ACTIVE CONTROL OF NEARWALL FLOW IN SUBSONIC DIFFUSER UNDER THE INFLUENCE OF PLASMA

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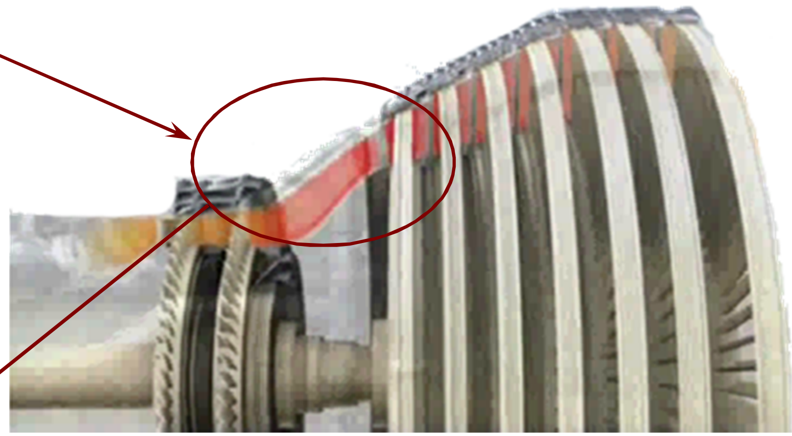
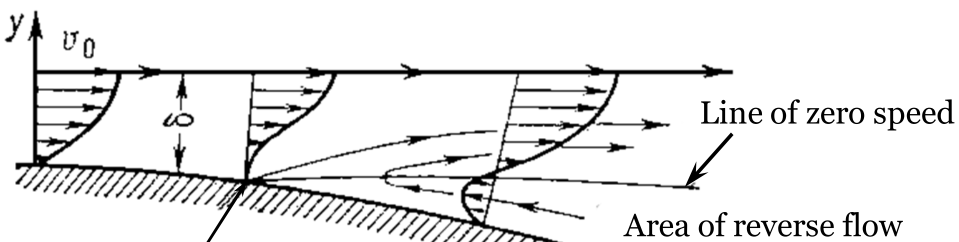
Necessity flow control

The appearance of separated areas flow in transient channels of turbojet engines

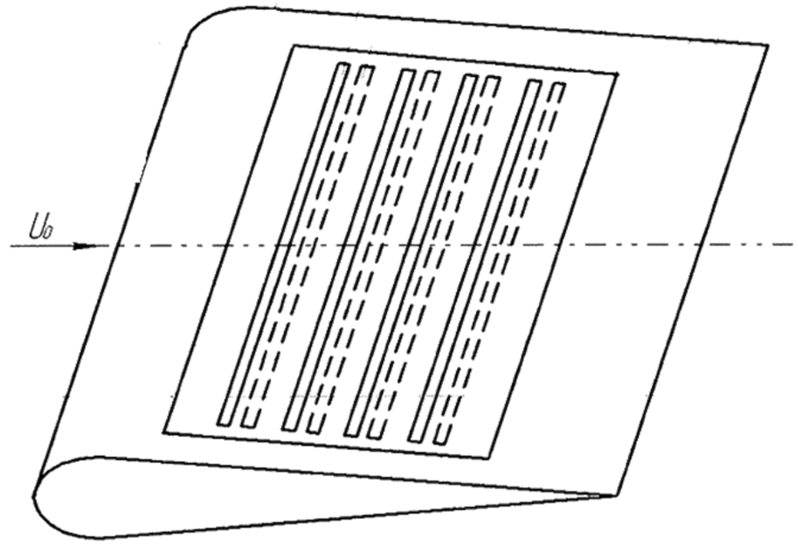


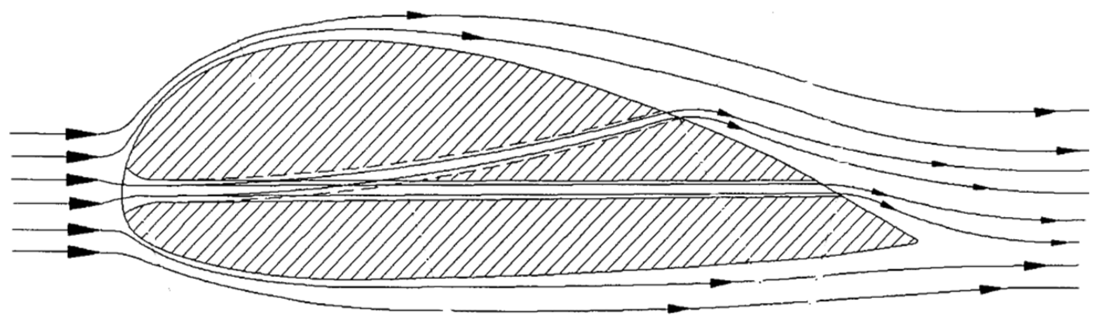
$M_{in}=0.3 \div 0.5$



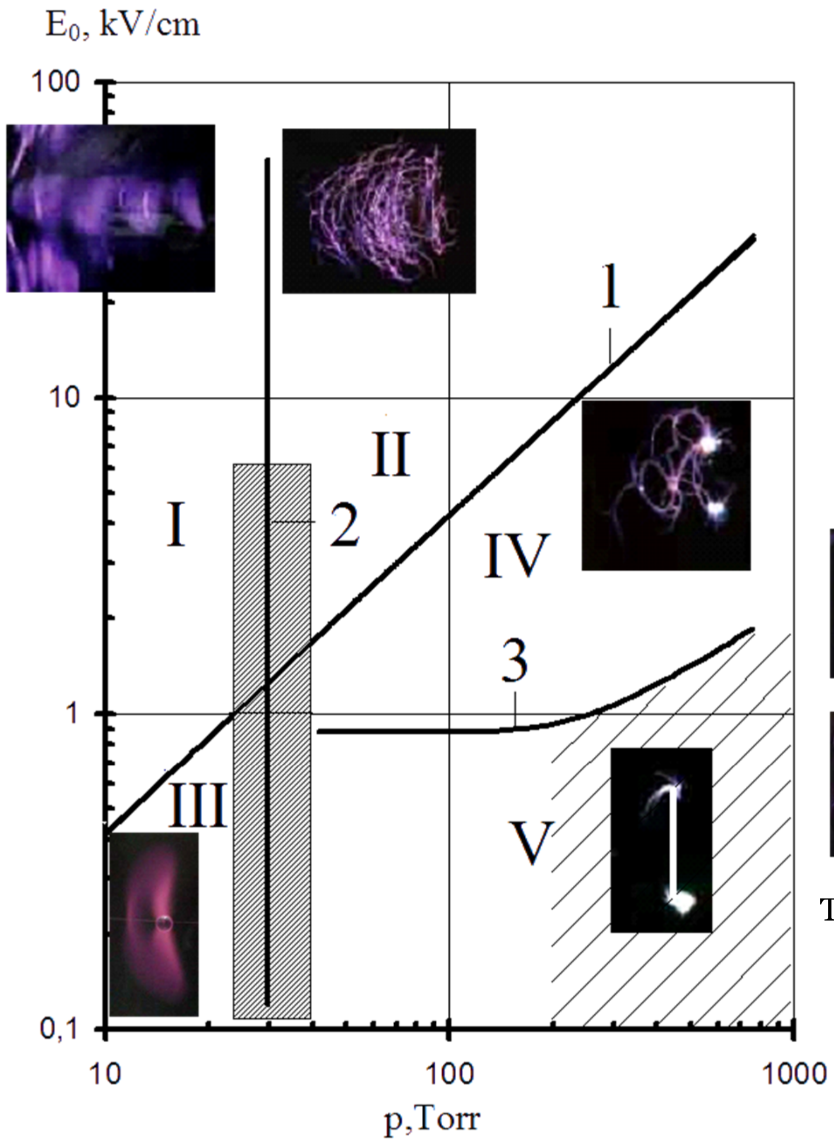
Flow control methods

- Passive gas dynamic influence
  - *Profiling channels*
  - *Installing interceptors*
- Active influence
  - *Injection, bleeding*
  - *Dielectric barrier discharge*
  - *Synthetic jet*
  - *Microwave plasma discharge*





Microwave plasma discharge



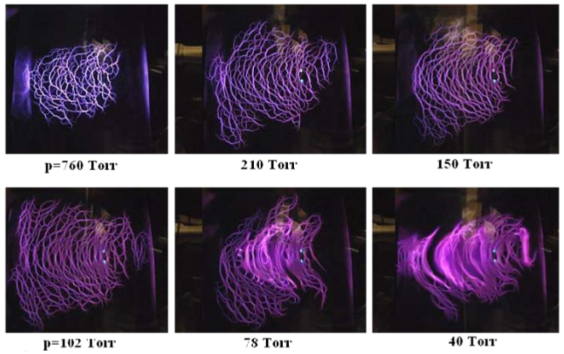
I. Supercritical diffuse discharge

II. Supercritical streamer discharge

III. Subcritical diffuse discharge

IV. Subcritical streamer discharge

V. Deep subcritical streamer discharge



The transition from a streamer to diffuse discharge with decreasing pressure

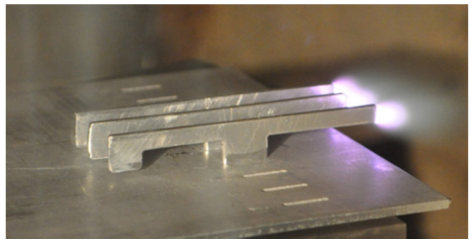


Photo of microwave discharge

P^*_∞ = 1 atm, T^* = 290 K, M=0

* Abstract of dissertation for the degree of Doctor "discharges in gases medium and high pressure in the quasi-optical electromagnetic wave beams the microwave range," I. Esakov

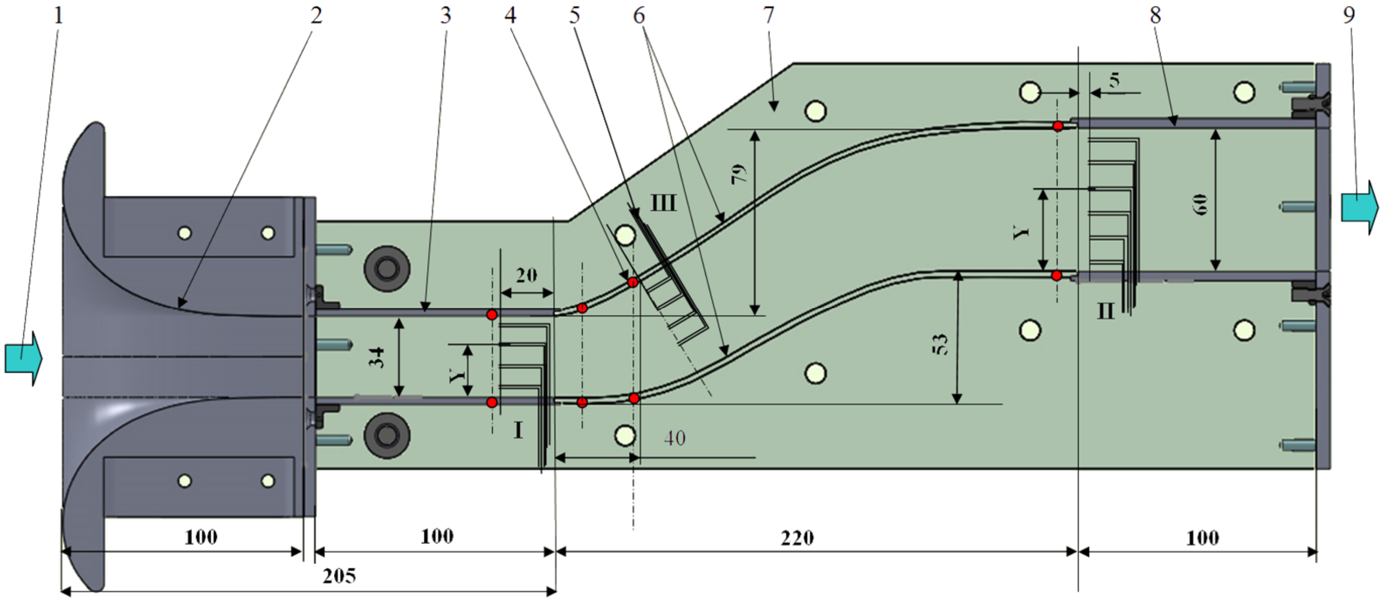
Advantages of microwave discharge application

- High efficiency energy input power supplies into the discharge
- Proven production technology, simplicity and cheap equipment
- Instantaneous energy supply
- Possibility localization of energy input area
- Possibility of pulse-continuous operation mode realization to reduce input power levels

Problems of microwave discharge application

- High erosive effect on the electrode material
- Desirable presence of free electrons source for initiation of stable plasma discharge
- Mass-dimensional limitations of microwave equipment and waveguide schemes in a practical application
- Influence of the electrode unit and applied channel constructive performance (dimensions, placement, material and etc.) on initiation of discharge and stability operation

Experimental model



Experimental conditions

P^*_∞ = 1 atm, T^* = 290 K

M_{in} = 0.1 – 0.8

Re_{in} = $(1,2 – 8,5)\times 10^5$

$\tau_{discharge}$ = 100 – 300 µs

f_{pulse} = 100 – 200 Hz

S = $(1\text{-}6) \times 10^{-4}$

$U_{magnetic}$ = 180 – 200 V

P_{pulse} = 6 kW

E_0 = 400 V/cm

λ_{wafe} = 12,4 cm

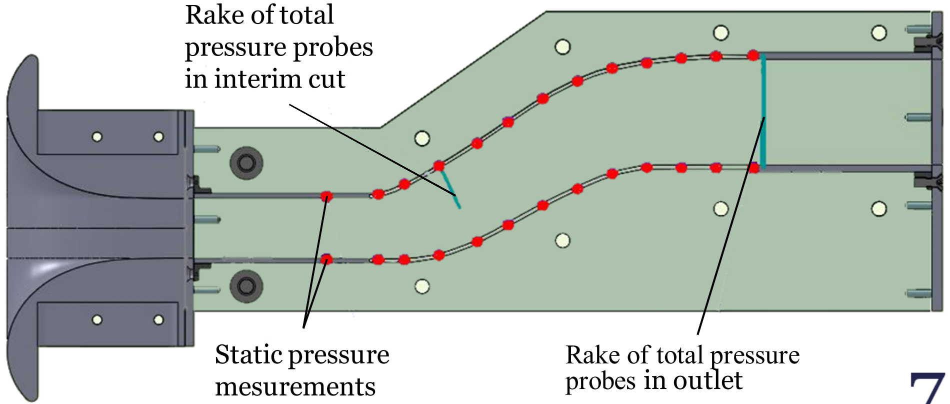
Channel diffuser ratio – 1,76

Scheme of test channel

1 - taken air from the atmosphere, 2 - lemniskate intake, 3 - straight section, 4 - receiver of static pressure, 5 - total pressure probes , 6 - a curved part of channel, 7 – sidewalls, 8 - smoothing section, 9 – to suction exhauster machines

Measurement accuracy of pressure sensors "Honeywell" (0.3-0.8) %

Arrangement of receivers pressure



Experimental model

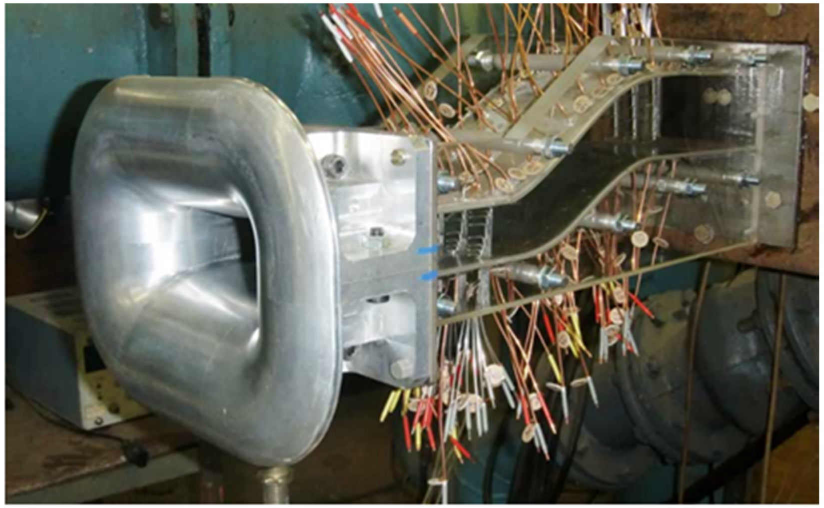


Photo of channel installed in CIAM's test facility

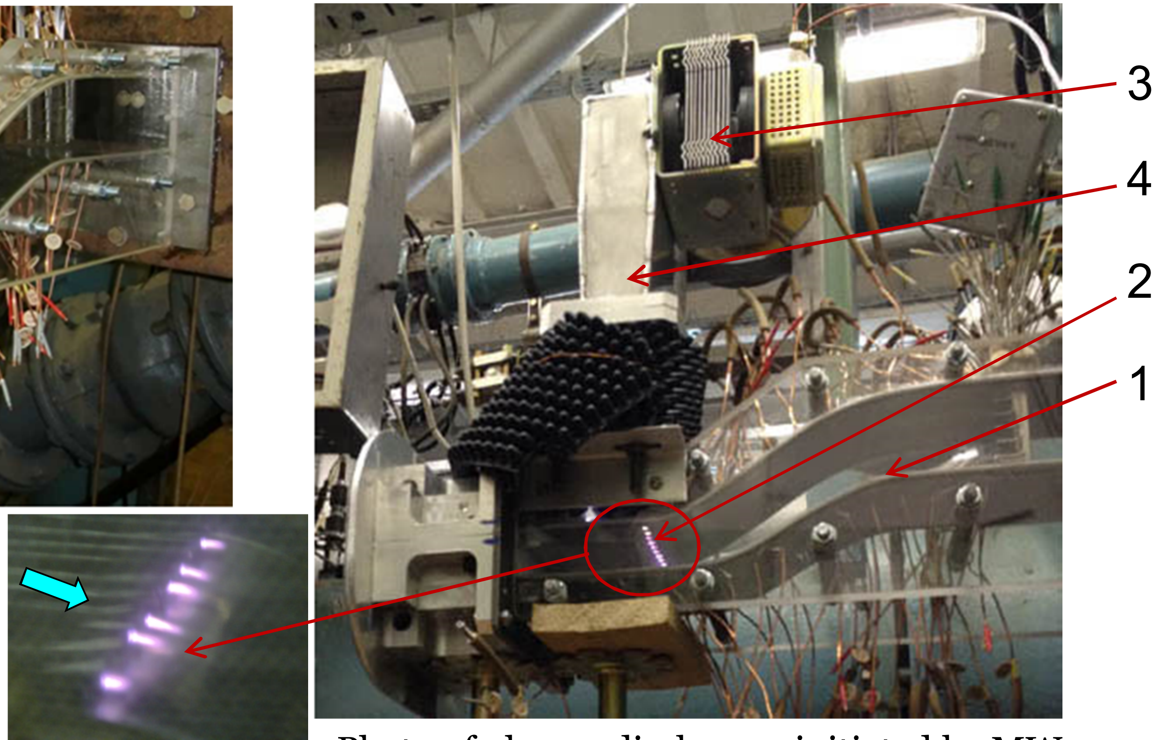


Photo of plasma discharges initiated by MW radiation in the flow at $M_{in} = 0.5$

1 – tested channel, 2 – MW plasma discharges, 3 – magnetron, 4 – waveguide

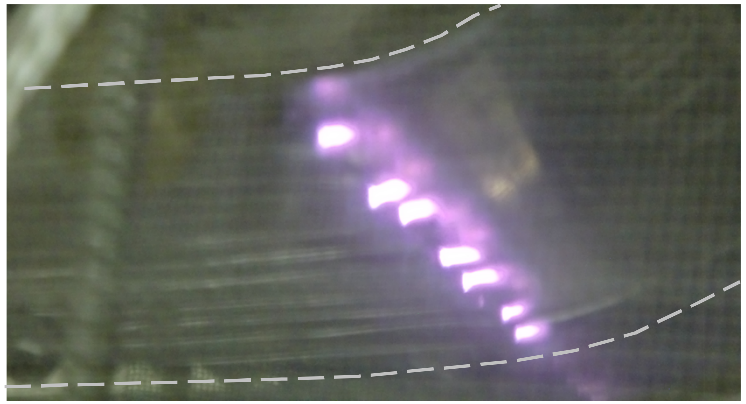
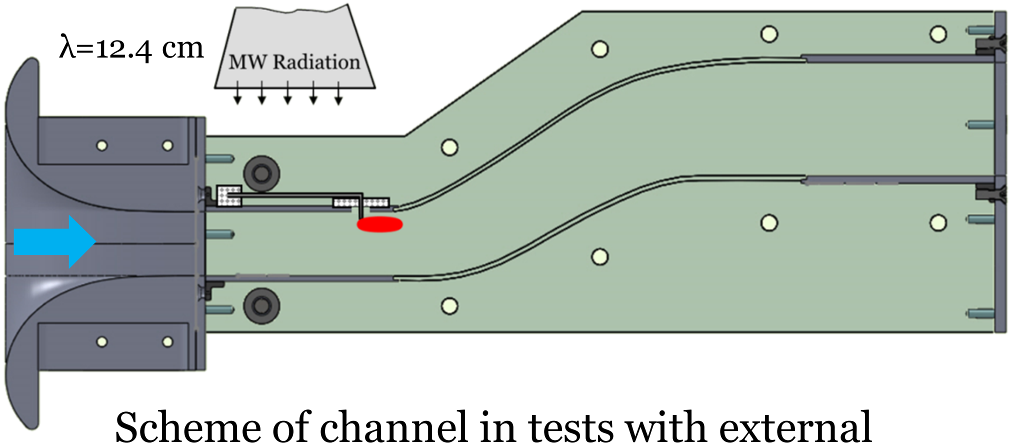


Photo of discharges initiated by MW radiation at incoming flow

$M_{in} = 0.8, f = 200$ Hz, $\tau = 300$ μs

Scheme of electrodes installation



Scheme of channel in tests with external adjustment of the electrodes

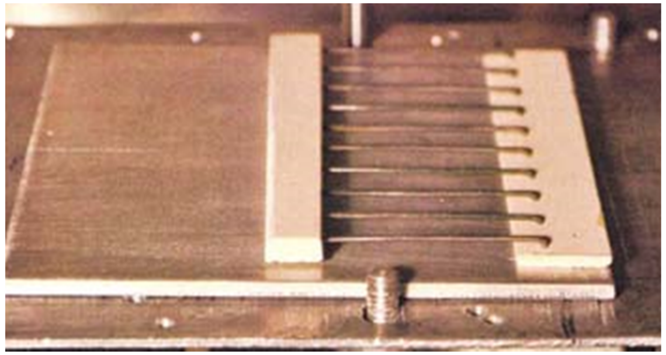
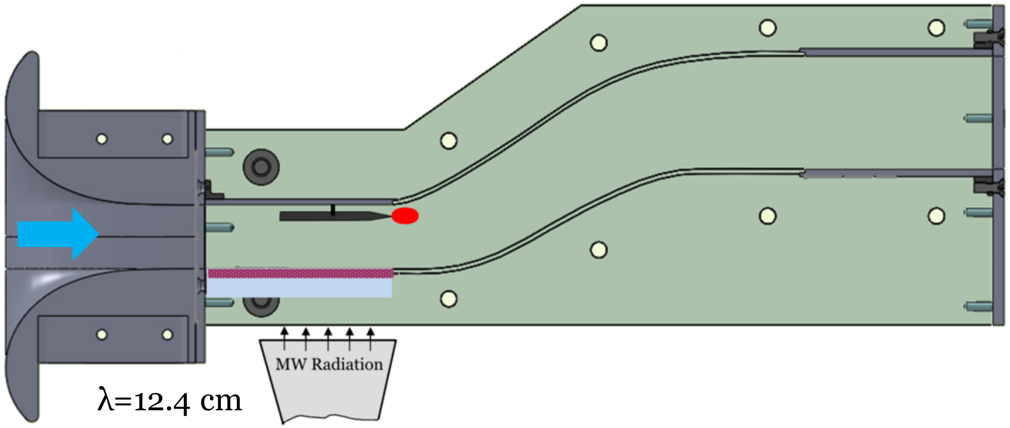
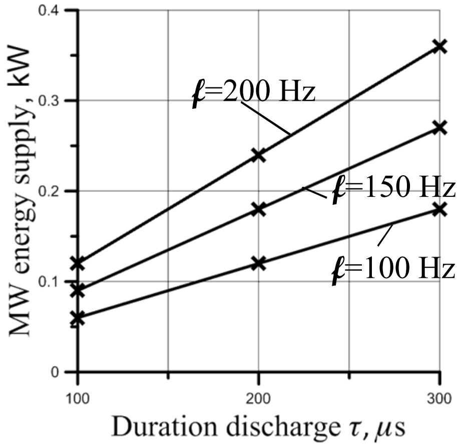


Photo of the electrodes with the external installation



Scheme of channel in experiments with internal adjustment of the electrodes

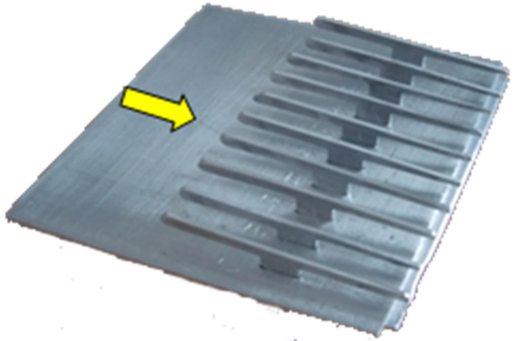


The levels of energy supply under impulse-continues mode operation

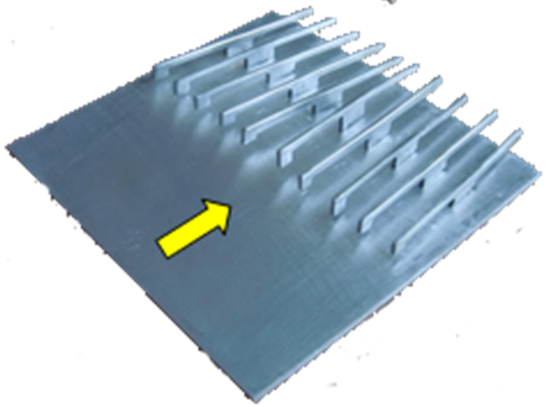
M	P_{flow}, kW	P_{flow}/P_{MW}
0.1	40.2	0.1-0.7
0.2	80.7	0.2-1.3
0.4	161.4	0.4-2.7
0.6	242.1	0.7-4
0.8	323.1	0.9-5.3

The level of energy under flow for different Mach number (MW energy 60-360 W)

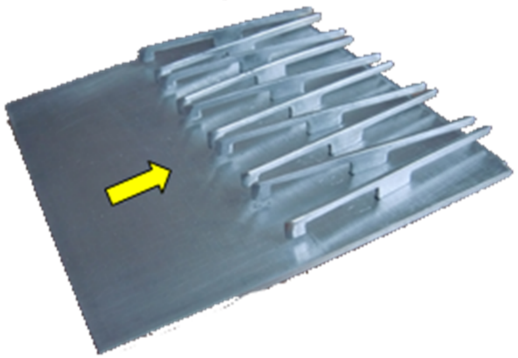
Types of electrode units



Unit №1 - a parallel arrangement of electrodes



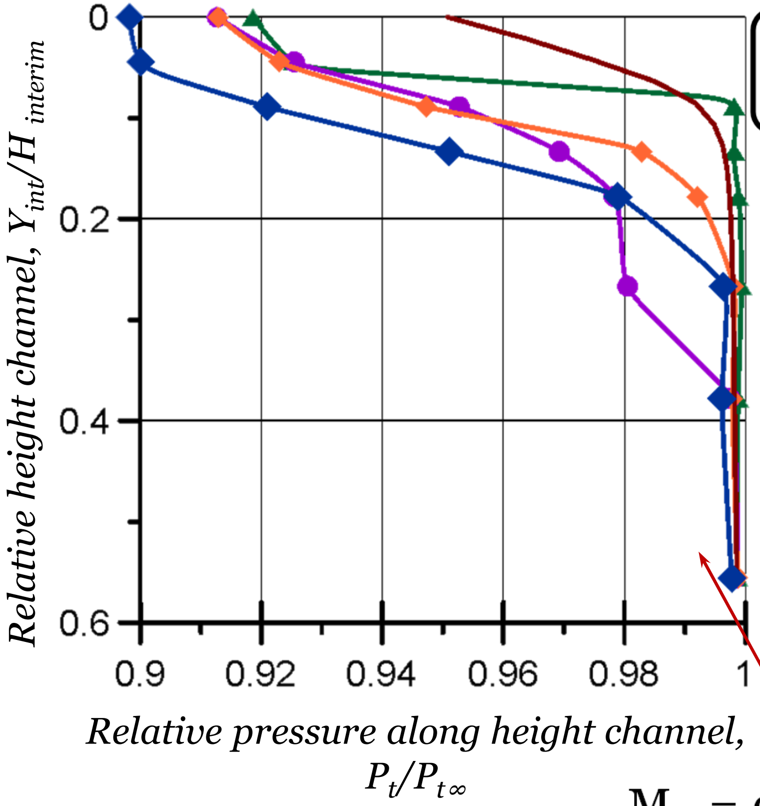
Unit №2 – a convergent arrangement of electrodes



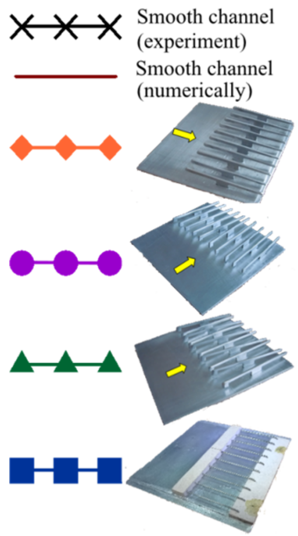
Unit №3 – a pairwise convergent arrangement of electrodes

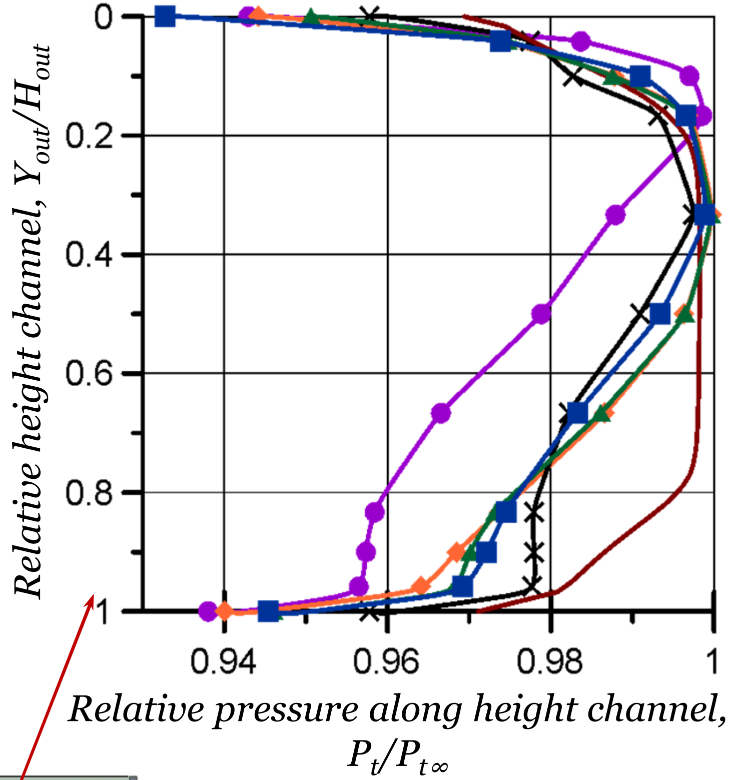
Experimental results

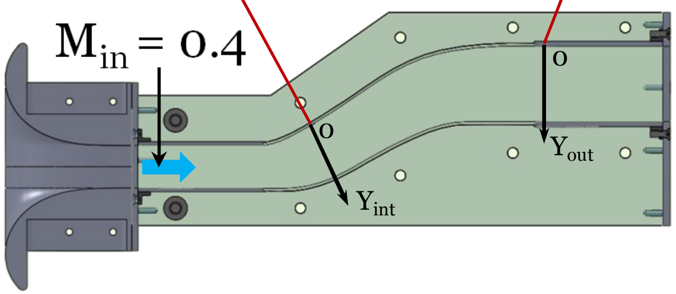
Profiles of the total pressure in the outlet and interim cuts for various configurations of electrode units



Without MW radiation







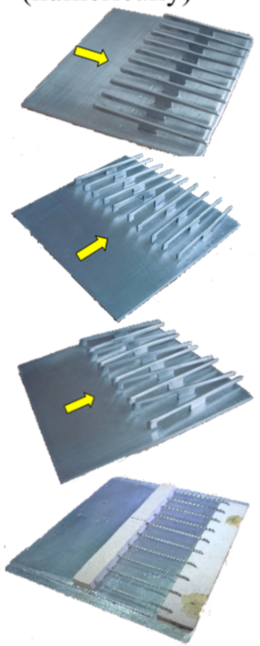
Experimental results

Distribution of static pressure on the upper and lower surfaces for various configurations of electrode units

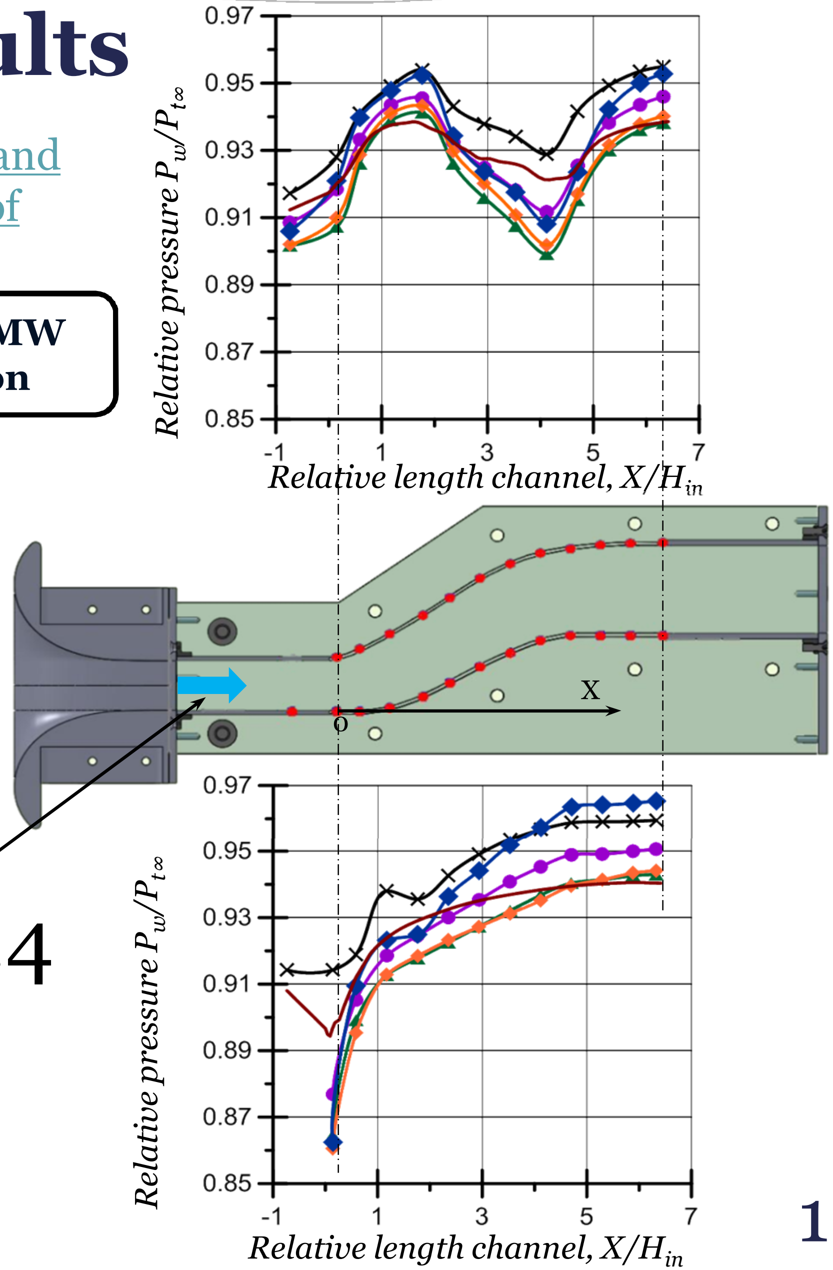
Without MW radiation

Smooth channel (experiment)

Smooth channel (numerically)

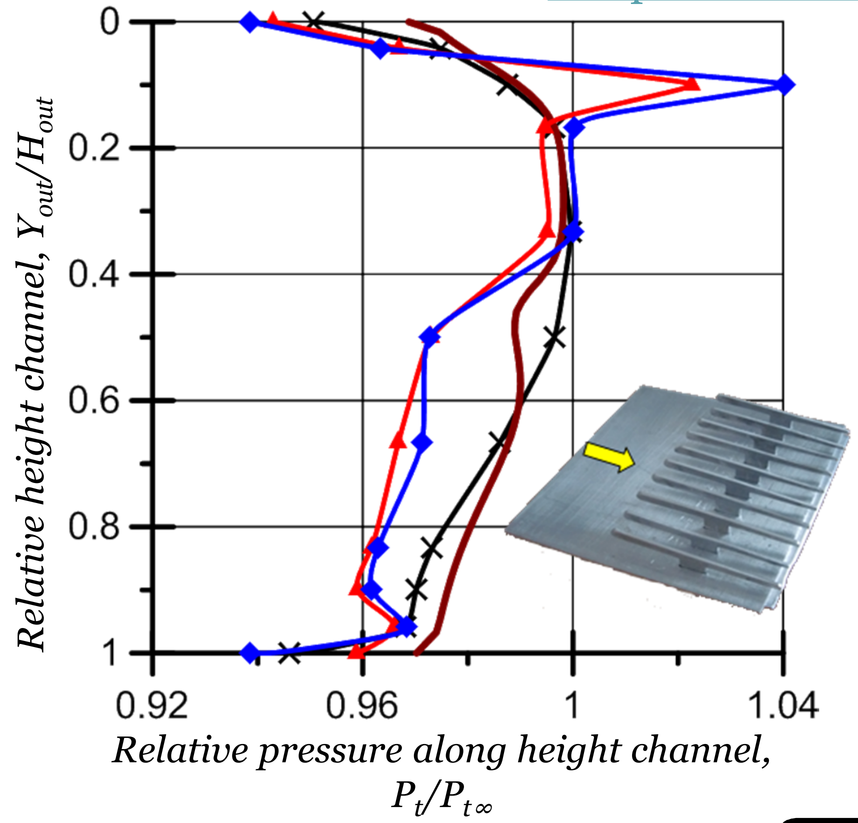


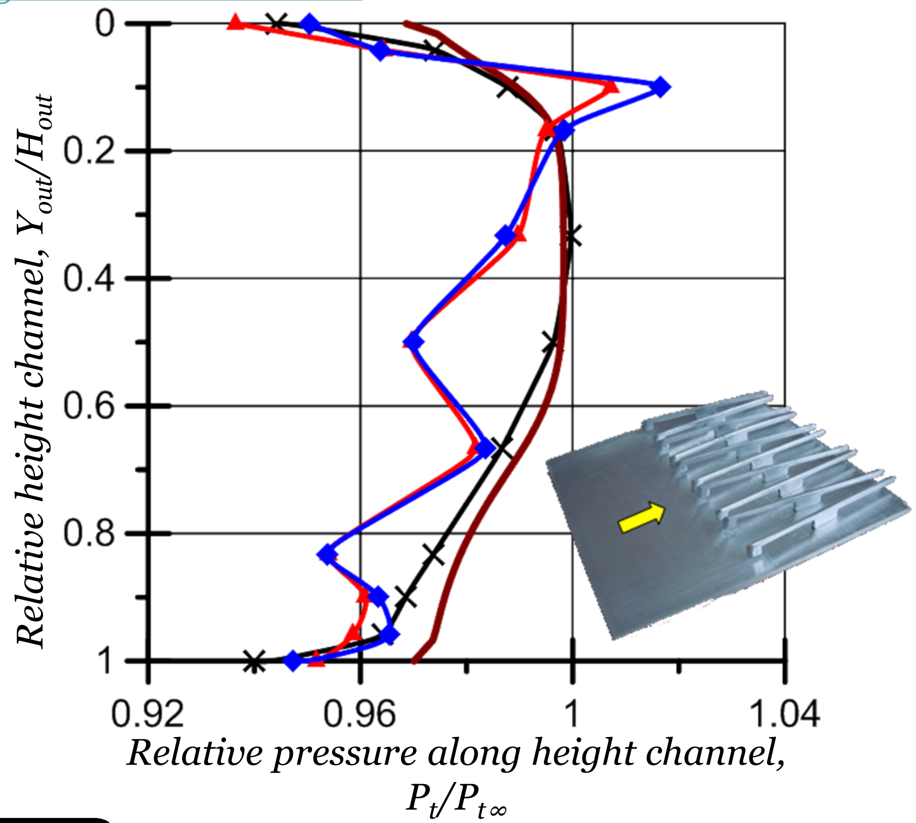
$M_{in} = 0.4$

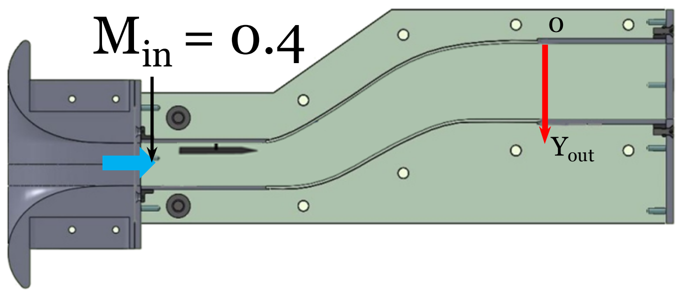


Experimental results

Profiles of the total pressure in the channel outlet with and without energy supply for parallel and pairwise convergent electrode units





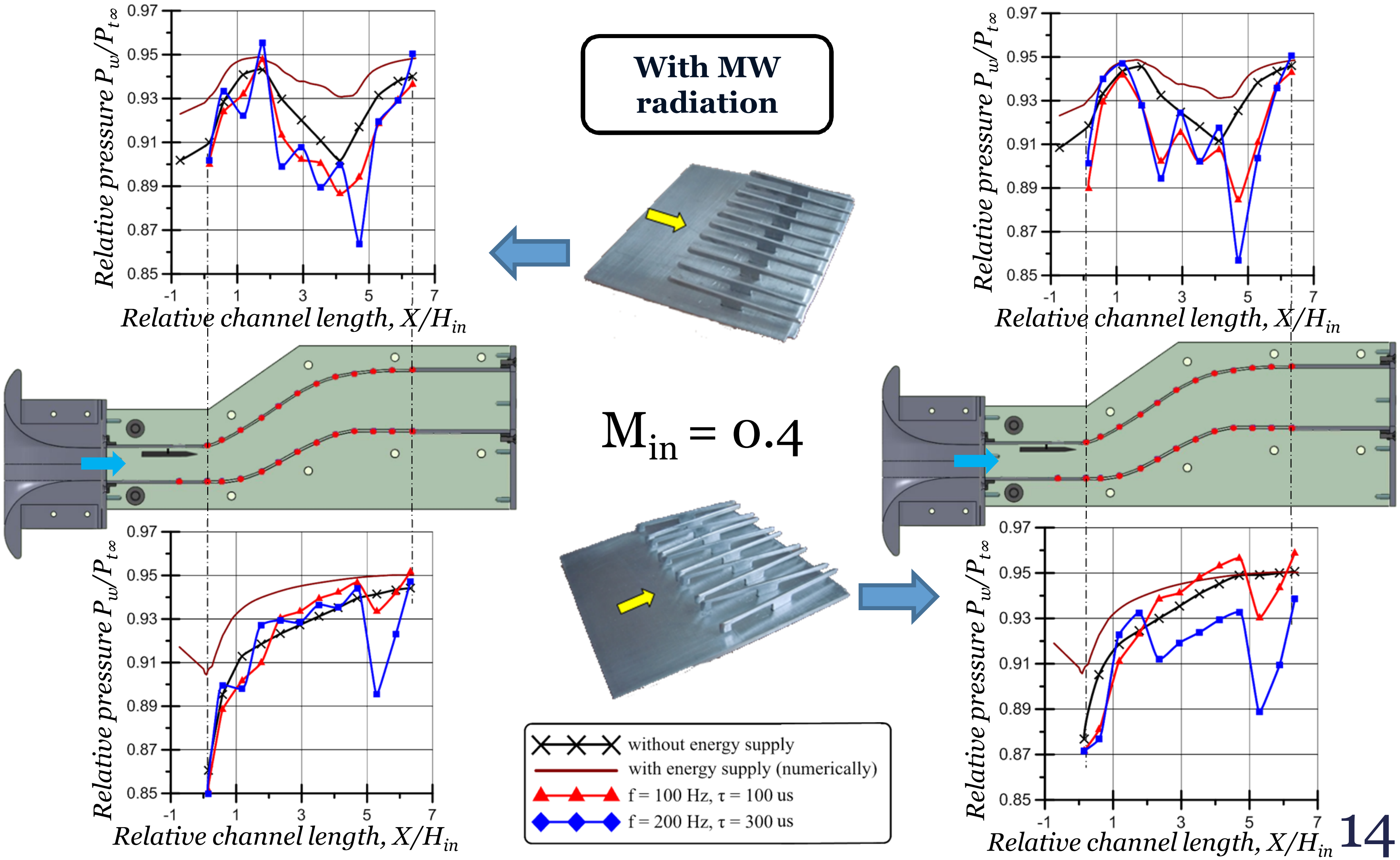


With MW radiation

- without energy supply
- with energy supply (numerically)
- f = 100 Hz, τ = 100 us
- f = 200 Hz, τ = 300 us

Experimental results

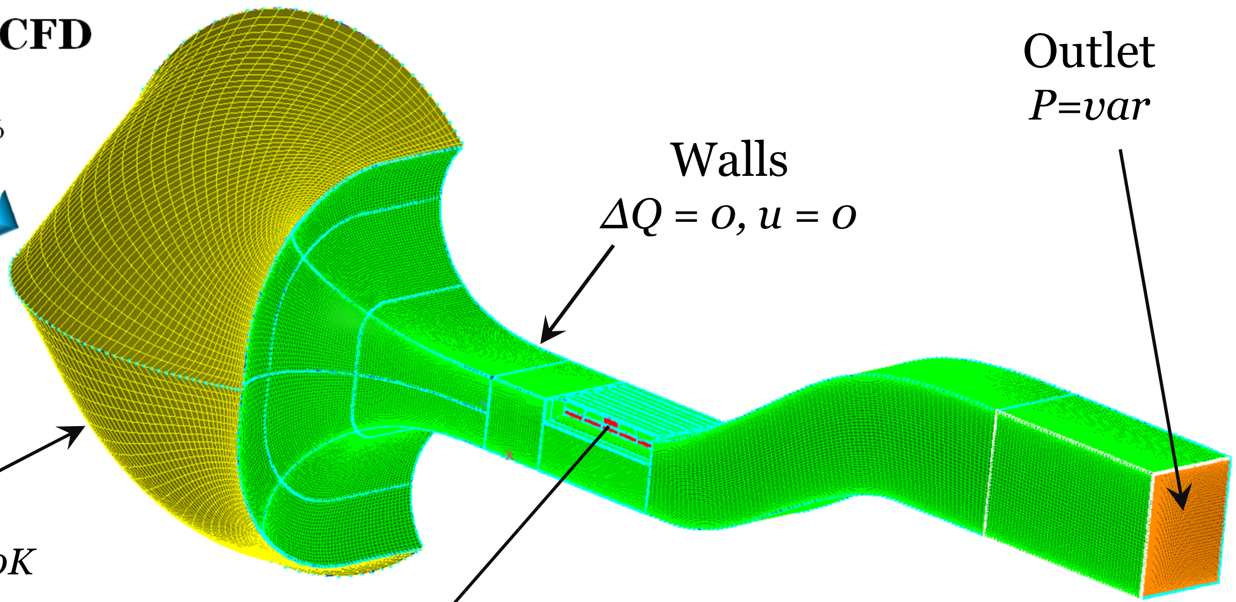
Distribution of the static pressure along the upper and lower surfaces of channel for parallel and pairwise converging electrode units with and without energy supply

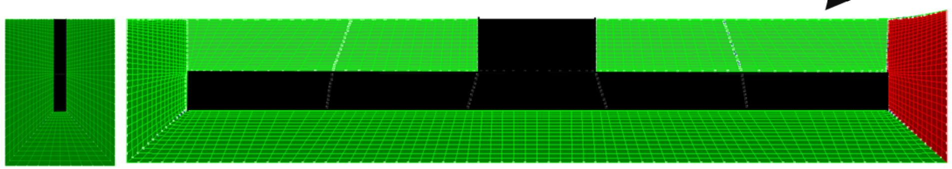


Numerical simulation of flow in the channel

A mathematical model, grid and boundary surfaces

Estimated package **ESI - CFD**
Structured mesh
Number of cells n = 2×10^6
Stationary modeling
RANS method
Gas - air, $\rho \neq$ const
Turbulence model: k-ε

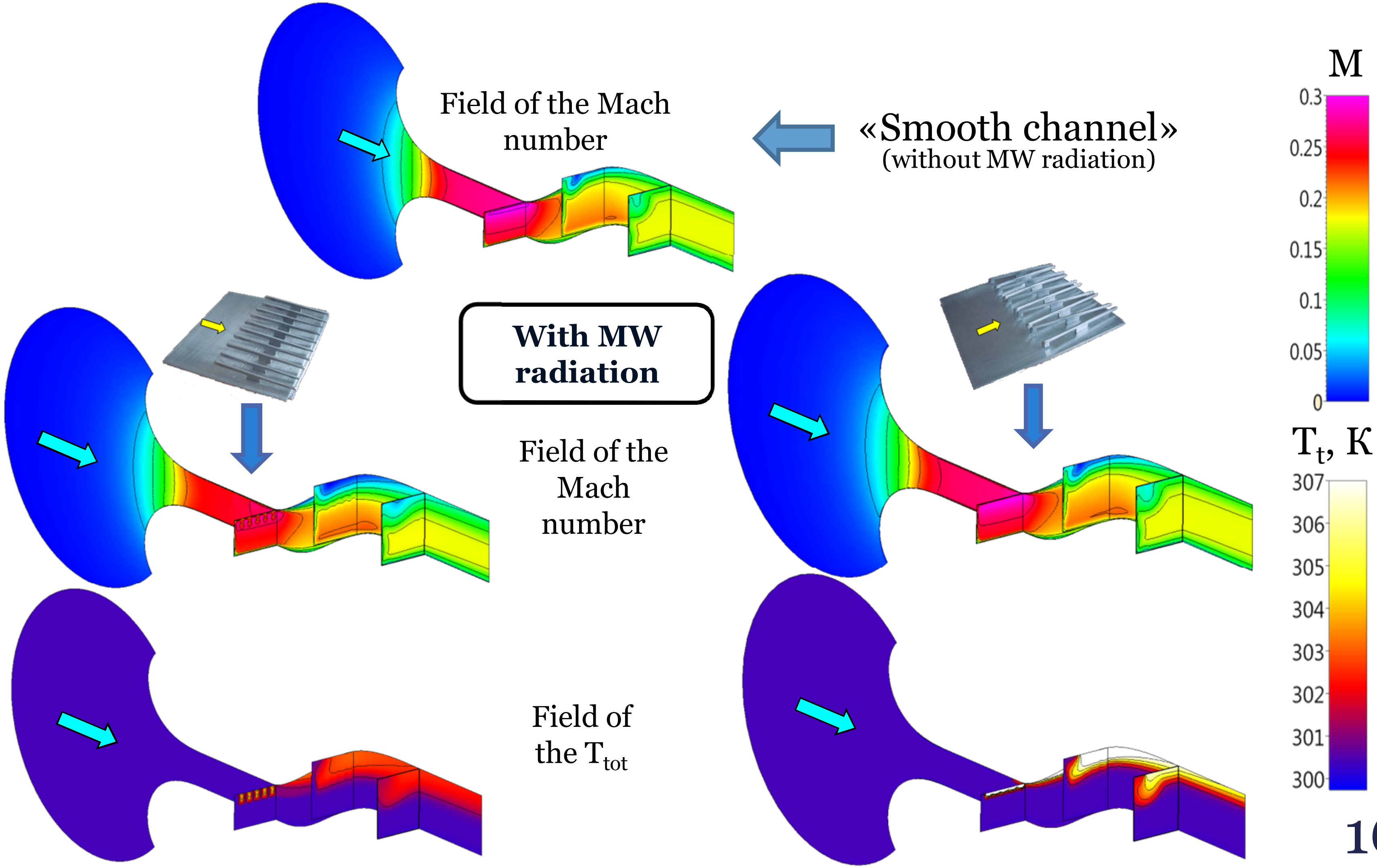




«Butterfly grid» around a single electrode

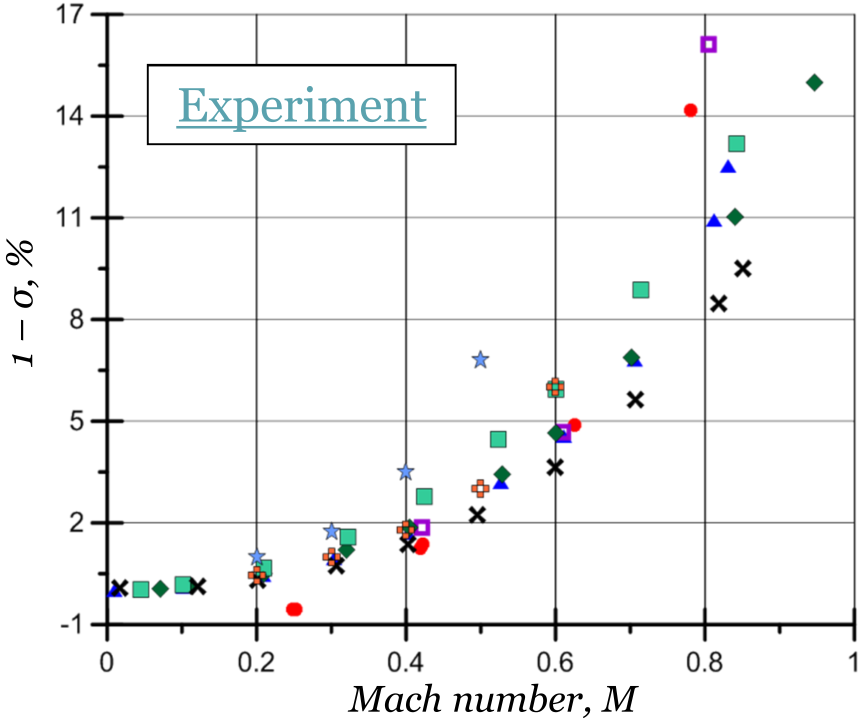
Results of numerical simulation

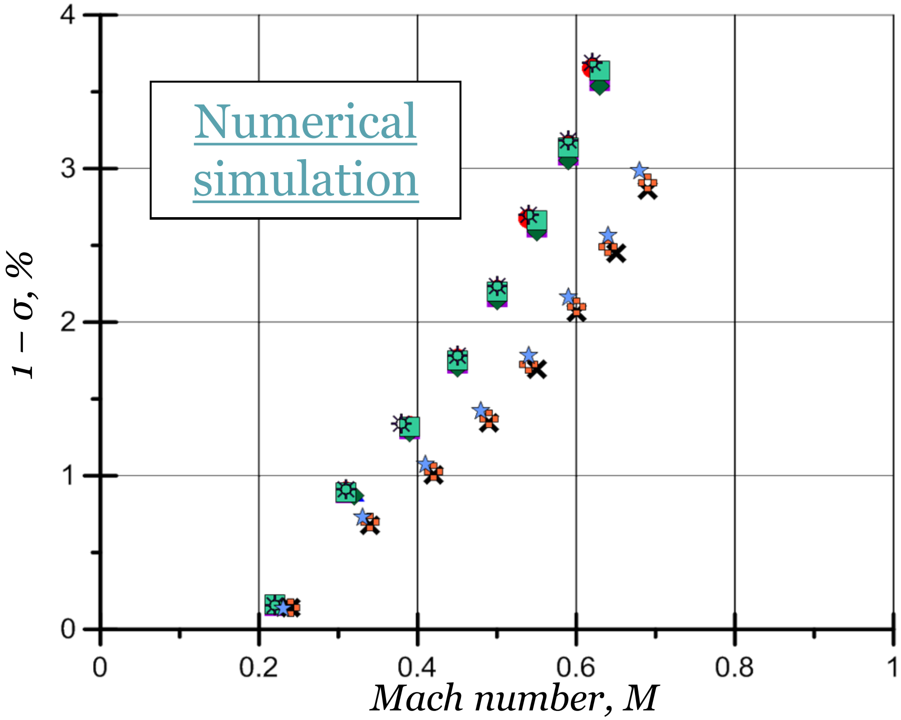
Field of the Mach number M and the temperature T_t for the "smooth channel“, channel with parallel and external electrode units with energy supply in the plane of symmetry



Summary results

Graph of the total pressure loss on the velocity

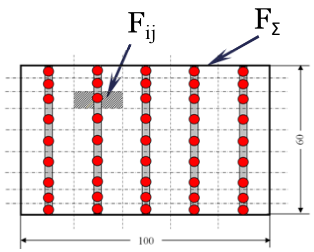


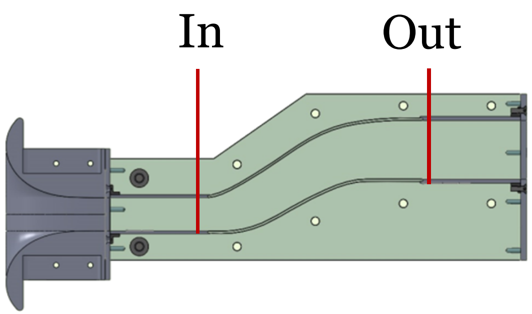


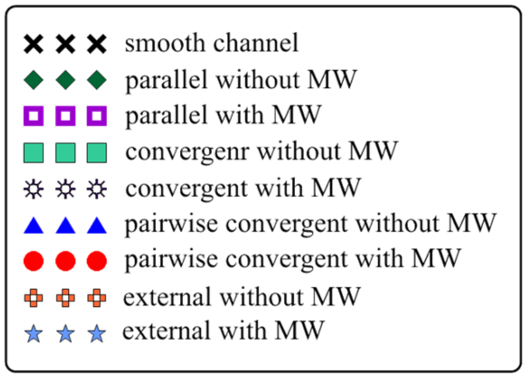
$$\sigma = \frac{P_{tot}{}^{out}}{P_{tot}{}^{in}}$$

$$P_{tot}{}^{in} \approx 1$$

$$P_{tot}{}^{out} = \sum_{i}^{5} \sum_{j}^{9} P_{tot}{}^{ij} \cdot \frac{F_{ij}}{F_{\Sigma}}$$







Conclusions

- Set of MW equipment to study the effect of microwave radiation on the subsonic flow in curvilinear diffuser channel with continuous and pulsed-continuous MW energy supply created and debugged;
- Calibration tests of the different electrode units were made and resonant lengths of the electrodes that provide uniform and stable generation of plasma formations across the width of the channel at different pressures 0.6-1 atm were determined;
- Influence of supplied energy level on the flow field was investigated and it was changed in variety 60-360 W at pulse-continued regimes and ~2 kW at continued mode (flow energy 40-320 kW). At low speeds M_{in} = 0.1 - 0.4 and MW energy input provided by pairwise-converging electrode unit the total pressure losses in channel decreased by 0.5% vs smooth channel. In case of M_{in} increase up to 0.5 - 0.8 the losses increased by 0.5-1%;
- Numerical simulation of flow field in tested channel under simplified (volume heat) physical model of MW energy input based on 3-D RANS formulation was carried out. Different placement and constructive features of the electrode units were considered and it was obtained small influence ($\Delta\sigma$=0.05%) on total pressure losses in channel. In case of energy supply absence there was a qualitative agreement between numerical and experimental static and total pressure distributions along the channel for similar electrode unit configurations.