# Successful experiments on an external MHD Accelerator: wall confinement of the plasma, annihilation of the electrothermal instability by magnetic gradient inversion, creation of a stable spiral current pattern.

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## HYPERSONIC VELOCITY

The faster you want to fly the higher you have to go. The slower you fly the lower you go to have sufficient lift.

Today, our modern airliners fly at 30,000 feet, and cruise just below the sound velocity, to avoid the excessive fuel consumption that would be induced by a wave drag.Concorde flew at Mach 2 at 50,000 feet.This altitude was necessary to decrease the air density for lower drag and therefore lower fuel consumption. The famous SR-71 "Blackbird" which flew at Mach 3.2 had to operate at 80,000 feet. Beyond this altitude, between 100,000 feet and 300 km, lies an "intermediary space", too high for conventional jets to venture into – not enough lift- , and too low for satellites – too much drag -.

In this intermediary space, hypersonic cruise is required.But the intense heat produced by the compression of air in the intake shock waves is problematic. For mid-hypersonic conditions (M<5) the use of special materials may solve the problem. But for very high Mach numbers, up to 10 and beyond, some solution must be found in order to avoid the disastrous thermal effects, due to the compression of the air behind the frontal shock waves and their associated thermal flux.

The best solution would be to prevent the shock waves themselves.

One might ask, why do these shock waves ever take place, around supersonic flying machines in the air-filled atmosphere?

### A SHOCKWAVE PROBLEM

Using Navier-Stockes equations, one may compute the Mach lines pattern around any supersonic object immersed in an air flow.
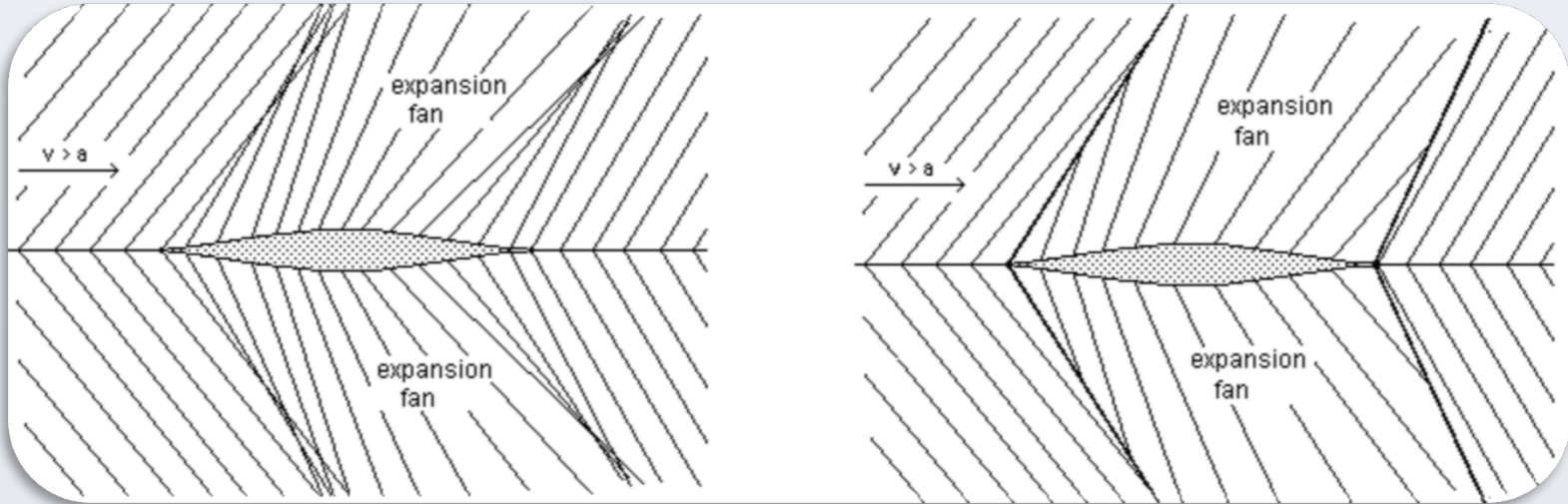


It was shown [1-5] that a convenient JxB Lorentz force field could prevent the birth of any shock wave, either at the front part and at the bottom of the profile.
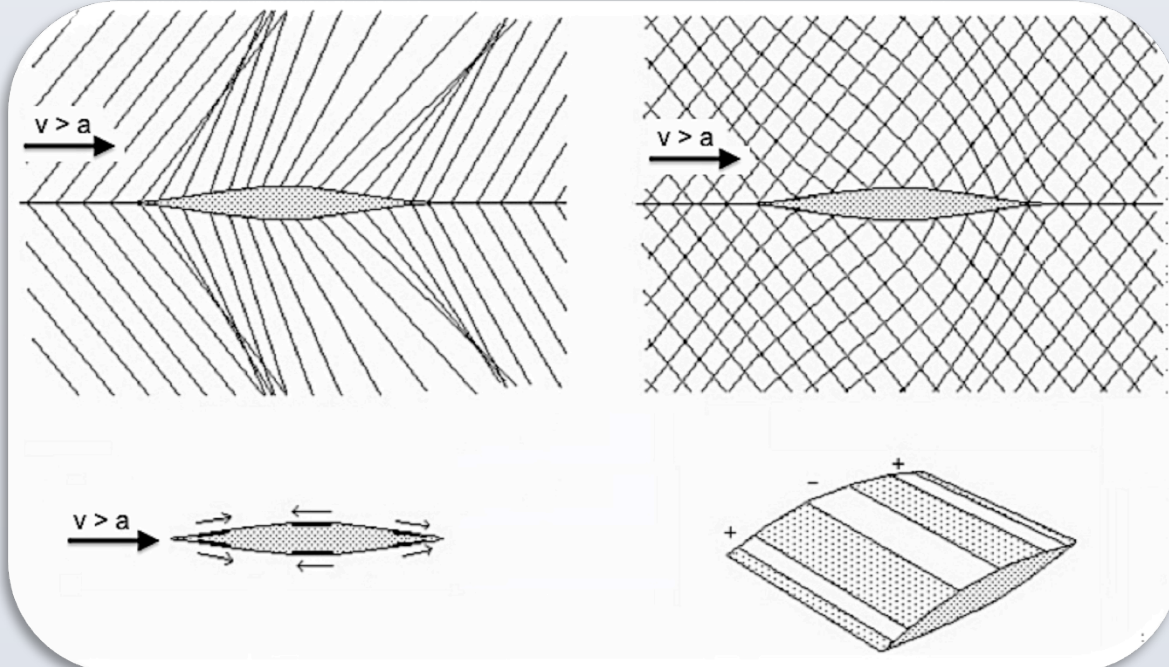


Convenient J x B field modifies the Mach lines pattern, so that they no longer accumulate, this accumulation of pressure perturbation being the source of shock wave birth ).

Slowing down Lorentz forces are obtained, transforming this constant cross section channel into a Faraday-type MHD generator, with transverse magnetic field and segmented electrodes, filled by supersonic hot argon flow ( T = 10,000°K ; p = 1 bar, V = 2750 m/s ; M = 1.4 ).

These experiments were carried out in the sixties at the Marseilles Institute of Fluid Mechanics (no longer active today) demonstrating that large enough Lorentz force field can strongly modify the characteristic pattern of a supersonic flow.

Conversely, strong accelerations were obtained (4000 m/s velocity increase along a 10 cm MHD channel). In France, at the beginning of the eighties, experiments were planned in order to completely cancel shock waves around a lenticular wing profile, immersed in a 10,000° supersonic argon flow, driven by a shock-driven wind tunnel.

Thus the constant cross-section tunnel is converted into a Faraday-type MHD generator, with segmented electrodes producing a transverse magnetic field.

To prevent the self-crossing of the Mach lines, it is necessary to accelerate the fluid in certain regions (near the leading and trailing edges) while slowing it in the thickest part of the profile, where the classical expansion fan lies.

Thus was created the concept of MHD bypass.

But these experiments could not be made in an official lab, due to the obvious links with the UFO phenomenon (noiseless supersonic).

## LOW DENSITY HYPERSONIC FLOW

Decades later, the Lambda Laboratory team, with private funding, revives this project. The shock tube setup was abandoned, on cost and complexity issues, and the team shifted to low density hypersonic flows, produced by a short duration wind tunnel.
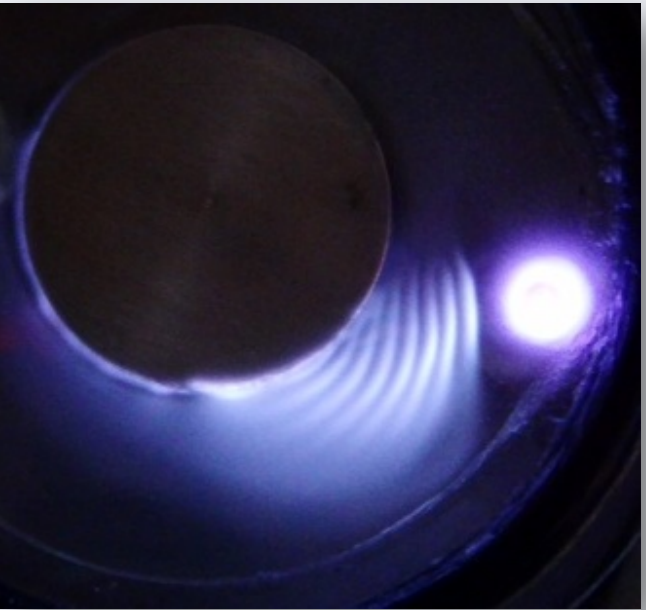
The low density gas flow, exhibits a decent electrical conductivity (which corresponds to the conditions in the intermediary space above).

In shock tube experiments, the value of the Hall parameter was quite low, due to high values of the collision frequency.
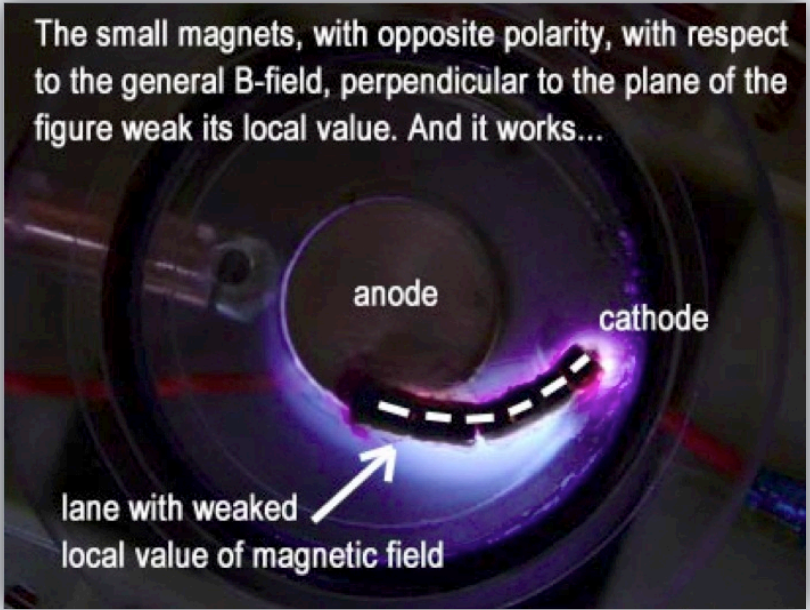
In low density experiments the medium is out of equilibrium ( Te > Tg ) and the Hall parameter ß is de-facto high, above the critical value ßcr leading to a rapid rise of the Velhikov instability (https://en.wikipedia.org/wiki/Velikov_instability), which leads to a number of problems, which have been solved by the team in the past years.

### ELECTROTHERMAL INSTABILITY

Velhikov's instability was overcome using a magnetic confinement of the current streamers, by inversion of the magnetic field gradient.



The small magnets, with opposite polarity, with respect to the general B-field, perpendicular to the plane of the figure weak its local value. And it works...

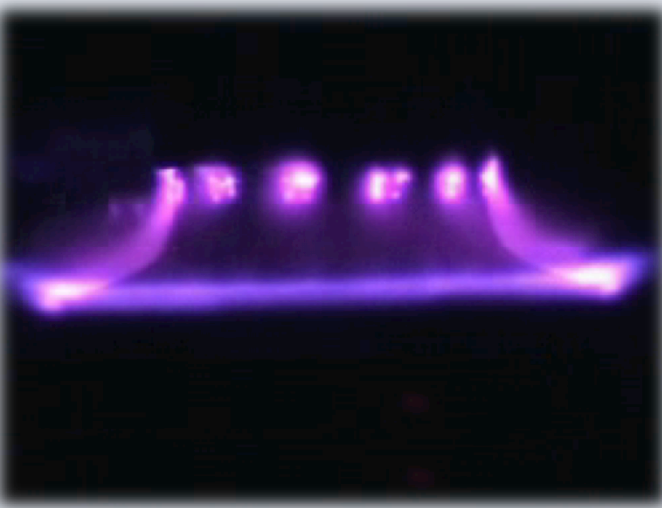Instability | Controlled instability

The current was thus incited to take the route of least electric resistance so as to bring the plasma, locally, into a Coulomb dominated regime, where we know that the Hall parameter critical value is then close to 2. The local Hall parameter value becomes, locally, lower than this value, the plasma is then brought into a stable configuration. The experiment aims to create spiral currents in order to obtain a quasi radial force field, even though the local Hall parameter value is low. The discharge geometry is then completely controlled by the magnetic geometry and not by the Hall effect.

### CLOSE TO THE WALL

Another problem was to keep the discharge far from the wall, in regions of lower electrical resistivity (where the Hall parameter was lower). This problem was solved using a wall confinement of the discharge due to the inversion of the magnetic gradient.
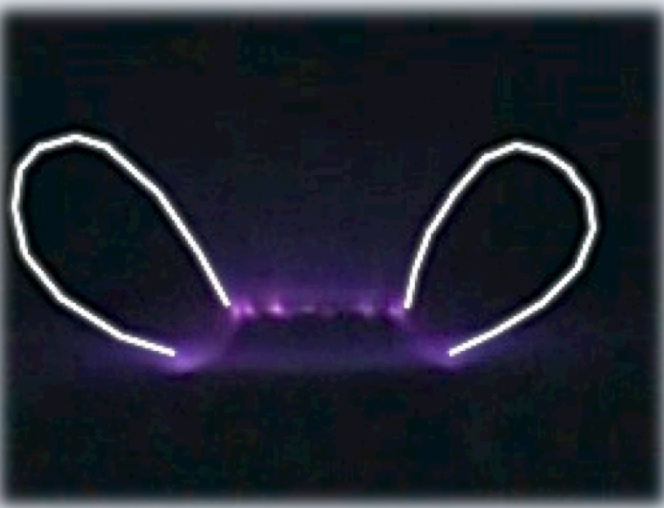


The discharge is blown away by the magnetic gradient | Wall confinment by inversion of this magnetic gradient

The effect of the pressure-gradient, literally squeezes the plasma against the wall. This wall is drawn perpendicularly to the field lines, and the craft hull, initially designed to be convex, becomes necessarily concave, in order to confine the plasma under the zone of strongest magnetic field.

## SPIRAL CURRENT STREAMERS PATTERNS

For high Hall parameter regimes, disk shaped MHD aerodynes are more suitable for a complete disparition of shock waves (CRAS 195---1976). Several formulae can be considered ( ref Bremen 2009 ). Presently the Lambda Laboratory team works on MHD aerodynes with spiral current streamers patterns (CRAS 1975).
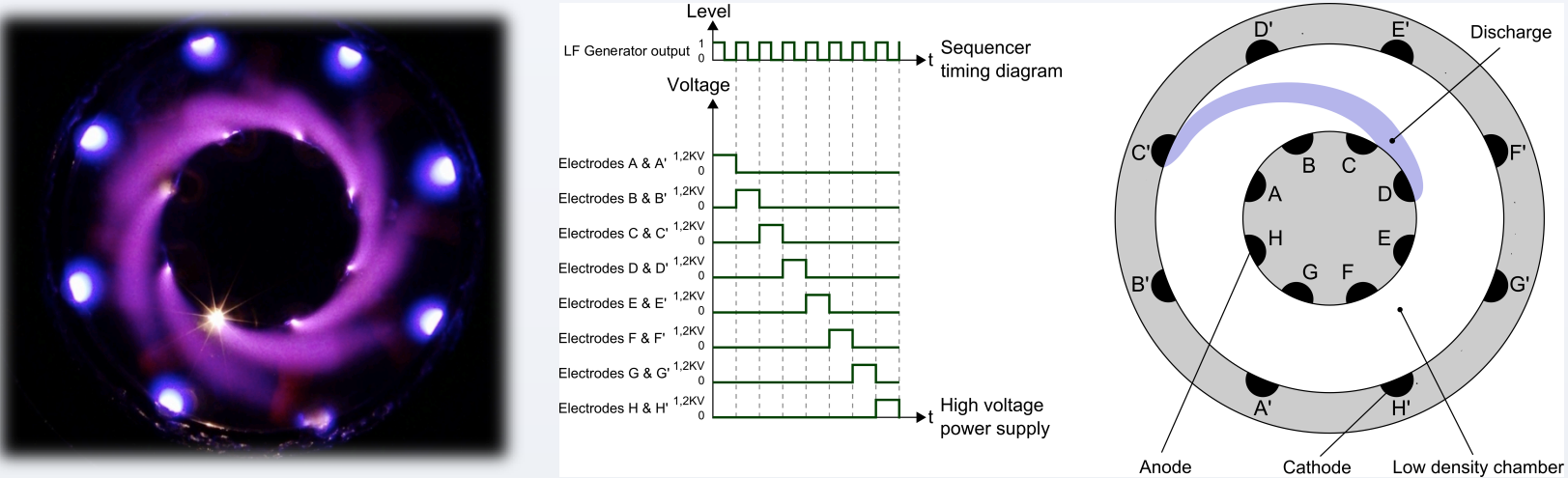


If one would attempt to establish the streamers simultaneously, they should badly interfere and such a regular pattern would not be obtainable. We therefore proceeded sequentially.

At any time only one cathode pair is powered-up. The setup works if the commutation period is shorter than the transit time of the gas around the machine.

### SUBSIDIARY RESEARCHES

In Lambda Laboratory we work on ionization control in the wall region, using microwaves and parietal pulsed micro discharges, this being linked to the disk shaped aerodynes formula ( Bremen 2009 ).
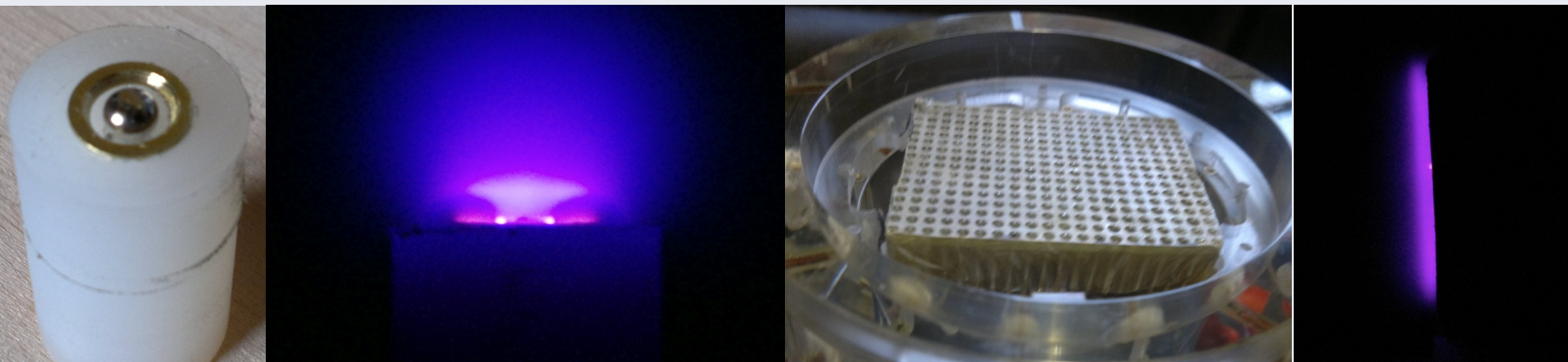


Mini focus single ionizer | Submini parietal ionizer

The first ones were aimed at studying the behavior of a single ionizer. Once the principal was well mastered, the following tests have been performed on a flat surface mounted with a series of similar ionizers, but miniaturized to a size not larger than one millimeter.

### MHD BYPASS SYSTEM

Disk-shaped crafts need a large internal power source.

But we can think about using the kinetic energy of the incoming hypersonic air flux. By using the electromotive field VB, we can choose a very low extension ratio wing, with a straight leading edge, and from the top part is parallel to the incoming gaseous flux.



wall convertor

three fingers' rule
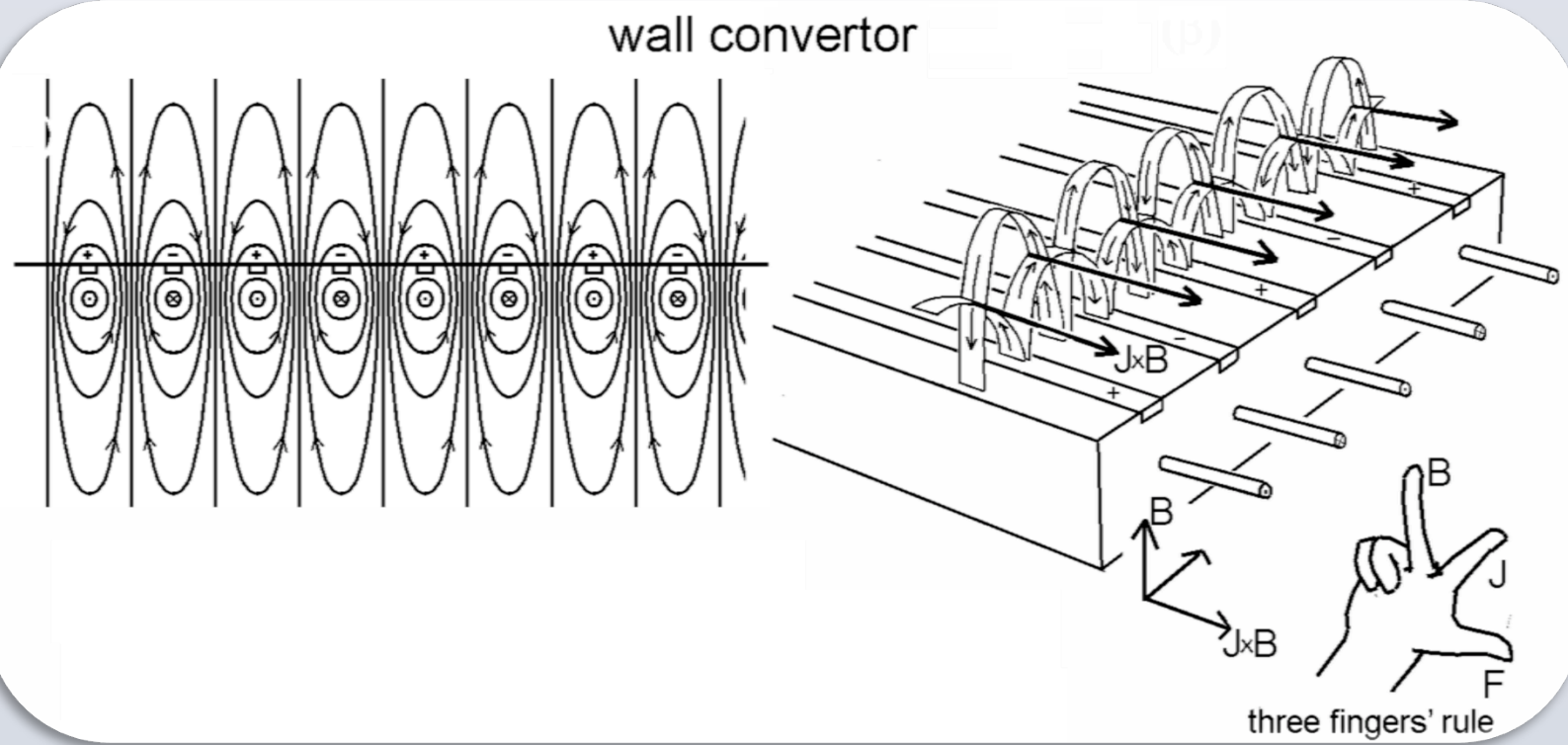
The shape of the corresponding machine is the following. The motor unit is located behind.
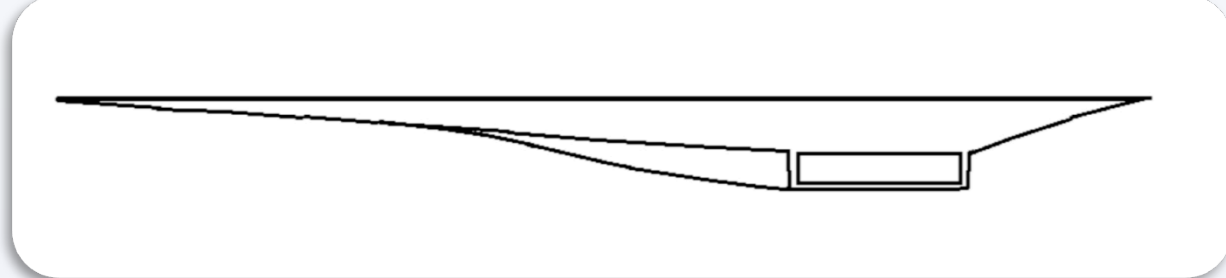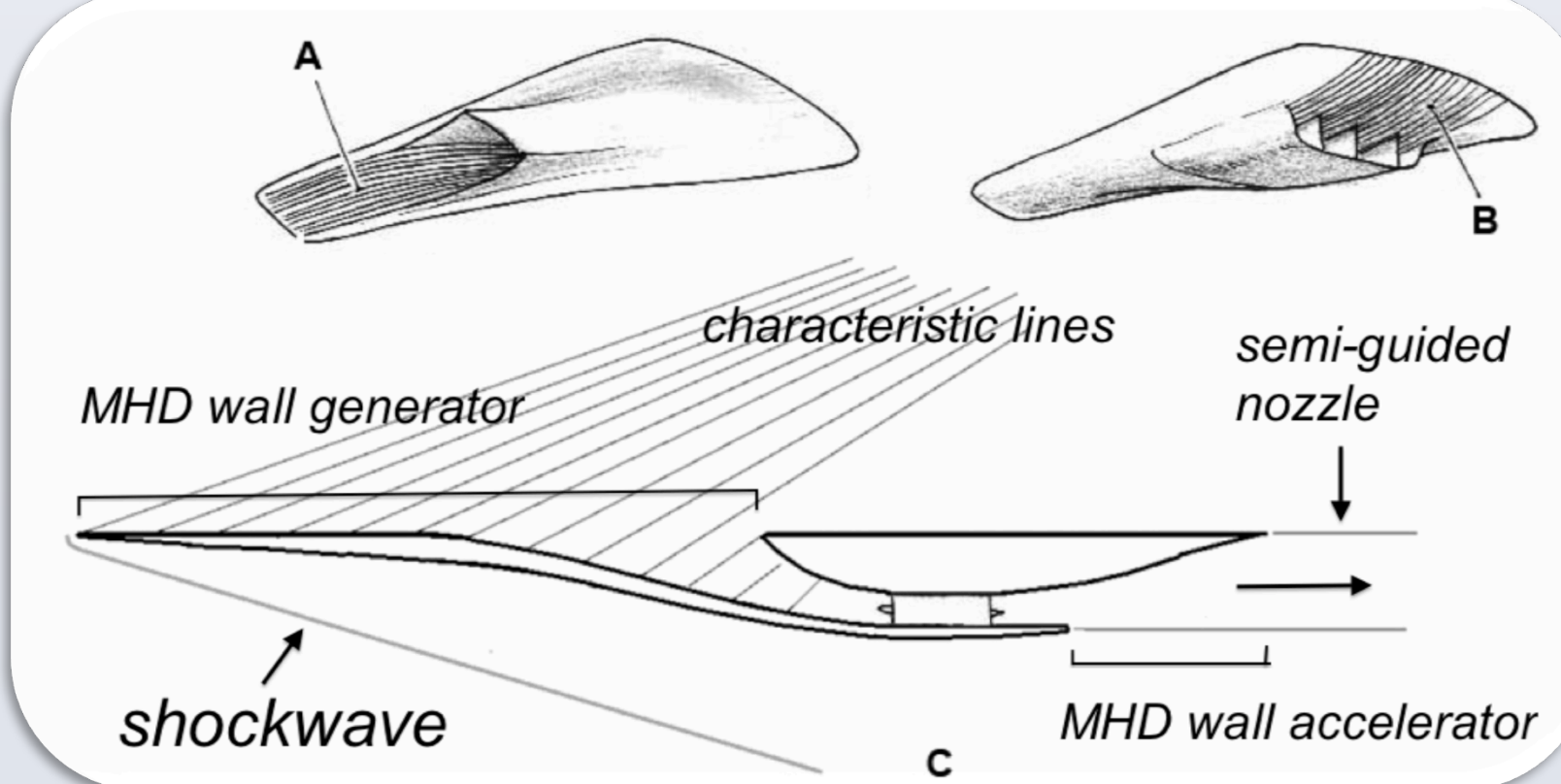


When taking off, classical turbofan are fed by inlets located behind this sort of wing, up to Mach 3---4.
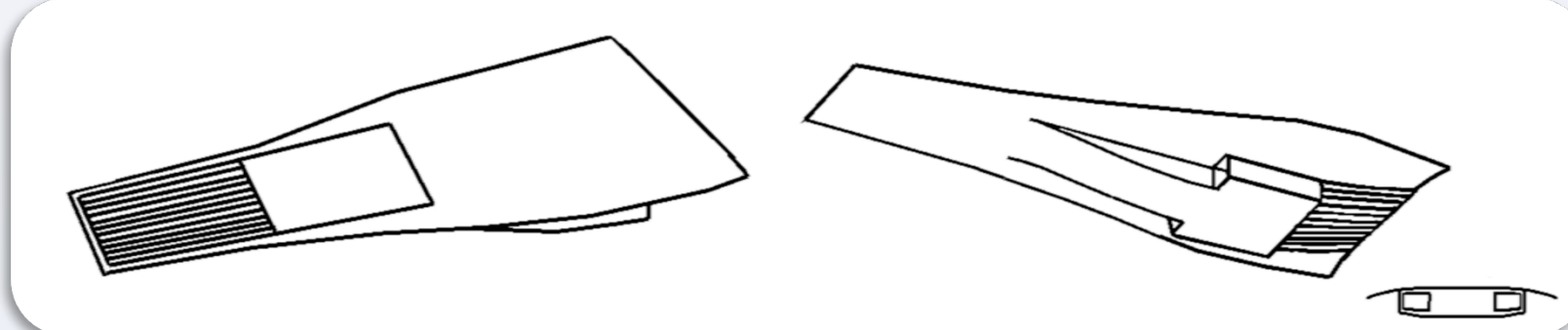


Then, when the altitude is high enough (and the electric conductivity of the low pressure air high enough too), those inlets are closed and other ones are opened at the top of the machine :
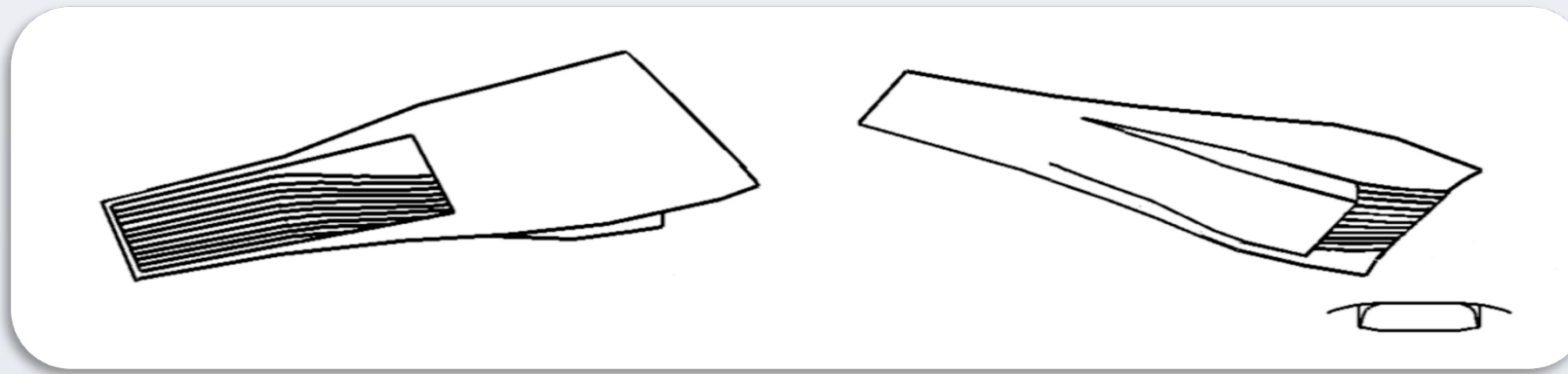


Ahead of this new inlet, there are electrodes and a magnetic field (confined close to the wall). This part acts as a Hall MHD generator, providing electric energy and a high electric field ( B V B ).



characteristic lines | semi-guided nozzle
MHD wall generator
shockwave | MHD wall accelerator

A) MHD wall generator. B) MHD wall accelerator after the engines. C) Profile cut view of the high-Mach number MHD-controlled inlet. Shockwave under leading edge. On top, air slows down along the long wall generator and Mach waves are progressively rectified with limited recompression and no shockwave until inlet's bottom.

The latter is used to create a plasma cushion at the leading edge, to protect it against the thermal flux.

The production of electric energy entails the slowing down of the flow (and recompression), from hypersonic conditions to moderate supersonic conditions.
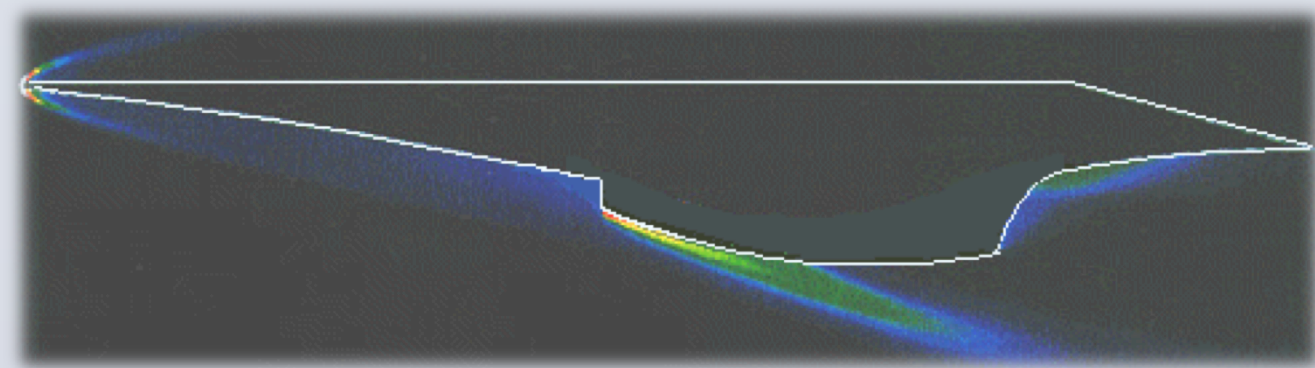


Russian Ayaks in supersonic wind tunnel test.

## CONCLUSION

The implementation of such a craft, including on laboratory scale, implies to fully dominate the questions of binding the plasma to the wall and annihilating the electrothermal instability.

Besides the evident strategic aspects, such machines could be used as fully reusable satellite launchers.

It is indeed nonsense to use the majority of the propellant of a rocket stage to fight gravity without benefiting from the atmosphere's lift, and to carry the oxidant (liquid oxygen in the case of cryogenic propulsion). Instead it would be beneficial to use the lift provided by an air-fed propeller, coupled to an MHD controlled inlet and a MHD bypass system.

An aircraft equipped with an MHD-controlled inlet would represent a new launch paradigm, including the use of wall MHD converters as MHD generators for re-entry braking without the use of ablation techniques.

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### Further Informations

Studies at λ currently cover low density experiments of magnetized non-thermal plasmas (MHD accelerators with various shapes, ionizers, streamer guidance and plasma wall-confinement systems).

Interesting fields of this activity relate to air-breathing MHD propulsion with flow control by Lorentz force field. This implies mastering the electrothermal instability through magnetic gradient inversion systems. MHD applications to aerodynamics, sometimes called magnetoplasma-aerodynamics or magnetoaerodynamics, are aimed to enable hypersonic flight by controlling heat transfer: MHD bypass systems on hypersonic waveriders, MHD-controlled inlets, wide high voltage cushion-discharges on leading edges, external-flow MHD accelerators, shock wave cancellation, etc...