THE SOAP FILM TUNNEL FOR SIMULATING TWO-DIMENSIONAL FLOWS

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Abstract

In this paper we present some applications of the soap-film tunnel built in the aerodynamic laboratory of the Politecnico of Torino. In particular, after describing the device, we produce the results of the experimental reconstruction of the Roshko's curve in the two-dimensional case and of an investigation on the two-dimensional shedding process behind two cylinder "in tandem". In this way we try to demonstrate the analogy between the flows on the soap film and the "traditional" two-dimensional flows. Furthermore we show some visualizations of complex flows as: plane plate normal to the stream; evolution of the two-dimensional grid turbolence; flow in a cavity; jet flow; shedding process behind a cylinder.

Introduction

Though the two-dimensional flows have played an important role in the theoretical and experimental studies of fluid mechanics, their practical simulation in a laboratory has been difficult if not impossible,owing in part to the difficulty of isolating the primary two-dimensional flow from evolving three-dimensional instabilities.

Mysels[1] in 1959 proposed soap films as potential candidates to produce and study two-dimensional hydrodynamics, thanks to their thickness equivalent to some micron. Couder and Basdevan[2] in 1986 proved the feasibility of this idea towing a cylinder in a steady soap film in order to study the evolution of the vortex wake produced behind it. Unfortunatly this technique has savere limitations due to the short period of observation, the non-uniform film thickness and the lack of a quantitative method for flow measurements. In 1987 Garib and Derango [3] invented a continuously running soap film tunnel which has eliminated these problems.

The soap film tunnel we built in the Laboratory of aerodynamics "Modesto Panetti" of the Politecnico is actually used for a research program on the shear flow behind thickset bodies using P.I.V. thechniques to measure the flows.

The Soap Film Tunnel

The device (see Fig.1) consists essentially in a frame, one end of which is positioned in a diluited surfactant mixture while the other end is subjected to a film-pulling mechanism.

The pulling mechanism is composed by a two-dimensional water jet which is produced by flow of water through a rectangular opening. In this way the liquid films are pulled by shearing action of the water jet. By varying the water flow rate is possible to vary the pulling force and, in consequence, the velocity of the liquid film in the frame.

The size of the frame is limited by the film tendency to bow at flat section of the tunnel. The maximum width of the tunnel to avoid this effect is about 8cm. The ideal streamwise lenght of the test section is about 20cm, in order to obtain a long life of the film. The leg at the film/water jet interface has fork-like structures. These structures help to stabilize the film/water jet interface increasing the supporting surface of the film.

Several factors, including dry air, severe ventilation, vibration and unsteadiness or turbolence in the water jet can shorten the life of the film. Fine cloth ribbons are glued to the top of the frame to help prevent rupture of the liquid films due to water evaporation. With a steady water jet and in absence of severe ventilation and vibration, the films can run for hours, provided that fresh surfactant mixture is added continuously to the reservoir.

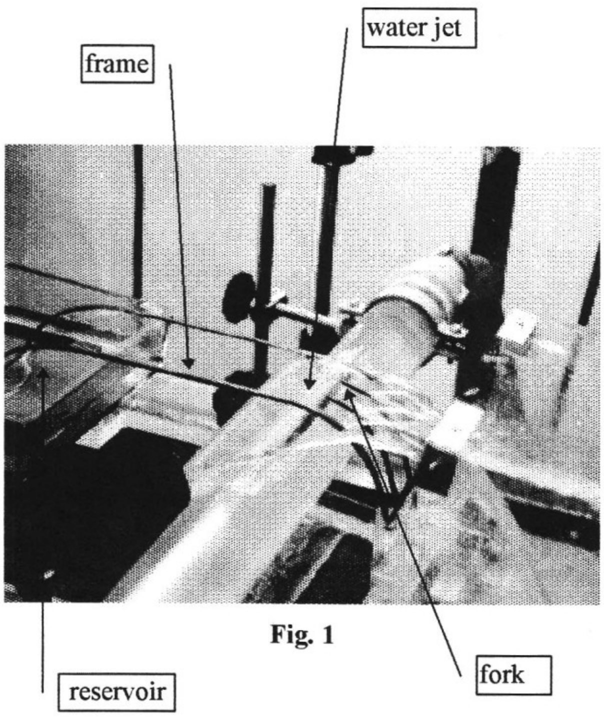


Fig. 1

Determination of the Reynolds Number

In order to determiny the Reynolds Number it is necessary to know the viscosity of the film:

$$\mu_f = \mu_b + \frac{2\mu_s}{e} \qquad (1)$$

where μ_b is the bulk viscosity and μ_s is the surface viscosity. Nevertheless, it is pratically impossible to know μ_s. For this reason the film viscosity has to be evaluated by empirical methods.

The phenomenon of vortex shedding behind a circular cylinder in a three-dimensional flow is described by the Roshko's empirical relationship[4]

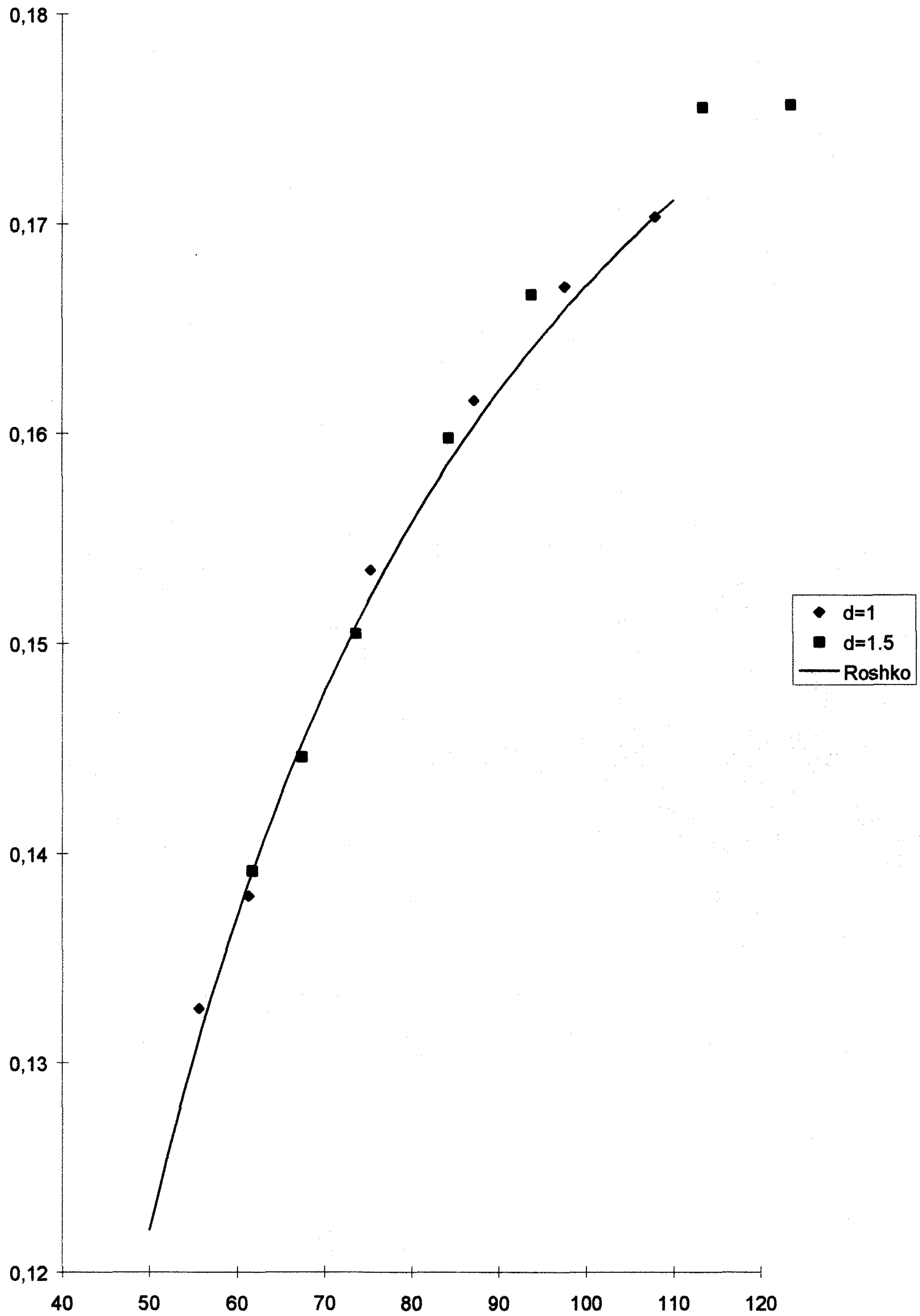
$$St = \frac{FD}{V} = 0.212 - \frac{4.5}{Re} \qquad (2)$$

where St is the Strhoual number, F is the shedding frequency, D is the cylinder diameter, V is the free stream velocity and Re is the Reynolds number. We assumed that, if there exists a similarity in the dynamics of the two- and three-dimensional flows, then Roshko's equation should be able to provide an estimate of Re (therefore also of μ_f) in our soap-film tunnel[3]. This was checked measuring the velocity upstream and the frequency of shedding of a known The obtained viscosity is strictly related to the concentration of surfactant in the solution. Our experiments were executed with a concentration of soap in water of 0.3%.

The free stram velocity and shedding frequency were evaluated using a CCD camera with P.I.V. techniques.

It was possible to determine an error of 5.5% on the Reynolds number so obtained.

Another experiment that allowed us to demonstrate the analogy between the flows on the soap film and the "traditional" two-dimensional flows is the analysis of shedding process behind two cylinder of the same diameter D positioned "in tandem" at a distance L one to the other . The results are showed in Fig.3, where we can observe a discontinuity of St between L/D=3.5 and L/D=3.8. Notice that it is possible to find the same discontinuity in similar experiments done in conventional water or wind tunnels.



0,18
0,17
0,16
0,15
0,14
0,13
0,12
40
50
60
70
80
90
100
110
120
d=1
d=1.5
Roshko

Fig. 2

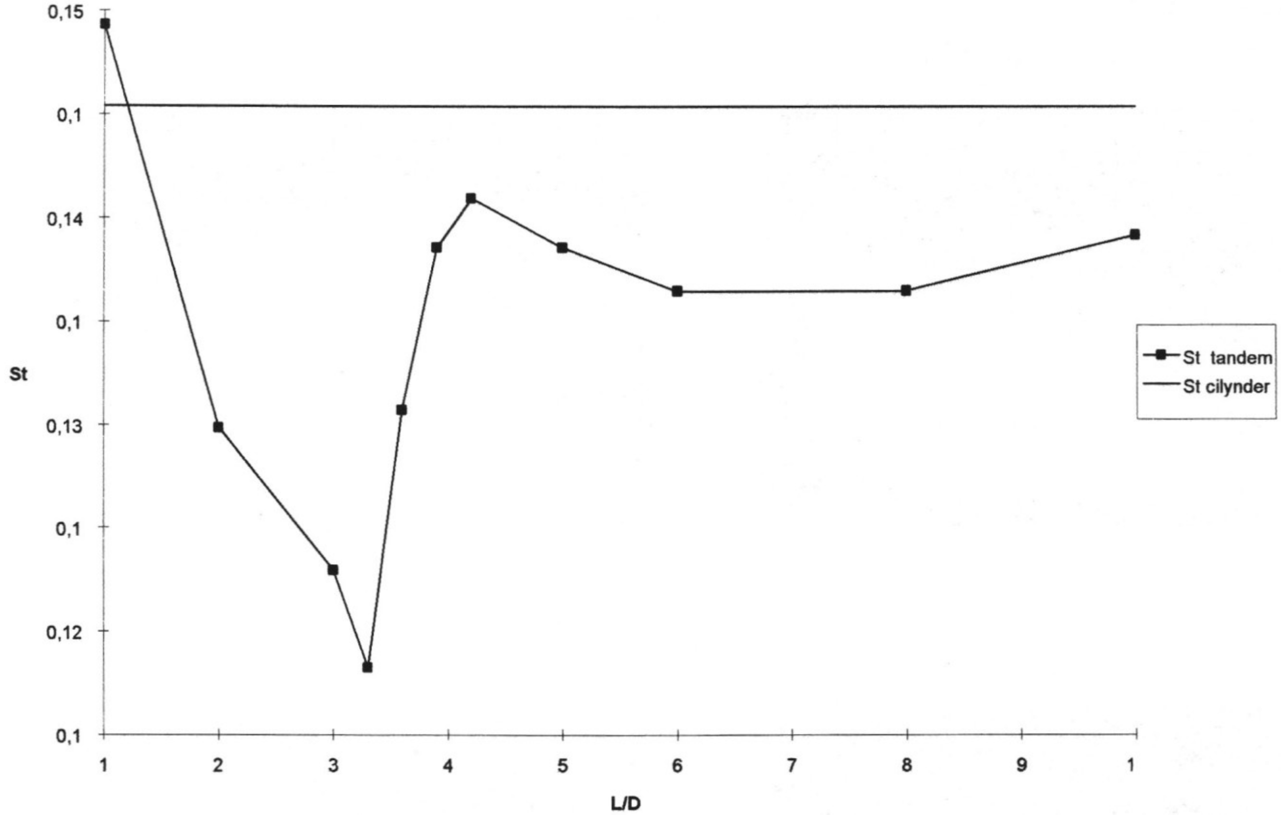


Fig. 3

Representative Two-Dimensional Flows

Single cylinder

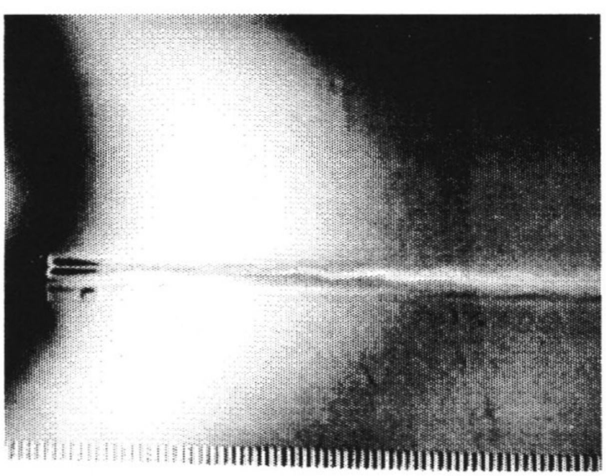


Fig. 4

Re = 20

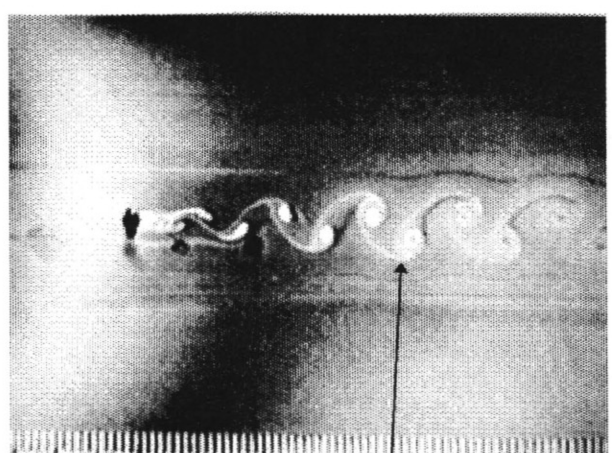


Fig. 5

Re = 65

Karman vortex wake system

Plane Plate, Re =300

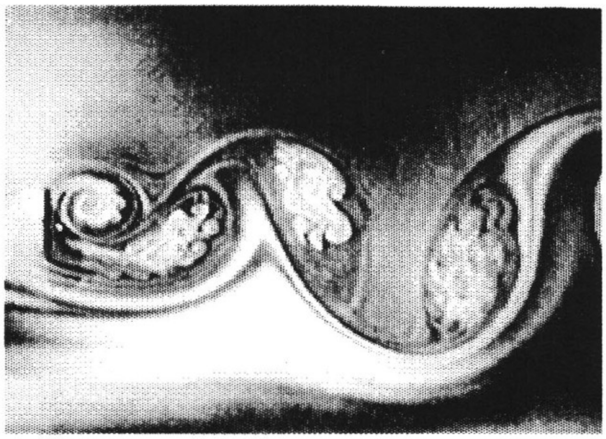


Fig. 6

t =0

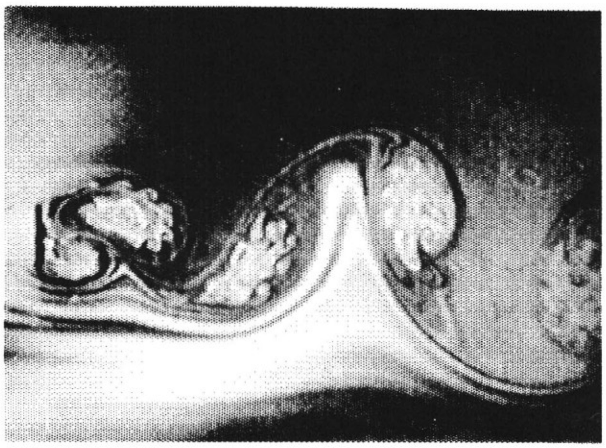


Fig. 7

t = 1/25 s

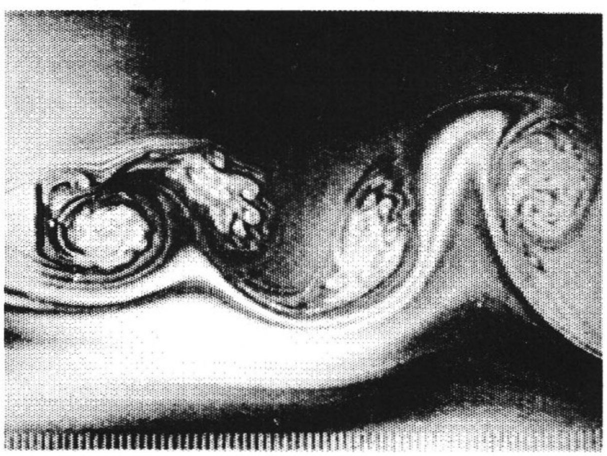


Fig. 8

t = 2/25 s

Cavity

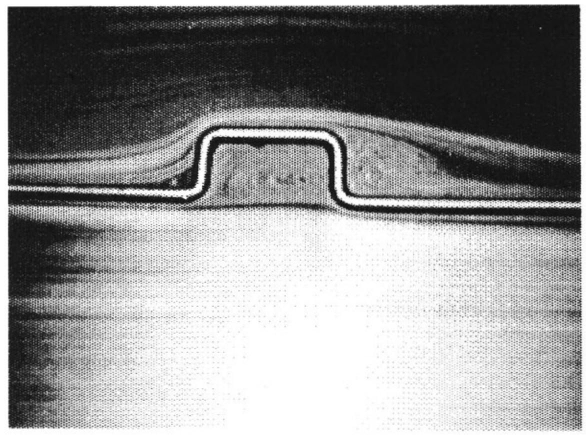


Fig. 9

h/l = 0.5

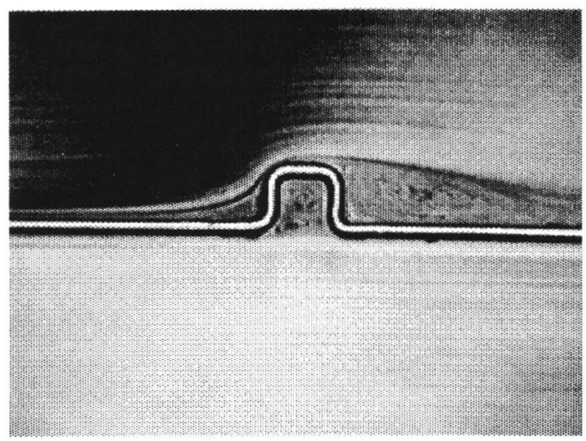


Fig. 10

h/l = 1

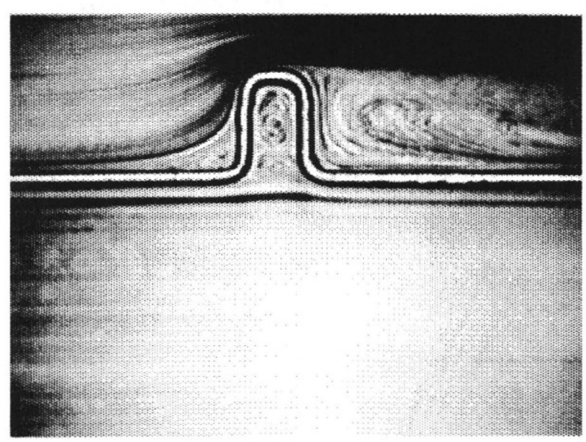


Fig. 11

h/l = 2

Two-dimensional Grid Turbolence

In Fig.13 we can notice that, moving downstream, the turbolence evolve to a larger scale

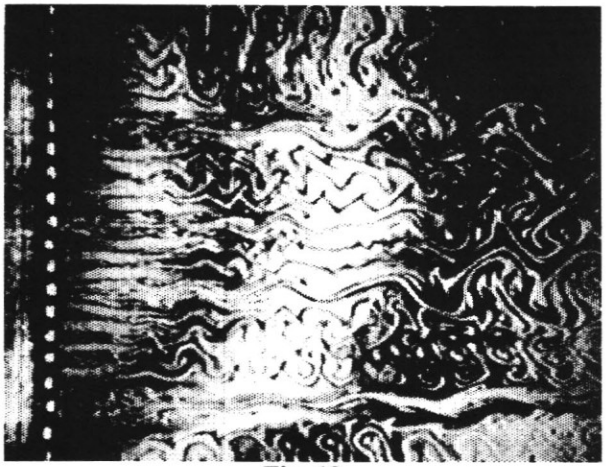


Fig. 12
Flow near the grid

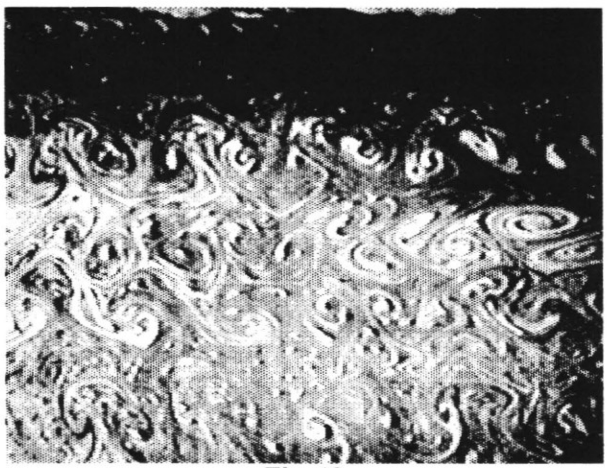


Fig. 13
Flow far from the grid

Jet Flow

Fig. 14

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