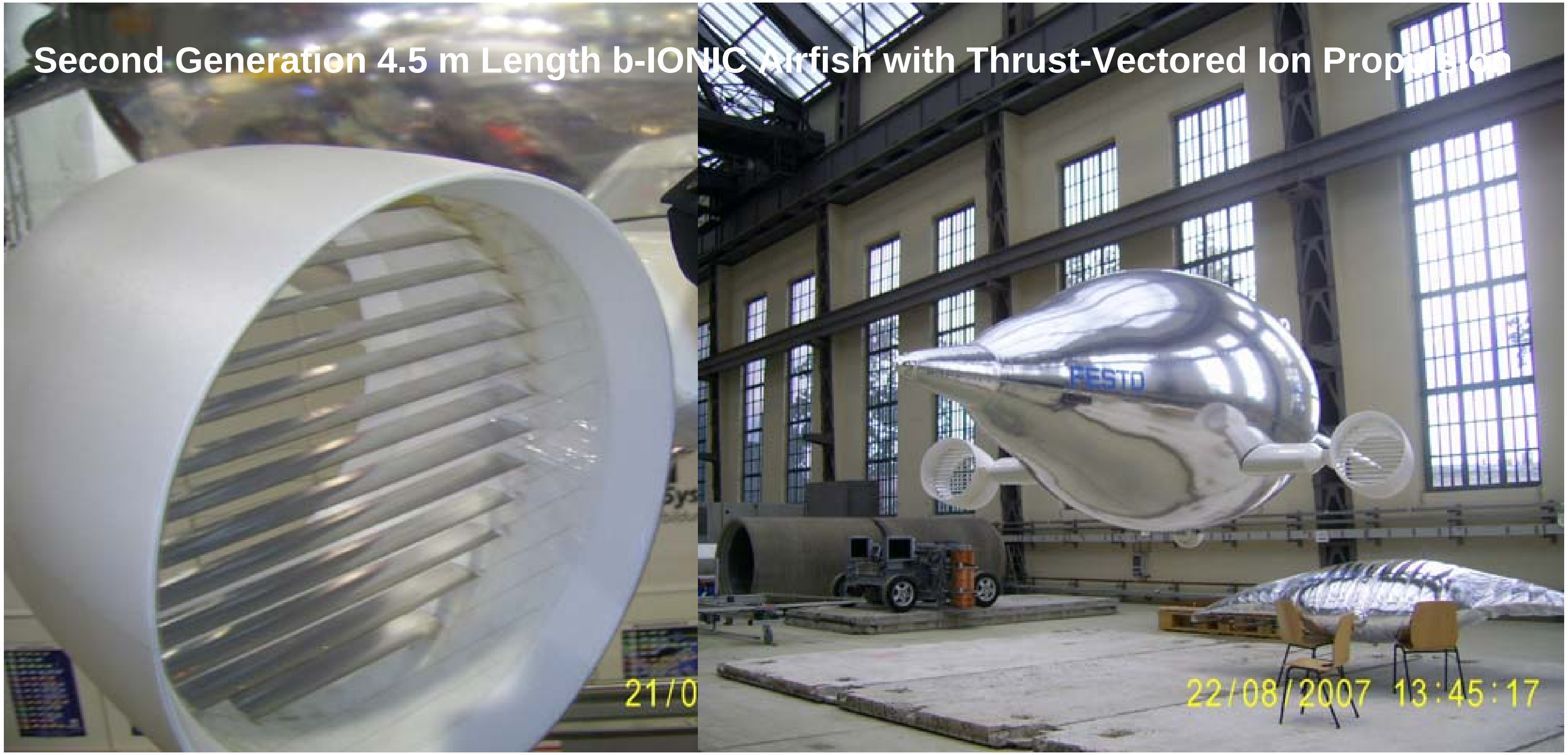

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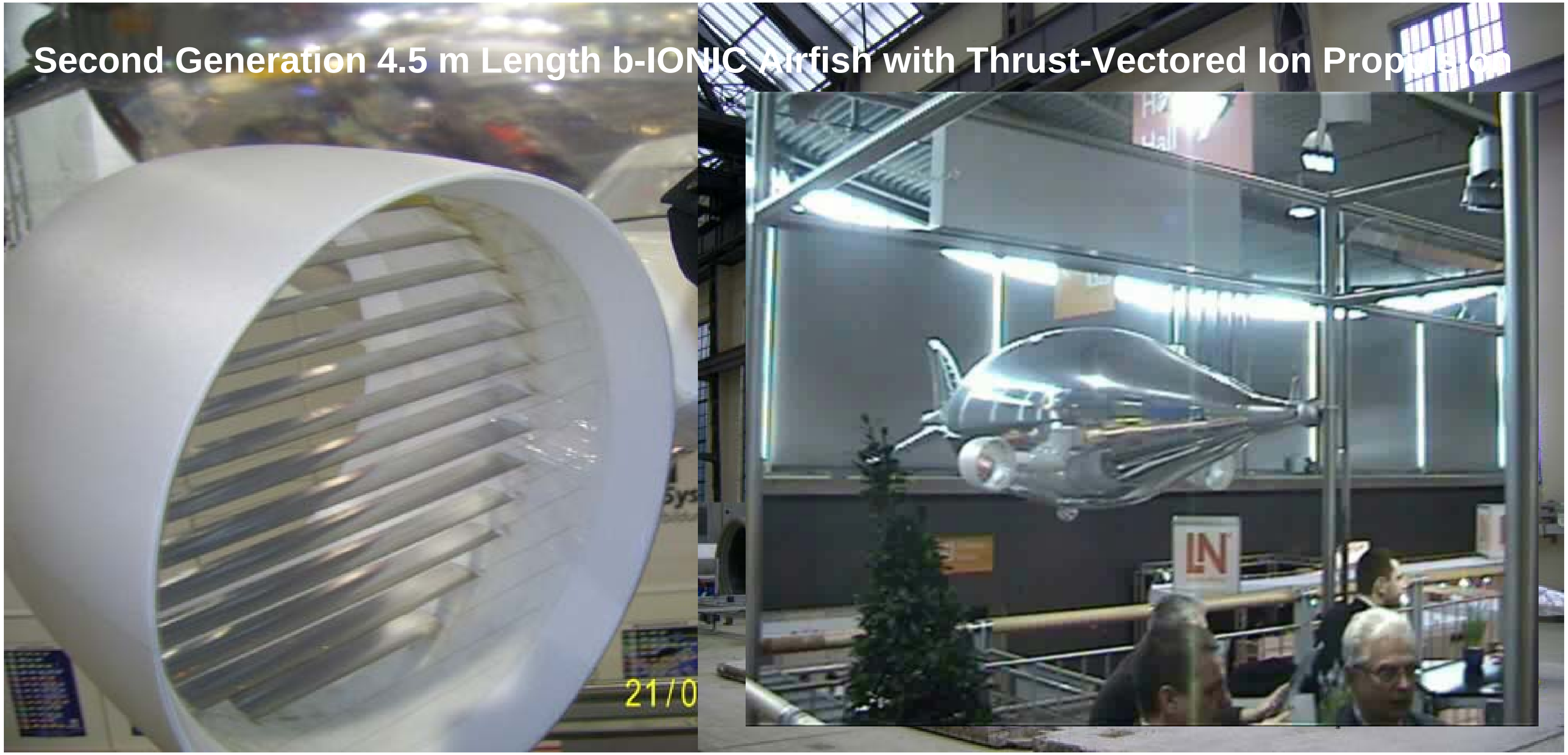

Second Generation 4.5 m Length b-IONIC Airfish with Thrust-Vectored Ion Propulsion

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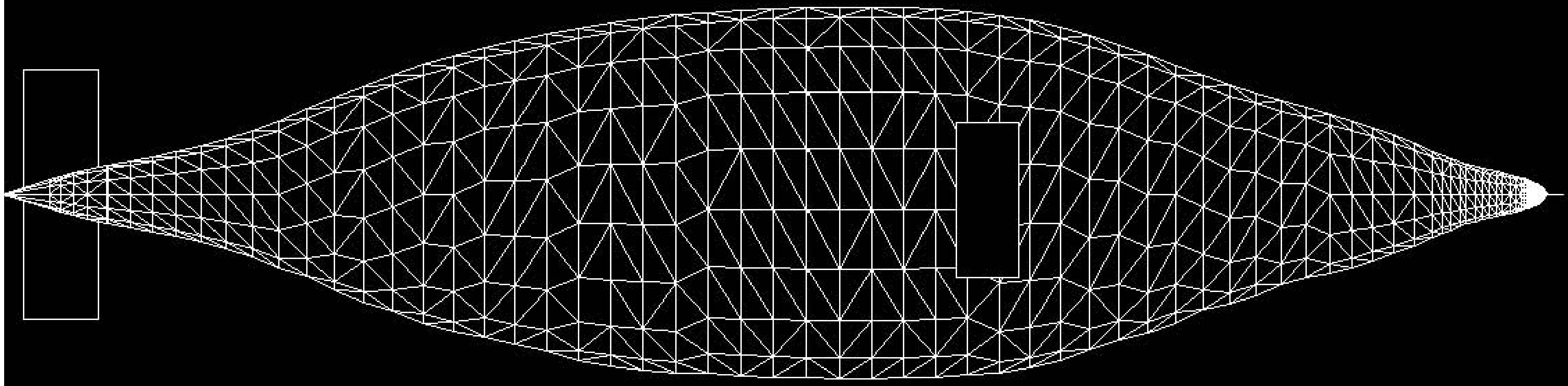

Altitude: 20 km, Temperature: -56°C, Net buoyancy lift: 200.7 kg
With total pressure = static pressure at ground: 15 m/s (54 km/h) with 120 N
With total pressure = 3 x static pressure at ground: 27.7 m/s (100 km/h) with 407 N

D=12,00 m
L=49,50 m
O=1166 m^2
V=2695 m^3

Area for solar cells > 388,6 m^2

Fläche für Rectenna > 300,0 m^2

Minimum solar power: 48 kW
Maximum solar power: 97 kW

Minimum MW power: 150 kW
Maximum MW power: 300 kW

100 kg structural weight (inclusive solar cells and electronics)
100 kg propulsion weight (inclusive thrusters and generators)

mit bis zu 200 N Schub wird eine Geschwindigkeit von 17 m/s (60 km/h) erreicht.

EHD-Propulsion system: 1 unit with 8.0 m diameter (50 m^2), 2 thrust-vectored units with 5.0 m diameter (20 m^2)

Total propulsion cross section area: 90 m^2. Using 2 cascade of thrusters, effective area: 180 m^2 ---> today 1 N/m^2 and 5 N/kW is state-of-the art ---> 180 N ---> 36 kW ---> 18.5 m/s (66.6 km/h)
Total propulsion cross section area: 90 m^2. Using 3 cascade of thrusters, effective area: 270 m^2 ---> today 1 N/m^2 and 5 N/kW is state-of-the art ---> 270 N ---> 54 kW ---> 22.6 m/s (81.4 km/h)
Total propulsion cross section area: 76 m^2. Using 4 cascade of thrusters, effective area: 360 m^2 ---> today 1 N/m^2 and 5 N/kW is state-of-the art ---> 360 N ---> 72 kW ---> 26.1 m/s (94.0 km/h)

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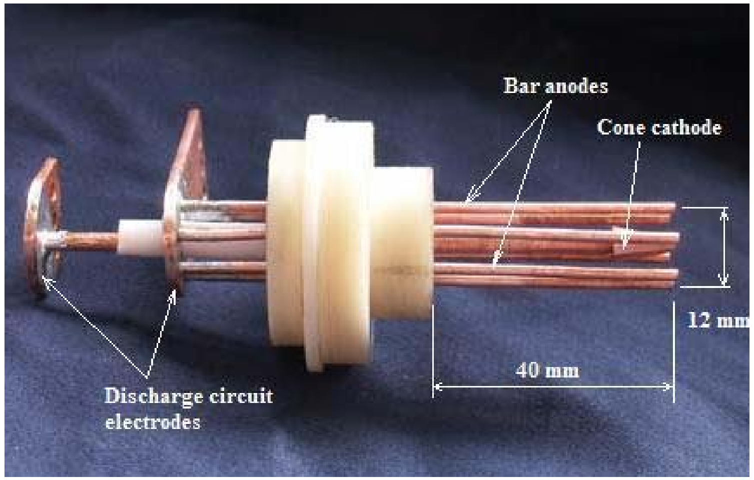
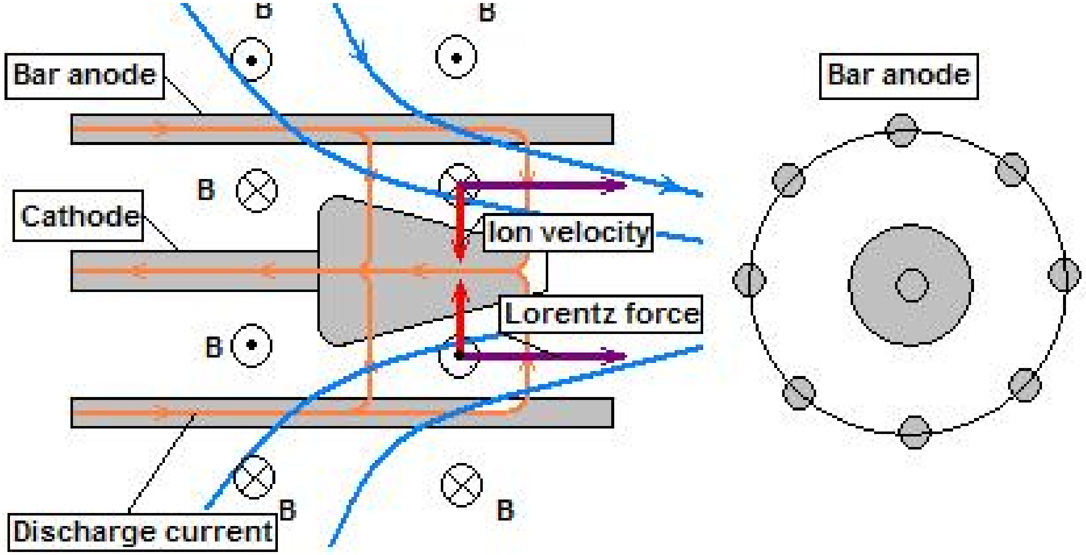
- **Future MHD-Plasma Jet Propulsion based on Miniature Magneto-Plasma Flux Compressors with *50 kN/ sqm* and *10 – 20 N/kW***





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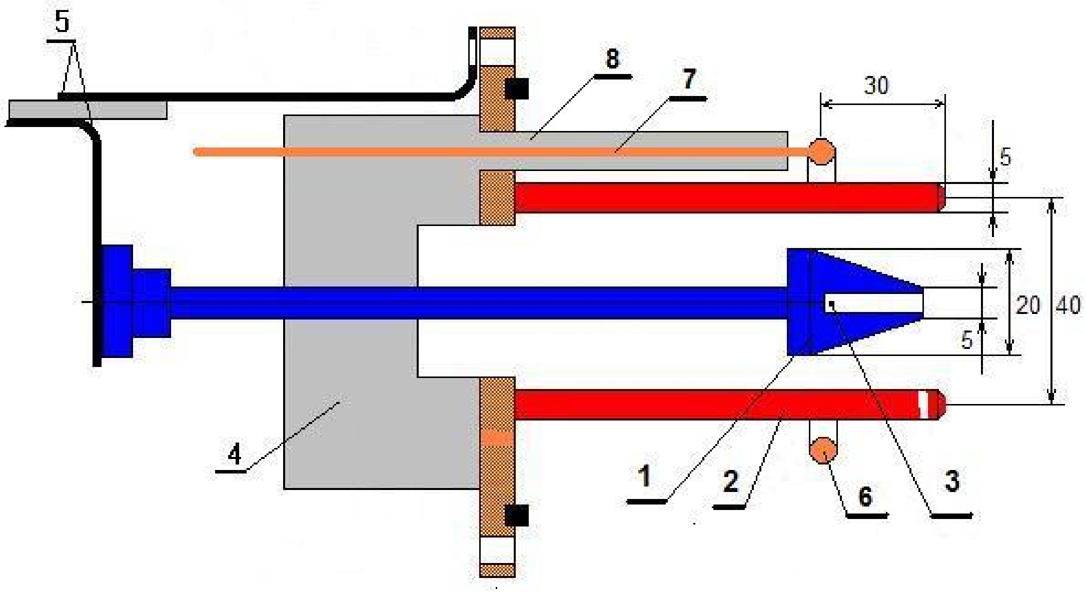
1- cone cathode
2-bar cylindrical anode
3-cathode divertor
4-Teflon body of MPC
5-copper conductors
6-Initiating Ring electrode
7-Initiating circuit
8-Isolator for eliminating of par discharges



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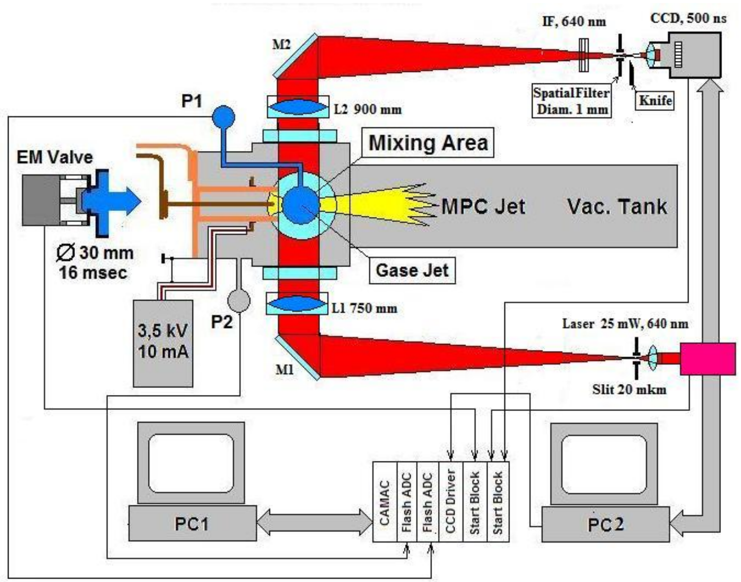
The scheme of Schlieren system, auxiliary discharge circuit and synchronization circuits for checking of mixing processes between the supersonic flow in impulse wind tunnel and hypersonic plasma jet, created by Magneto-Plasma Compressor.



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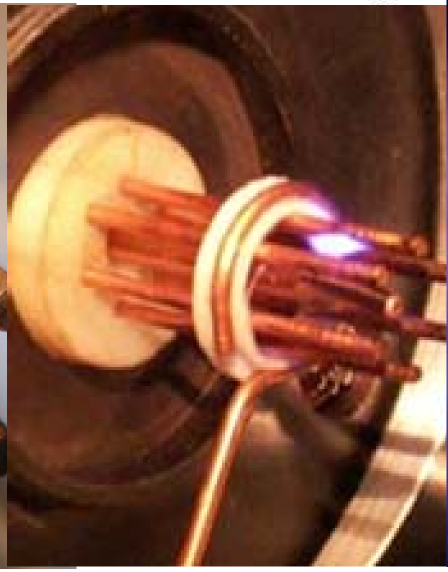

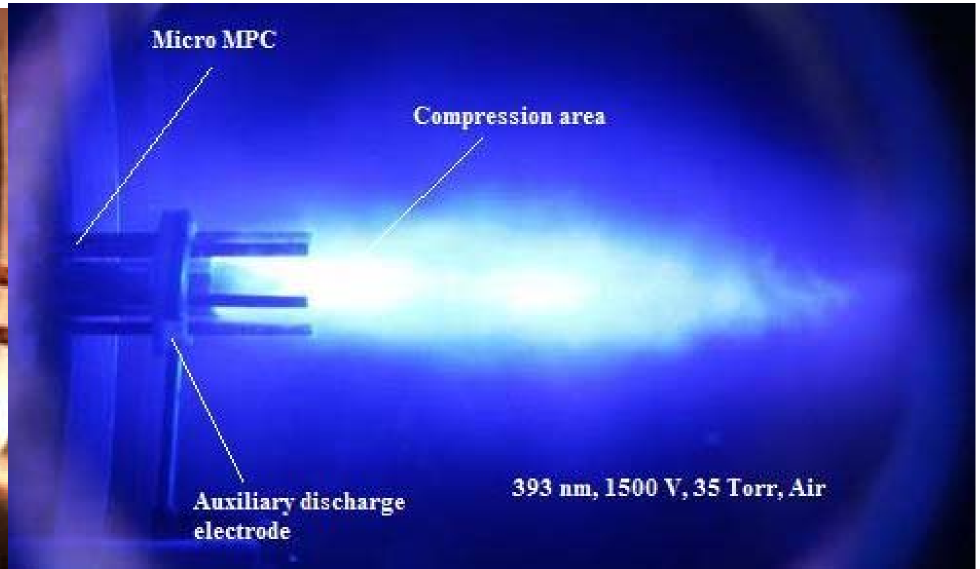

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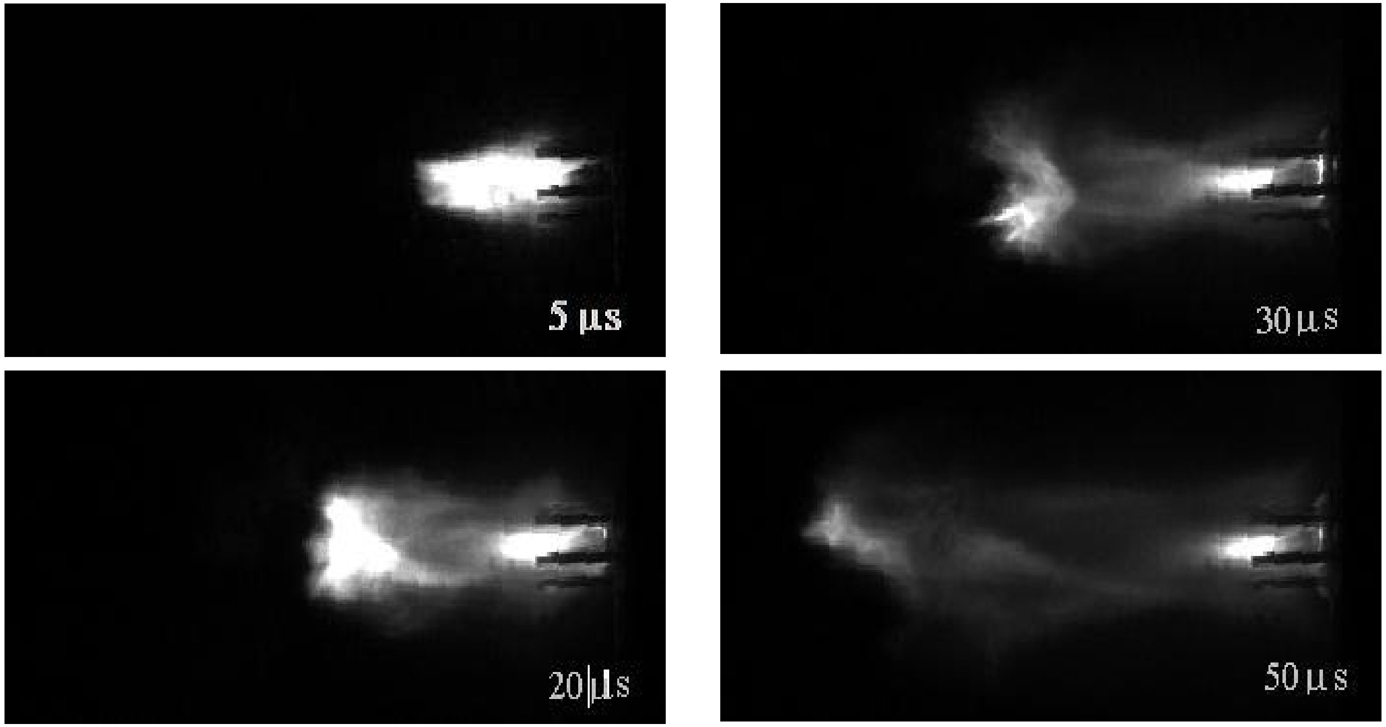

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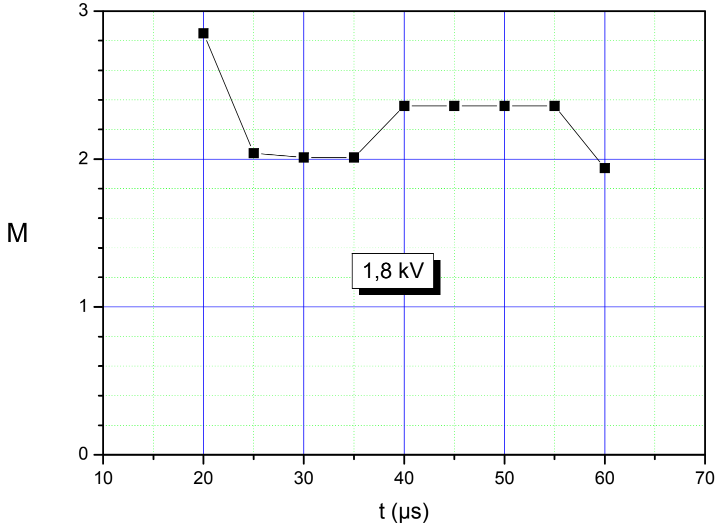

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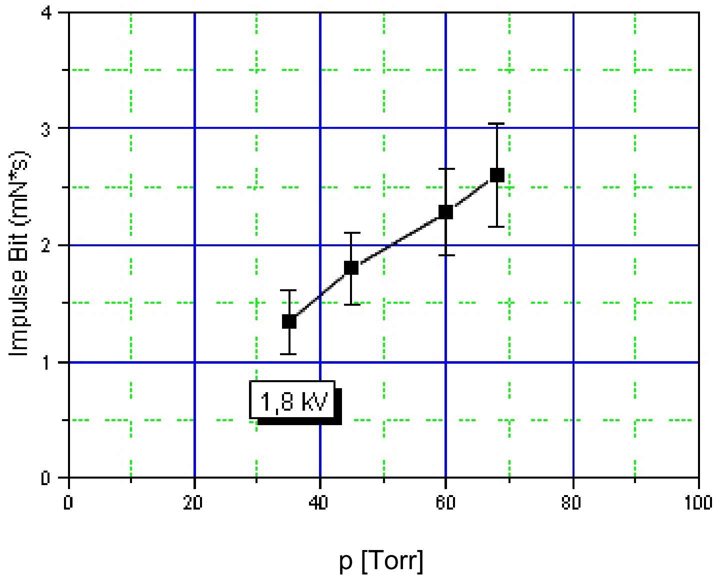

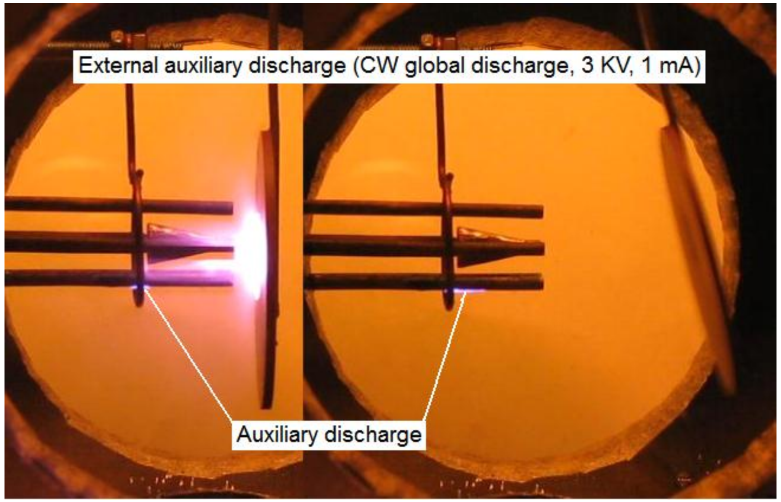

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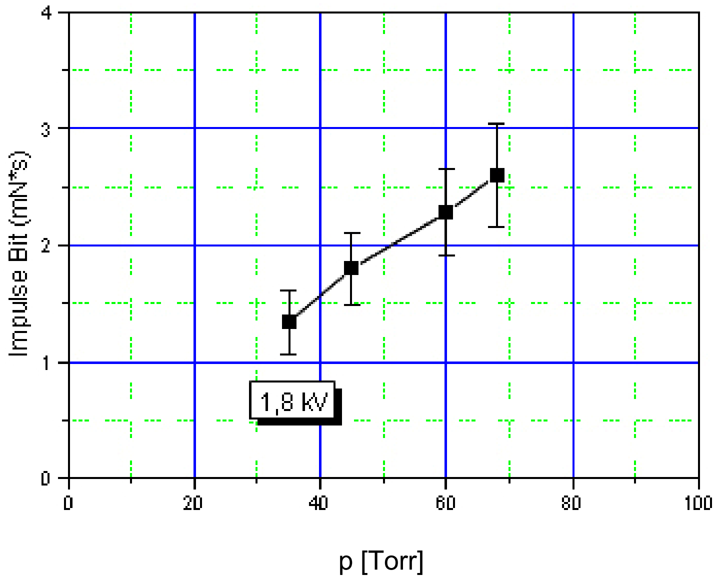

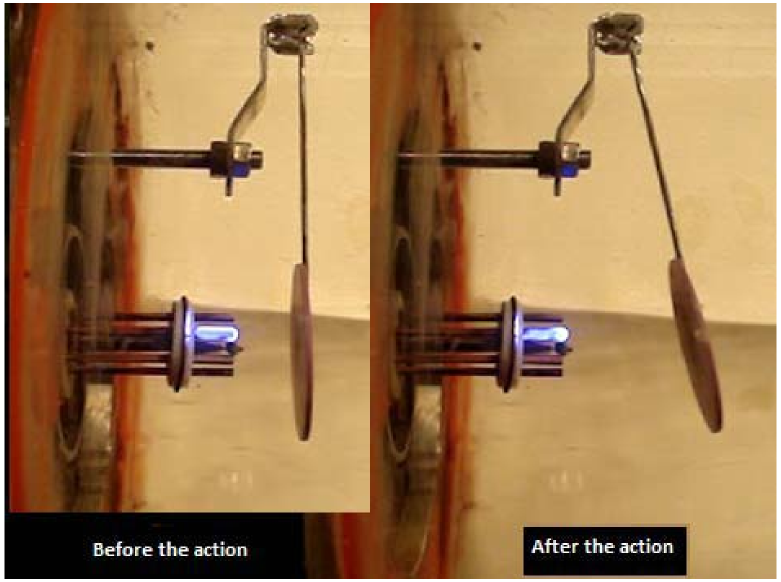

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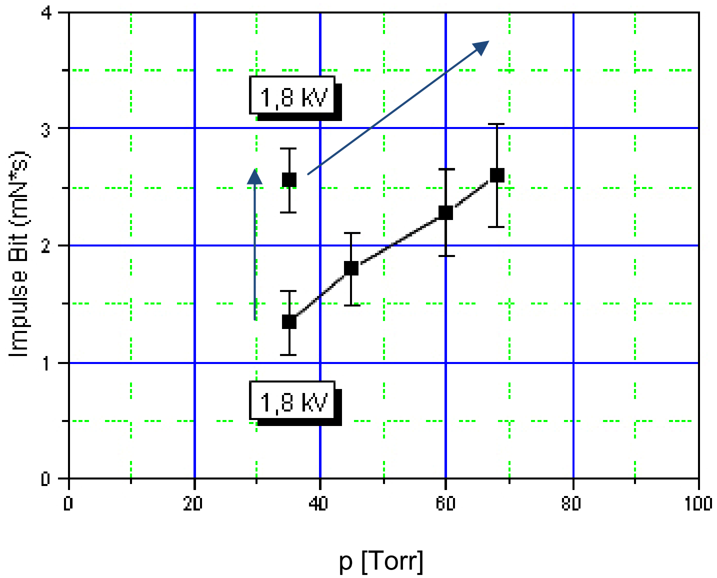

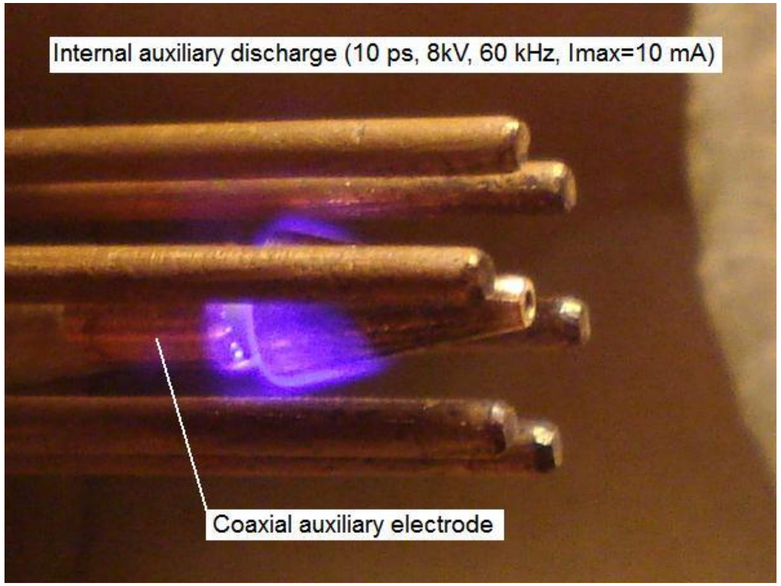

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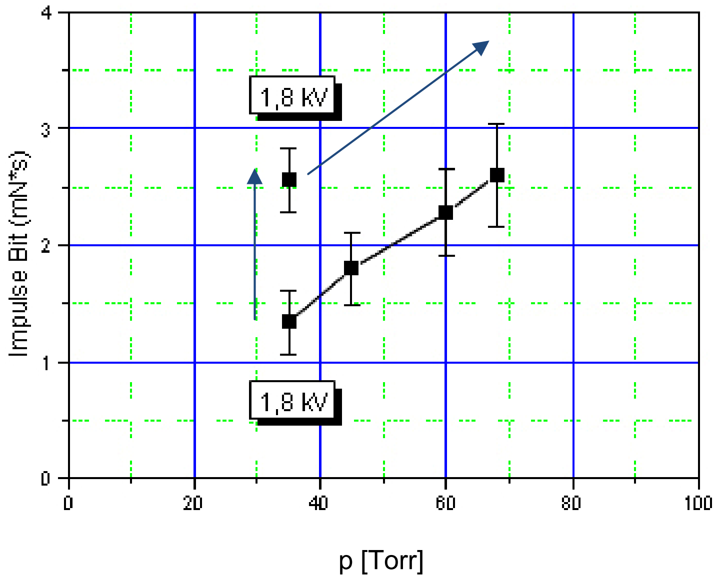

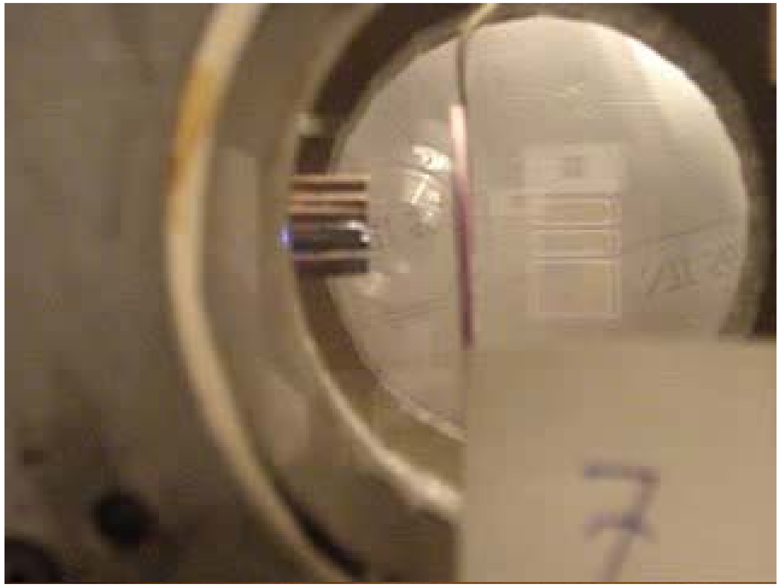

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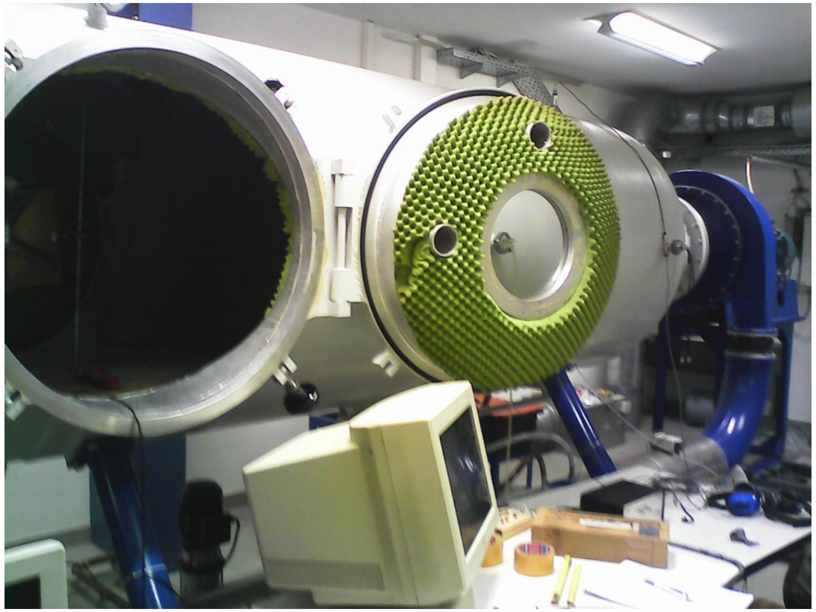

M. Tajmar (Vacuum Wind Tunnel, TU Dresden, 2012)

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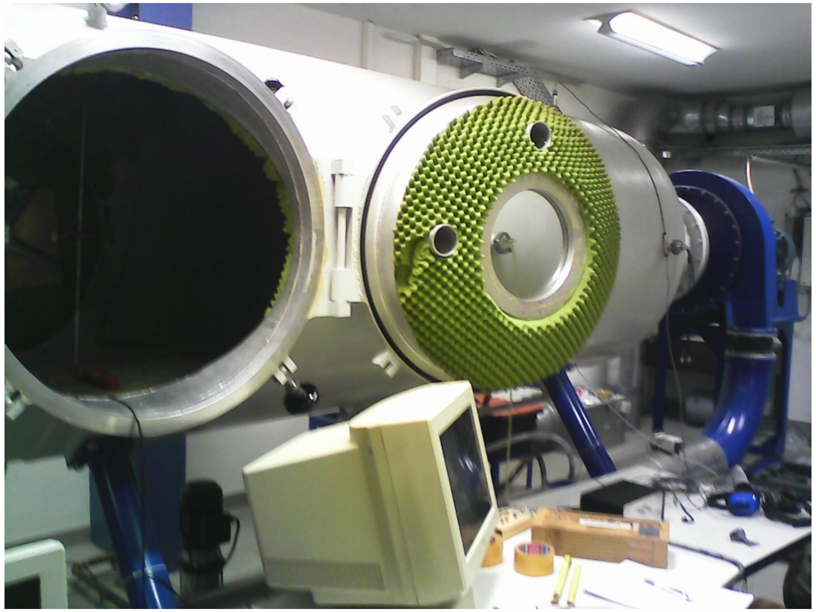

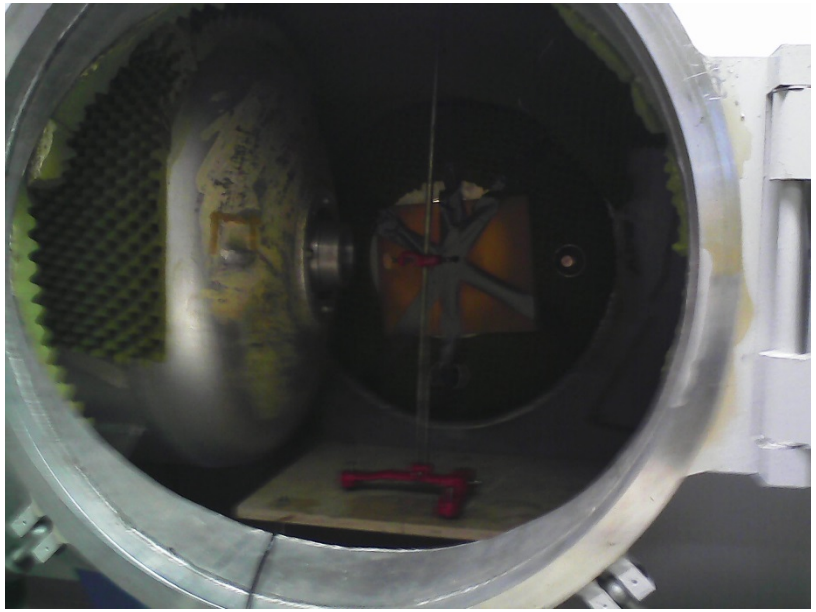

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The parameters of generators necessary for the MHD plasma jet propulsion system are:

- Peak current up to 20kA
- Pulse voltage up to 1 - 5 kV
- Pulse duration 50 – 100 μs
- Repetition rate up to 1 kHz

Such a generator will be made based on of Reversely Switch on Dynistor (RSD). RSD is a four layer thyristor like power semiconductor device. The switching capabilities of RSD are in few times higher than these of the best modern pulse power thyristors. For example 76mm wafer diameter RSD has more than 2kV blocking voltage and can commutate up to 300kA peak current with up to 50 kA/μs current rise rate. RSD has been designed for microsecond range power pulse application.

Megaimpulse Ltd.

Outline

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- *Electrohydrodynamic (EHD)* Pulsed Propulsion based on Sliding Corona Discharge with Ferroelectric Field Electron Emission
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- Combined Distributed EHD-MHD Fan Propulsion
- Conclusions and Outlook

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Combined Plasma Propulsion

Combined Distributed EHD/MHD Fan Propulsion for Higher Efficiency

- **EHD Drive with 1 – 10 N/sqm as Low-Speed Fan of the High-Speed MHD Core Propulsion with 10 – 50 kN/sqm**
- **EHD Drive's Electrostatic Oscillations or Pulses are used for MHD Preionization to Increase Core Propulsion Efficiency**
- **MHD Core with Diameter between 10 – 40 mm, EHD Fan with Diameter 80 - 120 mm**
- **Distributed Plasma Jet Propulsion with 100 Thruster Units on Trailing Edge of Aerodynamic / Aerostatic Platforms → Total Thrust of 500 N and More Upscaling**

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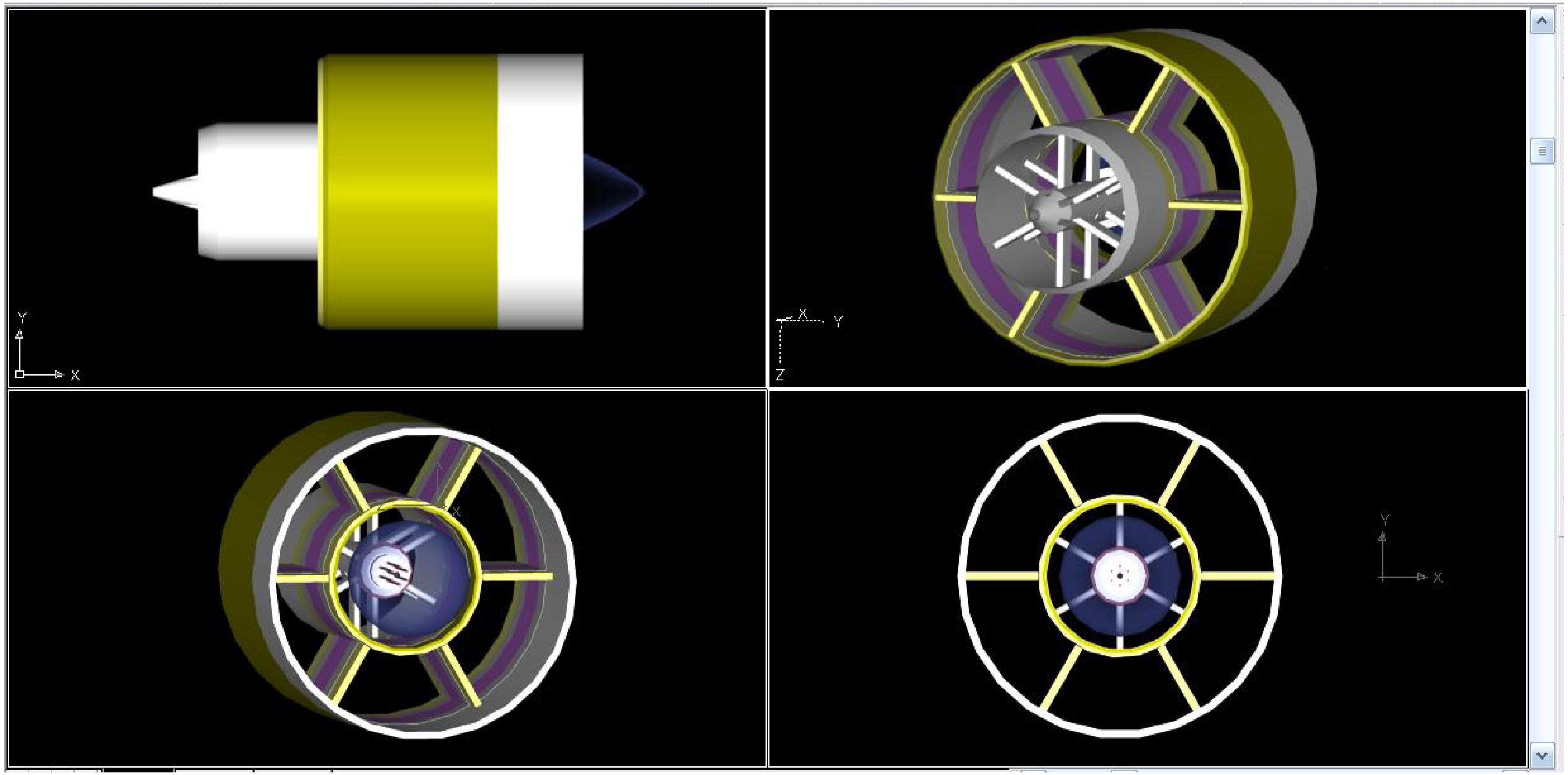

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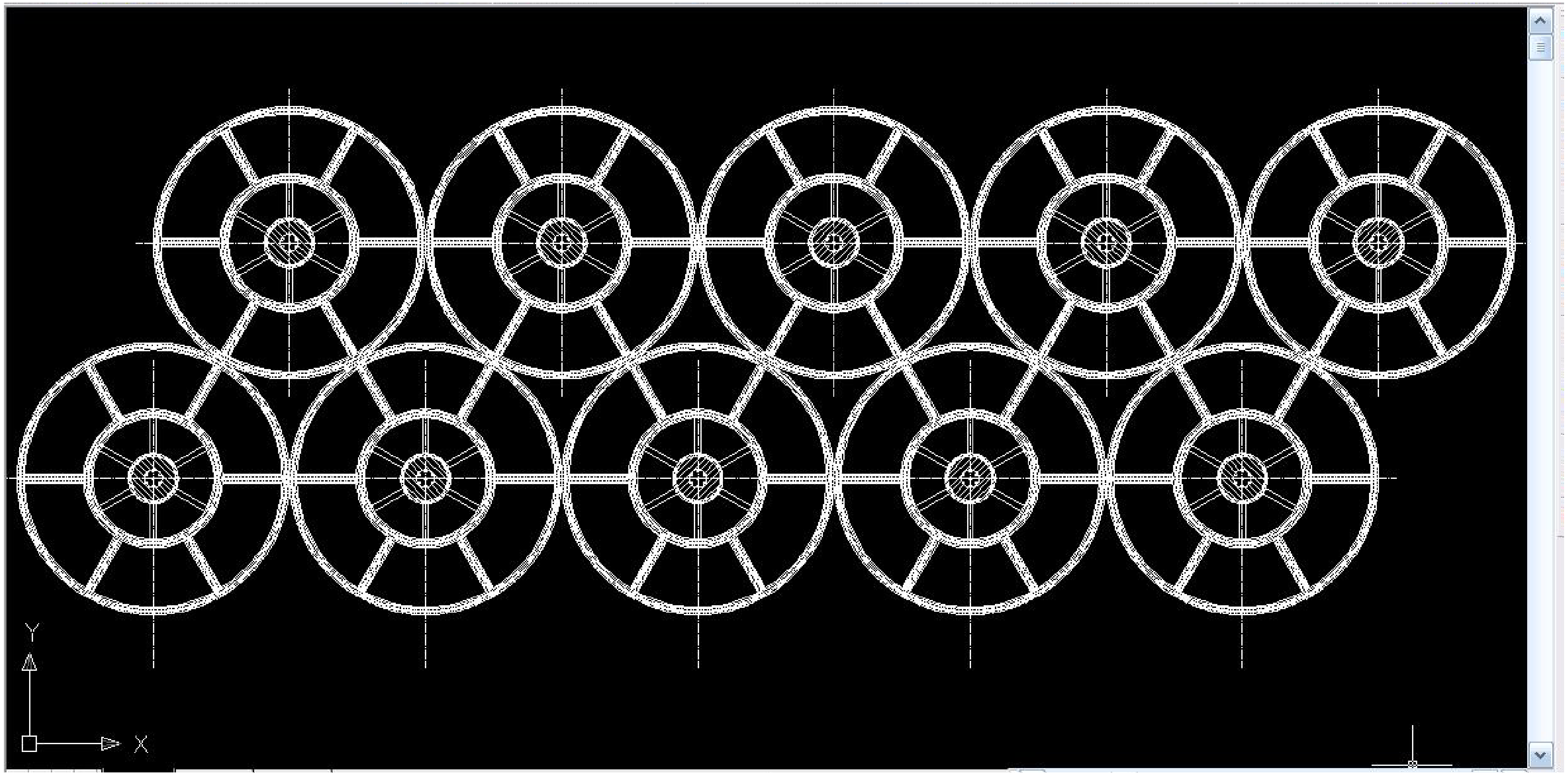

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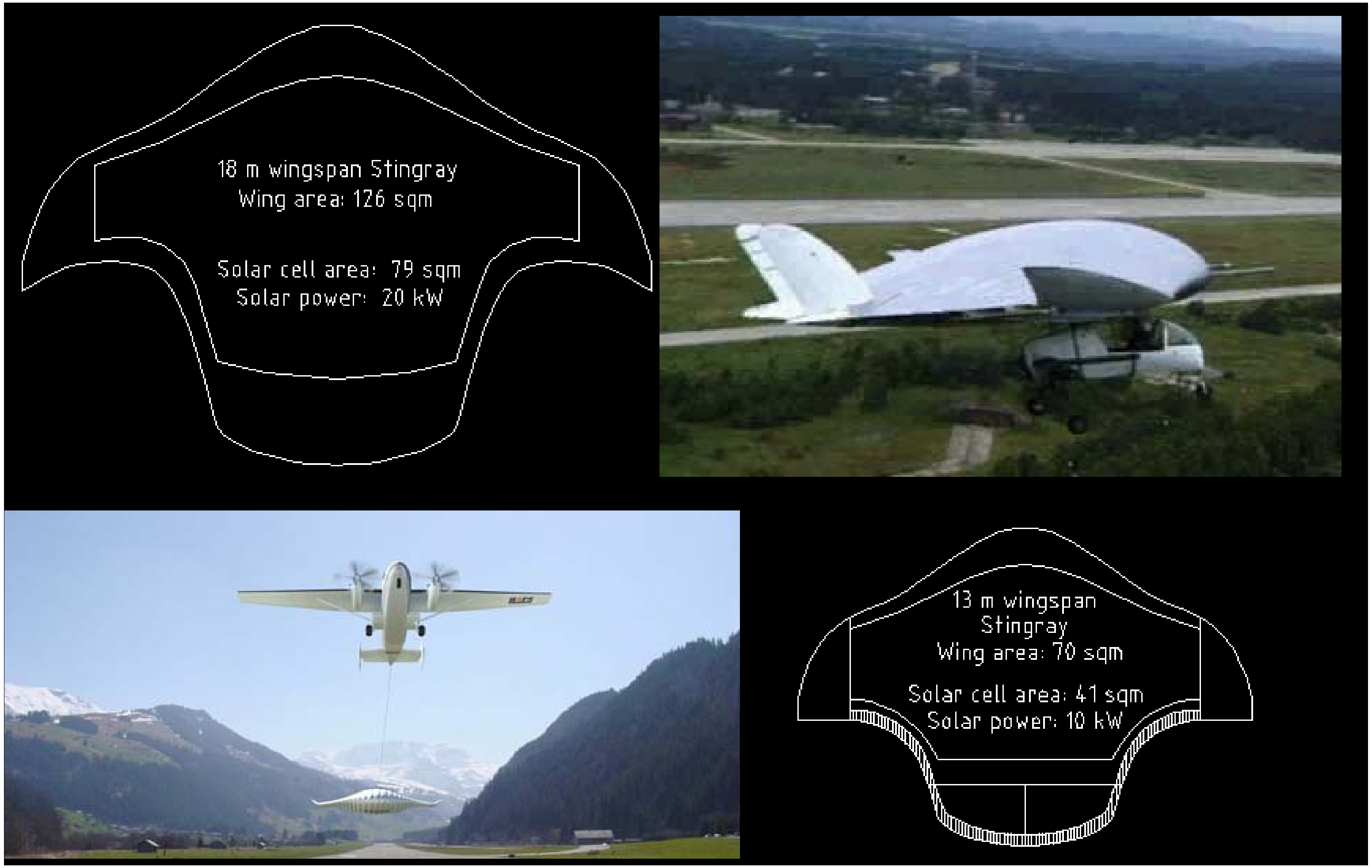

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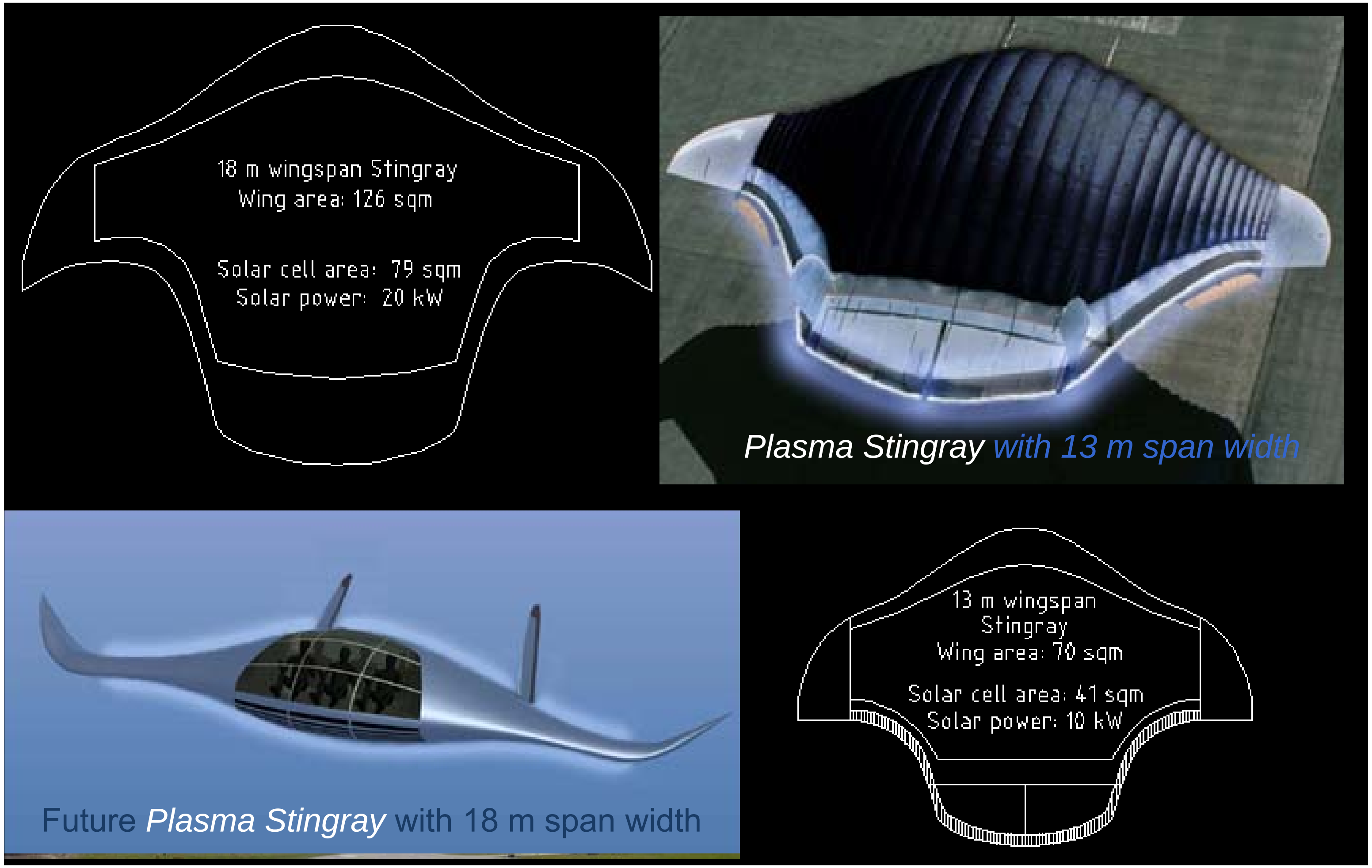

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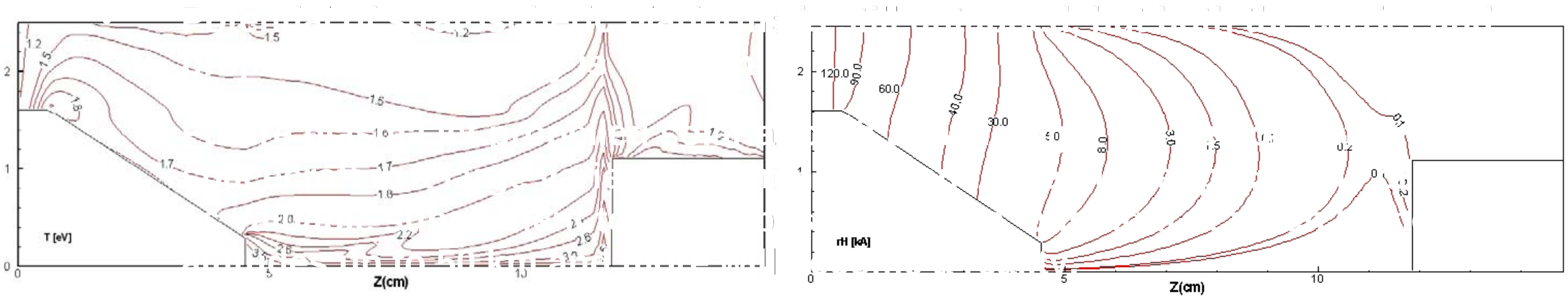

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- **Before, however, plasma jets can be successfully employed on future solar flyers, the thrust-to-power and thrust-to-area rations have to be optimized using *numerical tools*, vacuum test chambers simulating high-altitude flight conditions and new lightweight solid-state high-voltage power supplies.**
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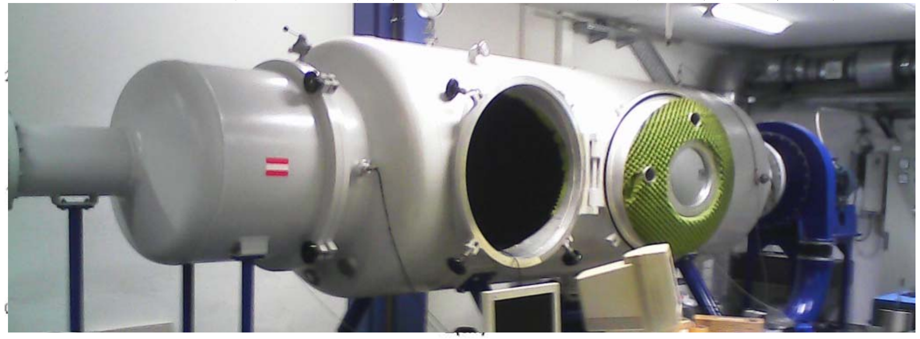
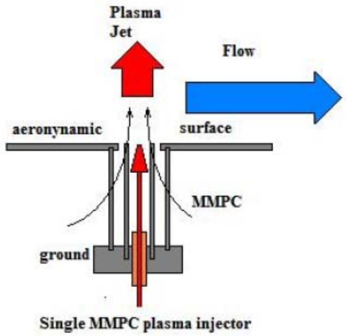
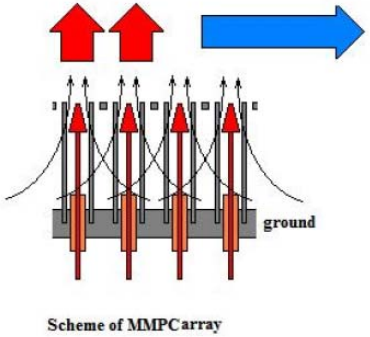
Conclusions and Outlook







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Thank You for Your Attention

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