Professor Ion Stroescu and the boundary layer: a precursor of the flow control

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DOI: 10.13111/2066-8201.2011.3.S4

Comemorative speech for professor Ion Stroescu (1888-1961)

1. ACTIVE FLOW CONTROL (AFC)

Active Flow Control represents the control of the local flow around a wing or blade. Its purpose is to improve aerodynamic performance of a profile or lifting surface. For the particular case of wind turbines the main concern is reducing the extreme loads caused by strong wind gusts along with reducing fatigue strain, which varies along turbine blades and occurs randomly.

To achieve this, the active load control systems or „smart" devices must include actuators and sensors located along the span of the turbine blade. The system must be able to detect changes in local flow conditions and respond quickly to counterbalance any negative impact on the blade loading.

This arrangement provides the so-called Active Smart Control on the rotor.

By definition, an active intelligent structure involves distributed actuators and sensors and one or several microprocessors to analyze the sensor responses and use integrated control theory to drive the actuators so they act upon local stress and displacements to alter the system response.

Numerous research on AFC devices have proved that an important reduction of loads is possible.

1.1 Flow Control Categories

Flow control can be divided in three categories: sensors/control, actuators/devices, and flow phenomena. Communication between these starts from contrtols and sensors that continuously update the control system with flow properties and general functioning data. When adjustments are required, the control system commands the actuators to drive the flow control devices. Then the devices modify their functioning altering local flow phenomena. The sensors detect this modification and the cycle repeats. Figure 1 shows the flow control categories and lists some examples of wind turbine control. The figure shows that a flow control problem requires an interdisciplinary approach and research.

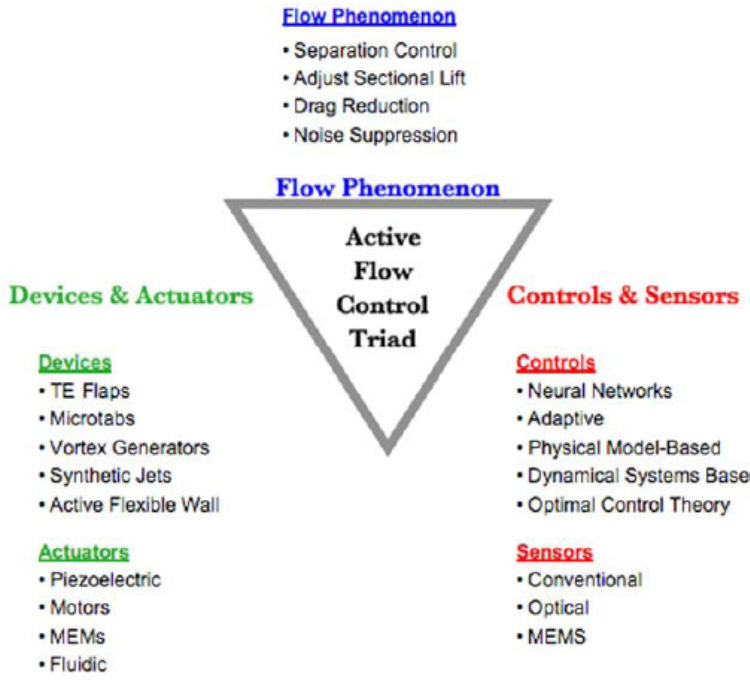


Figure 1 Flow control triad

Table 1 The main active flow control speciffic devices

	Devices	Geometric (G) / Fluidic (F) / Plasma (P)	Leading Edge (LE) / Trailing Edge (TE) / Mid-Chord (MC)	Inc. Lift (I) / Dec. Lift (D) / Delay Stall (DS)	Steady (S) / Unsteady (U)
1	Traditional Trailing-Edge Flaps	G	TE	I / D	S / U
2	Nontraditional Trailing-Edge Flaps	G	TE	I / D	S / U
3	Microtabs	G	TE	I / D	S / U
4	Miniature Trailing-Edge Effectors	G	TE	I / D	S / U
5	Microflaps	G	TE	I / D	S / U
6	Active Stall Strips	G	LE	D	S
7	Vortex Generators	G	LE	DS	S
8	Blowing and Suction	F	LE / TE	DS	S / U
9	Circulation Control	F	TE	I / D	S
10	Plasma Actuators	P	LE	DS	S
11	Vortex Generator Jets	F	LE	DS	S / U
12	High-Frequency Micro Vortex Generators	G	LE	DS	U
13	Synthetic Jets	G / F	LE	DS	U
14	Active Flexible Wall	G	LE	DS	U
15	Shape Change Airfoil	G	MC	I	S / U

In the following pages we will present two such circulation control systems, a concept derived from the conventional methods of boundary layer blowing and suction, linked to Professor Ion Stroescu's early research (1925).

2 BOUNDARY LAYER BLOWING AND SUCTION

The conventional boundary layer suction and blowing procedures delay the stalling, adding an increased impulse to the air in the boundary layer.

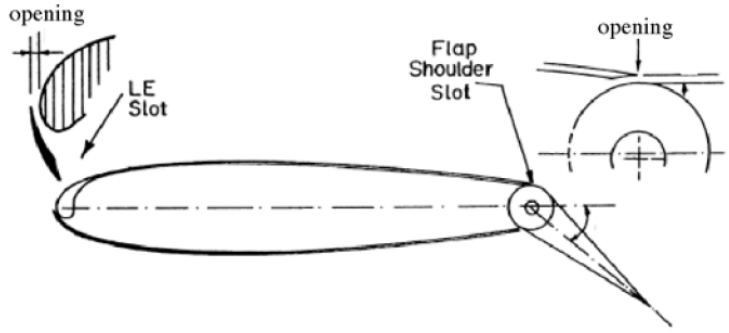


Figure 2 Illustration of a possible blowing/suction configuration

Usually the slots are uniformly distributed along the blade span, and the suction/blowing effect can occur in steady or unsteady regimes. Circulation control wing, CCW, is a derived concept of the conventional sucking and blowing procedure meant to increase circulation (lift) given by a profile. The device consists of a series of high speed narrow jets of air that blow high impulse air tangentially over the surface of a profile („Gas jets, tangential to the upper side of the leading edge", patent no.11169 of 9 January 1925).

Under the influence of this jet the boundary layer remains attached to the curved surface much further down the chord than usual and moves the stagnation point from upstream to the underside of the profile thus increasing the circulation around the whole profile.

Figure 3 illustrates the modifications in the flow field at a windspeed of 7 m/s (NREL wind turbine rotor) as the impulse coefficient of the jet increases, also increasing the circulation around the profile. The figure also shows the deviation of the flow lines at the trailing edge.

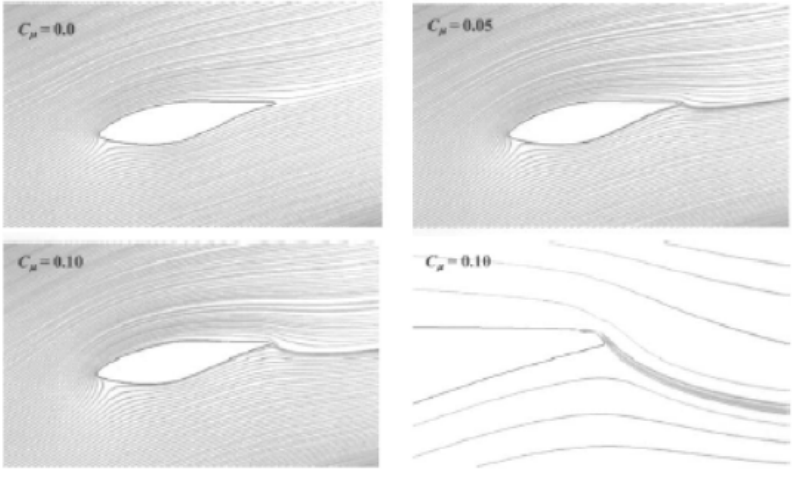


Figure 3 Flow field changing by CCW

3. SYNTHETIC JETS

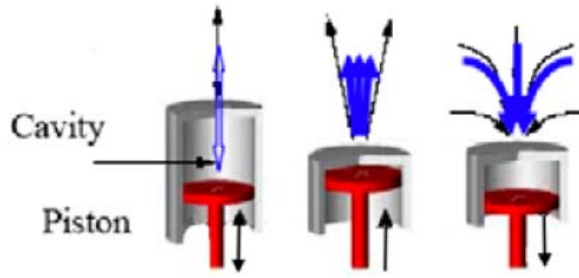
A major drawback to the blow/suction system is the necessity of installing high pressure air ducts. Synthetic jets elliminate this disadvantage.

They create vortex rings on the direction of the main flow, similar to the jets that generate pulsating vortices.

The main difference is that synthetic jets are zero-net mass-flux devices (*ZNMF*), meaning that they do not need a compressed/high impulse air source.

The jets are normally generated by an oscillating membrane that is located in an embedded cavity having the wall at the same level as the aerodynamic surface. The jets are formed from the working fluid flowing on the profile.

Figure 4 shows a typical device that creates a synthetic jet using a „breathe in- breathe out" mechanism.



Principle of synthetic jet generation

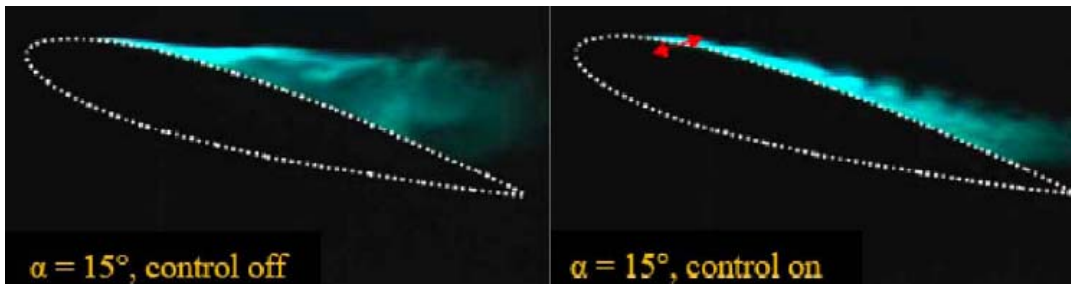


Figure 4 Experimental visualizations

- The synthetic jet generation depends mainly on three parameters:
- the Stokes number, $S = \sqrt{\dfrac{2\pi f D_0}{\nu}}$
- the Reynolds number, $\mathrm{Re}_L = \dfrac{\overline{U}_0 L_0}{\nu}$; $L_0 = \overline{U}_0 T$ (range length)
- the Strouhal number, $Str = \dfrac{f D_0}{U_\infty}$

The jet formation criterion is given by (fig.5, fig.6):

$$1/Str = \mathrm{Re}_L / S^2 > K$$

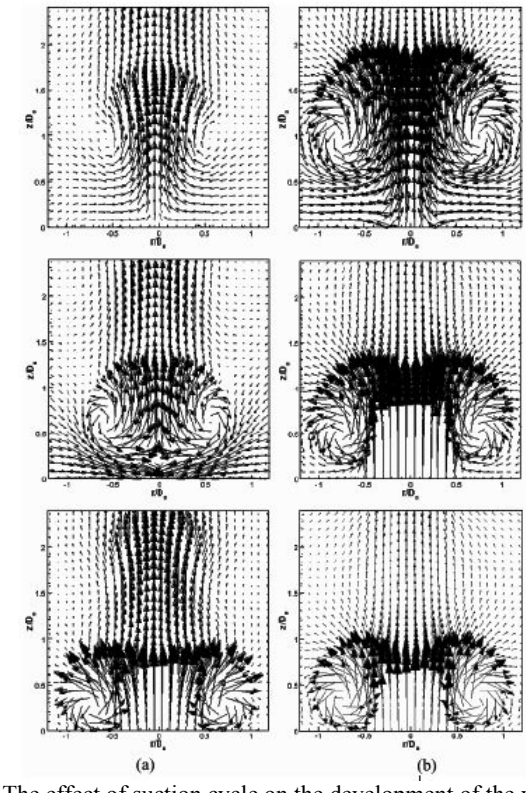


Figure 5 The effect of suction cycle on the development of the vortex ring:
(a) f=50 Hz, Δ=0.5 mm, S=22, L=1.7, Re_L=237 and (b) f=50 Hz, Δ=0.8 mm, S=22, L=3.0, Re_L=757

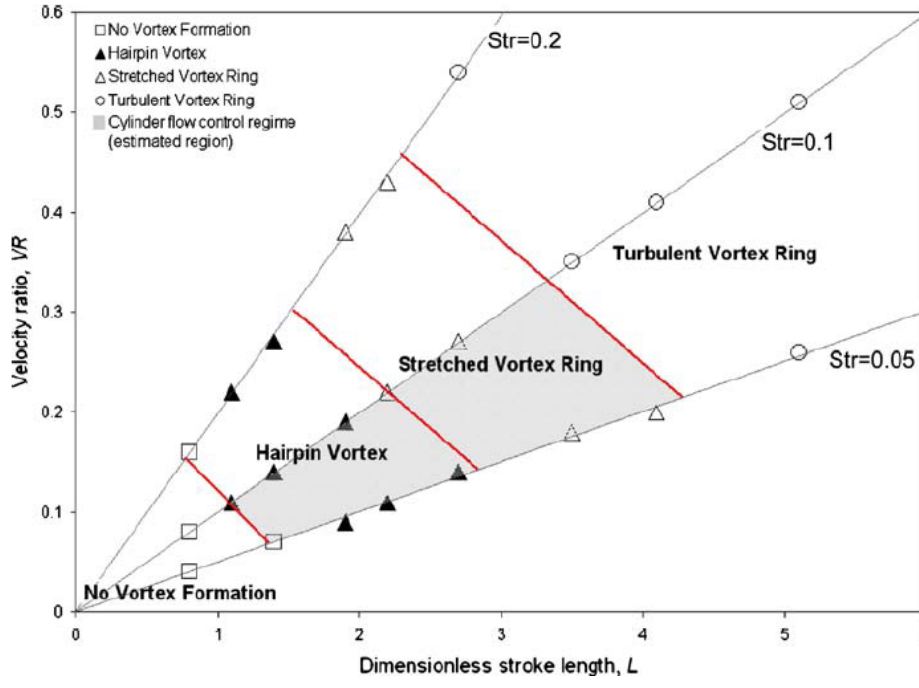


Figure 6 The interaction of the synthetic jet with a boundary layer, types of turbulent structures
(the shaded area indicates the structures that intensify the boundary layer flow)

4. SCIENTIFIC CONTRIBUTION OF PROFESSOR STROESCU

The rich design activity of prof. Stroescu evolves around three main ideas:

A. Effects of the boundary layer suction/blowing on the upper side of an airfoil
B. The Magnus effect that Flettner realised for ships with rotating cylinders
C. The high-efficiency wind tunnel realised by supressing all (flow?) resisting elements, especially the guiding blades.

We review the avant-garde ideas based on the boundary layer theory:

Patent no. 11169 / 1925"Airfoil with gas jet" (figure 7**)**

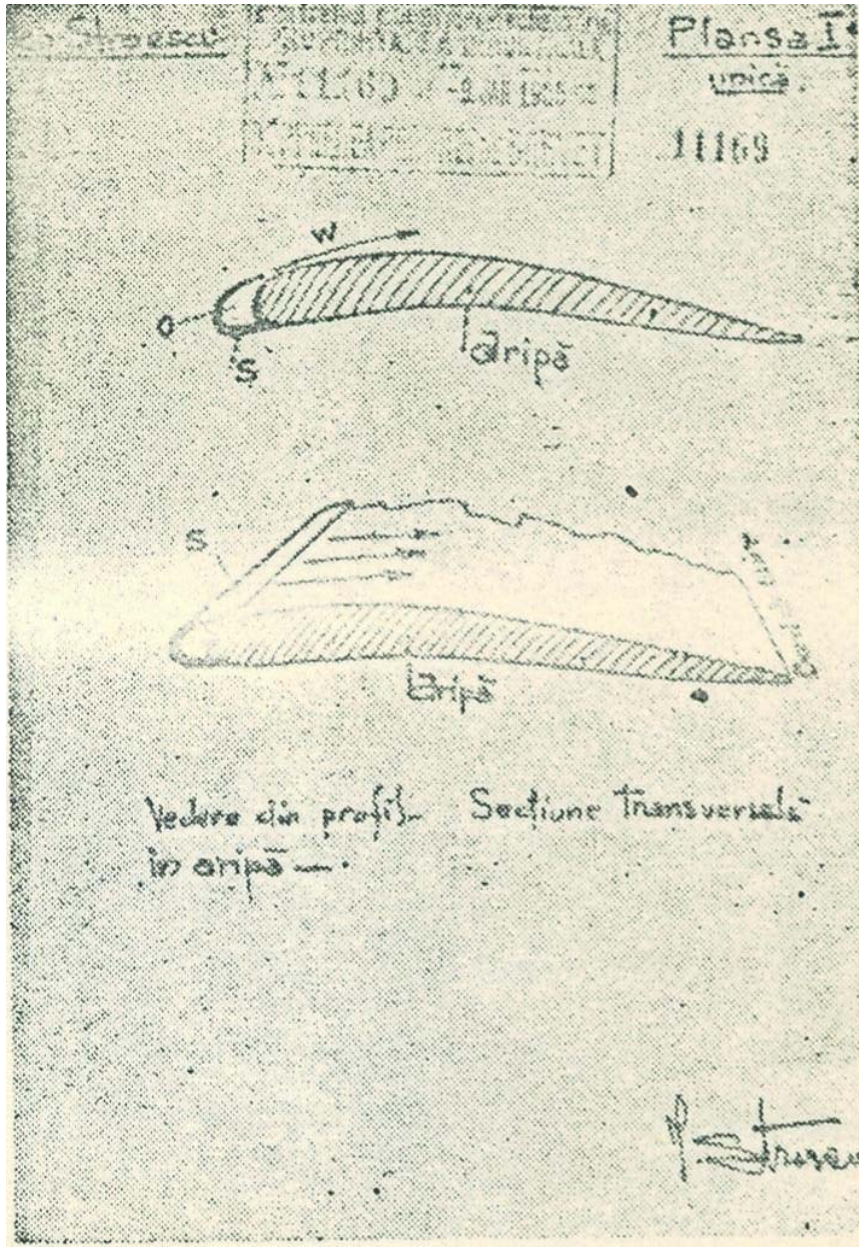


Figure 7 Leading edge blowing

Patent no. 13676 / 1927,"Propeller with tangential fluid jets" (figure 8).

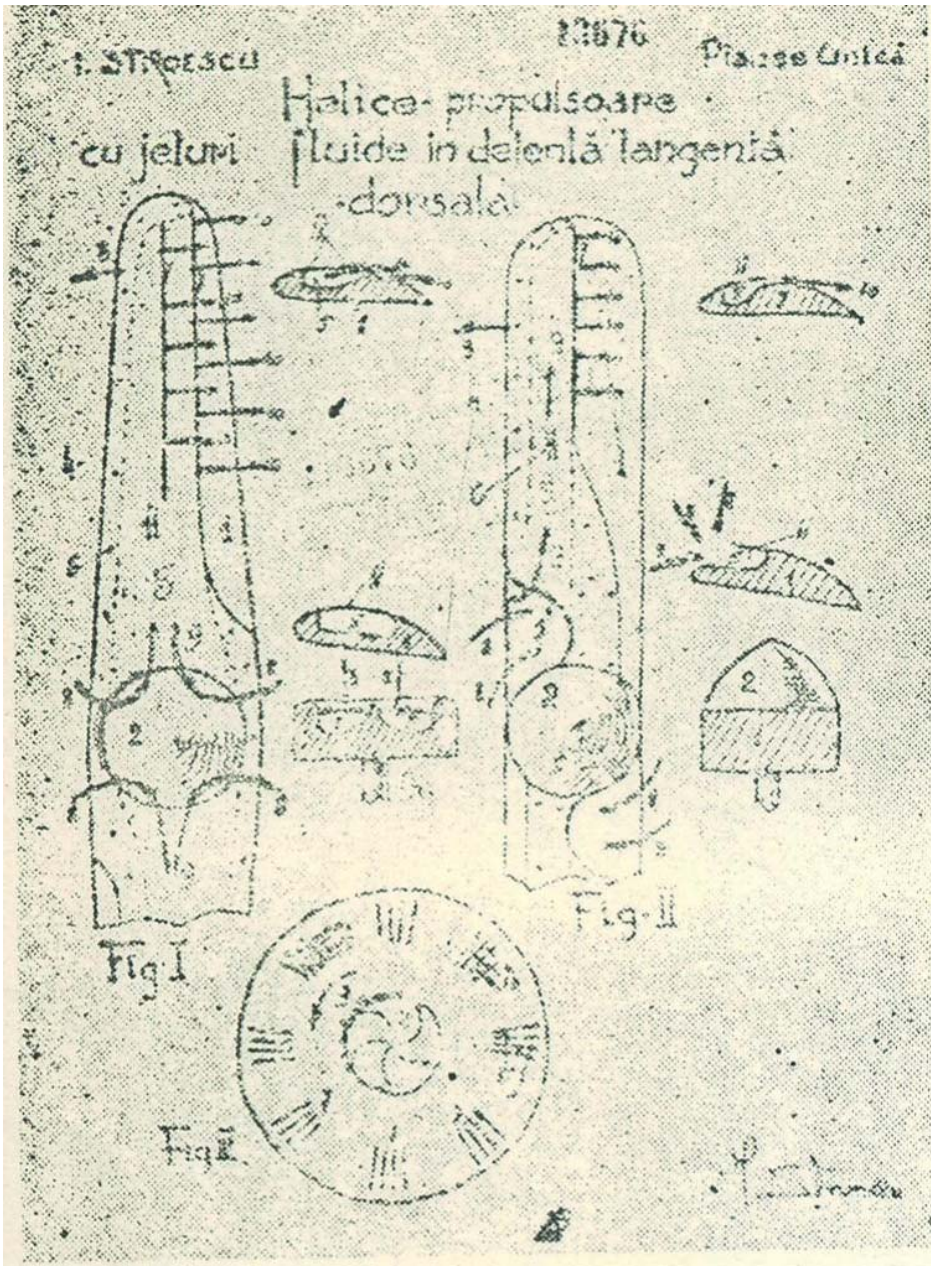


Figure 8 Trailing edge blowing

Patent no 13677 / 1927. „Device meant to intensify lift by the Lafay-Stroescu method of tangential fluid jets” (figure 9)

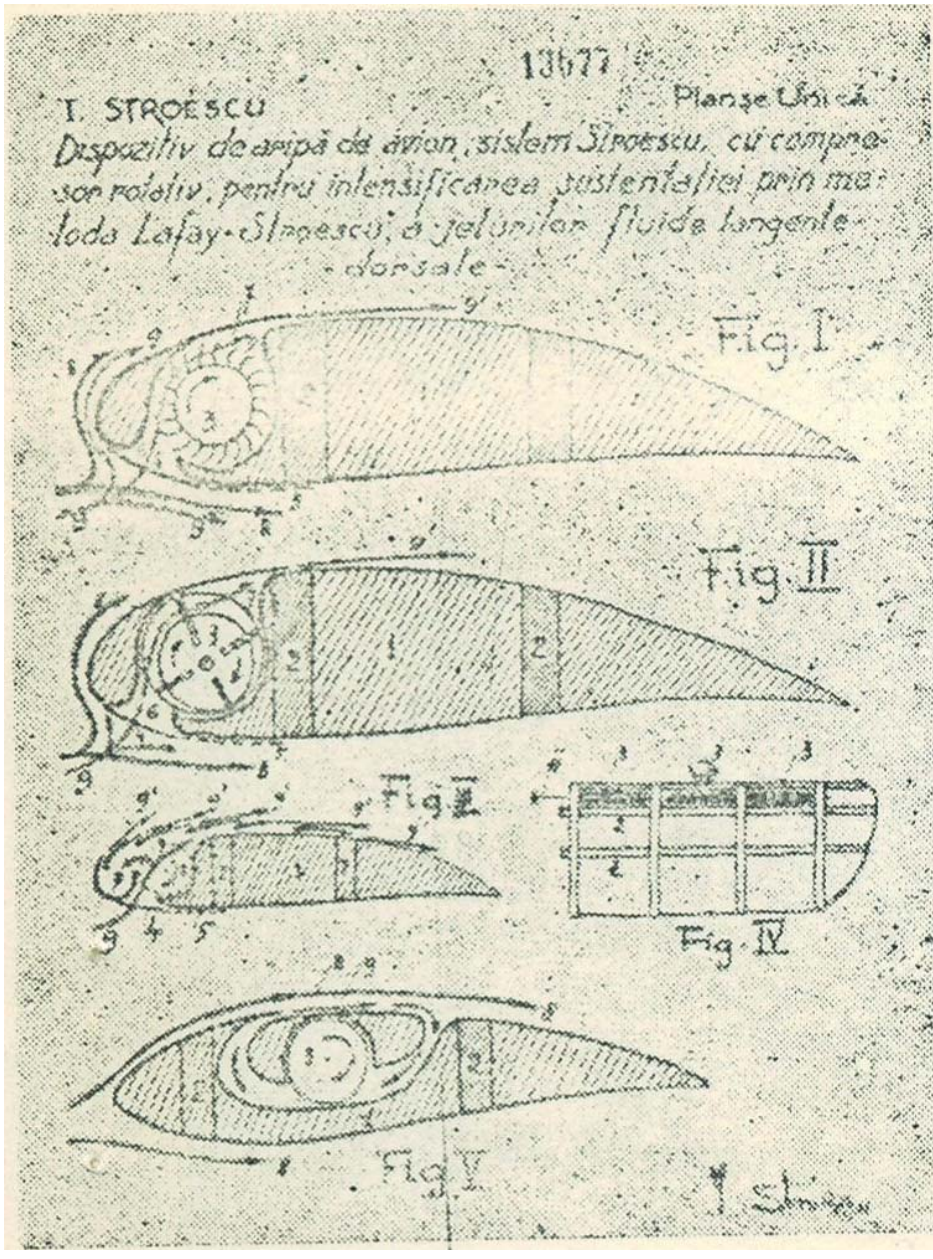


Figure 9 Intensification of the circulation on the upper part of the profile

By his exceptional achievements in boundary layer suction and blowing, the great inventor **Ion Stroescu** remains one of the precursors/ pioneer of the active flow control.