Exercise 5a

Visualisation of the incompressible flows.

1. **Goal of the exercise**
   Students are getting familiar with some visualisation techniques of the incompressible flows and interpretation basics of the obtained images.

2. **Theoretical background**
   Historically, visualisation is the oldest method of flow analysis. Visualisation played significant role in understanding complex flow phenomena and verification of mathematical models used to describe this type of phenomena. Image of general flow features can significantly reduce or sometimes eliminate time-consuming quantitative measurements and allows to state, whether they were done correctly or not.

   The possibility of employing a given visualisation method strongly depends on the flow velocity range that we consider. Separate techniques were developed for the incompressible and the compressible flows. In the first case, one typically injects into the flow "markers". In the compressible flows one usually employs optical methods as they are non-invasive for the flow. Considering these differences, the visualisation methods for the incompressible and compressible flows will be presented separately.

   As it was mentioned above, incompressible flow visualisation relies on the injection into uniform, transparent medium or at the surface of immersed body "markers" that can be observed directly or register them by means of more or less sophisticated photography method. Markers should have similar density compared to fluid density that is under consideration. The size of markers should be adjusted to the length-scale of the phenomenon that we want to capture. (For instance: flow velocity in the river can be determined by observing a boat, whereas turbulence in the air flow – by watching the markers with the size lower than 1 micrometer.)

   To analyze air flow and other gases we employ different types of smoke or small bubbles filled with helium. To visualise liquid flows we can use different dyes and paints, bubbles of hydrogen (produced by means of electrolysis), polystyrene spheres with density similar to liquid and other types of inclusions.

   Flow images obtained by means of visualisation, sometimes spectacular considering shapes and esthetic proportions, they are suppose to provide information about the quantities characterizing vector flow field.

   Before any image interpretation we have to recall some basic terms from flow kinematics.

   Streamline – line tangent to velocity vector at every point. The streamline equation is the following:

$$\frac{dx}{V_x} = \frac{dy}{V_y} = \frac{dz}{V_z} \quad .$$

Pathline – is the line (trajectories) produced by a given fluid particle. The equation for the pathline is the following:

$$\frac{dx}{V_x} = \frac{dy}{V_y} = \frac{dz}{V_z} = dt\,.$$

Streakline – line formed by fluid elements that flow through a given (constant) point in space.

In case of unsteady flow streamlines are instantaneous flow features, i.e. one can find such lines in the flow, that velocity vectors at every point on these lines are tangent to these lines. In the next instance of time at every point in space, there can be local change of velocity and because of this one can define new instantaneous streamlines.

Pathlines of different fluid elements, in case of unsteady flow, are the envelope of the instantaneous streamlines going through successive locations of the considered fluid element.

In case of steady flow – streamline, pathline and streakline coincide (they become the same line).

As one can notice, the analysis of the captured image of the flow is not as easy as one could naively think. Only for the motion entirely (on the macro and micro scales) steady all three lines become the same line.

In nature and different applications we are typically dealing with unsteady flows at the length-scale of the phenomenon or only locally (e.g. steady flow around cylinder is unsteady in the wake). Therefore, to describe flow features on the image one needs to be familiar with the visualisation technique and image registration.

2.1. Streakline visualisation

Taking a photograph of the flow in this technique is relatively the simplest, e.g. in the smoke tunnel (fig.1.).

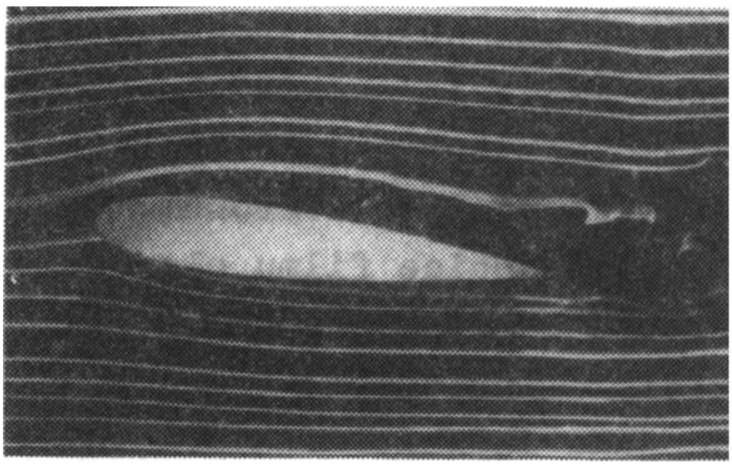

Figure 1 Flow around airfoil - streaklines.

2.2. Visualisation of instantaneous pathline

Instantaneous trajectories of fluid elements can be determined by taking a photograph with a short exposure time. In the figure one can notice then directions of motion, and instantaneous velocity can be evaluated by considering the distance covered by the element in a given exposure time. Example of this visualisation is presented in the fig.2.

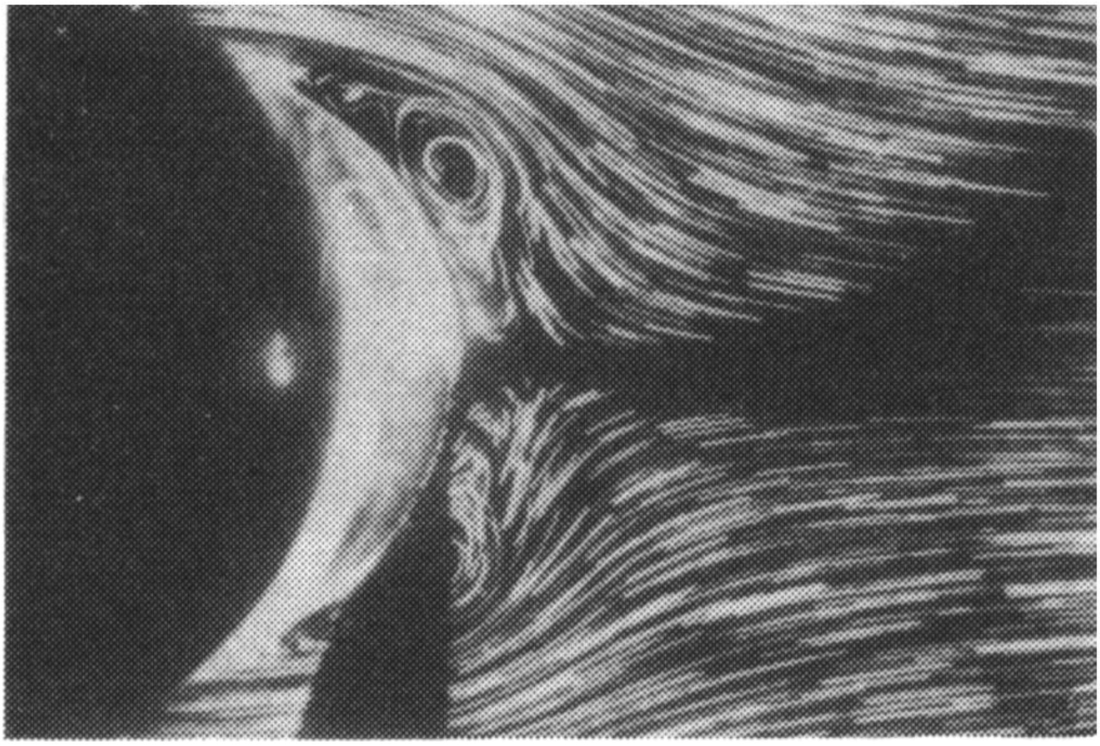

Figure 2 Flow structure behind a cylinder - instantaneous pathlines.

2.3. Visualisation of instantaneous streamline

Instantaneous streamlines can be obtained by recording a movie of the periodic injections of inclusions. This is very difficult technique.

2.4. Surface visualisation – oil film method

Surface visualisations are very common and provide interesting information. There three most commonly used methods that are: (i) the oil film method, (ii) directional “markers” and (iii) sand saltation method.

In the oil film method the surface of interest is covered by thin layer of pigmented oil (e.g. soot or titanium white). The speed of oil motion on the surface depends on its viscosity and shear stress at the model surface that depends on the flow velocity. By adjusting oil viscosity one can keep oil for longer time. Flushed oil leaves more pigment on the surface when its removed slowly, i.e. for lower shear stress. Image obtained in this way presents a map of averaged in time velocity and shear stresses (fig.3).

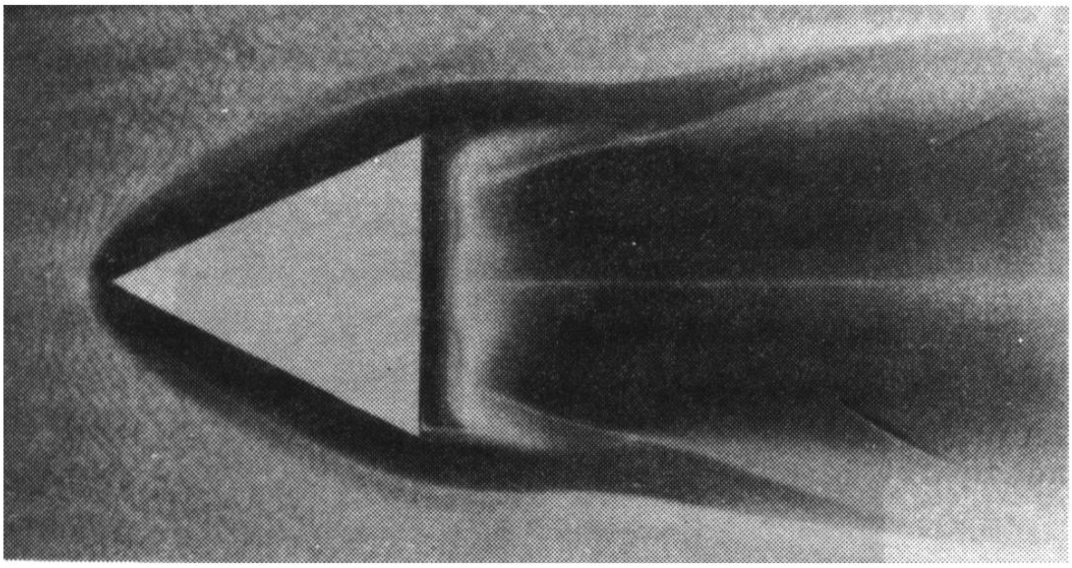

Figure 3 Surface visualisation - oil film method.

2.5. Surface visualisation – method of “directional markers”

In the second of mentioned methods, one attaches to the surface a tuft of wool by means of very thin glued threads. It is done in such a way that they can freely move in each direction. During the flow the tufts are adjusting position accordingly to the flow. Additional advantage of this technique is the possibility of obtaining some information about the character of the flow within boundary layer. In case of laminar boundary layer, tufts are tightly adhered to the surface and remain still. In turbulent flow tufts are fluctuating. Because of this temporary behaviour they become blurred in the image. In the separation zone tufts are clearly “standing out” from the surface and perform chaotic motion. In the fig.4 it was shown an example of such visualisation in case of the body and the wing of a glider Jantar Standard.

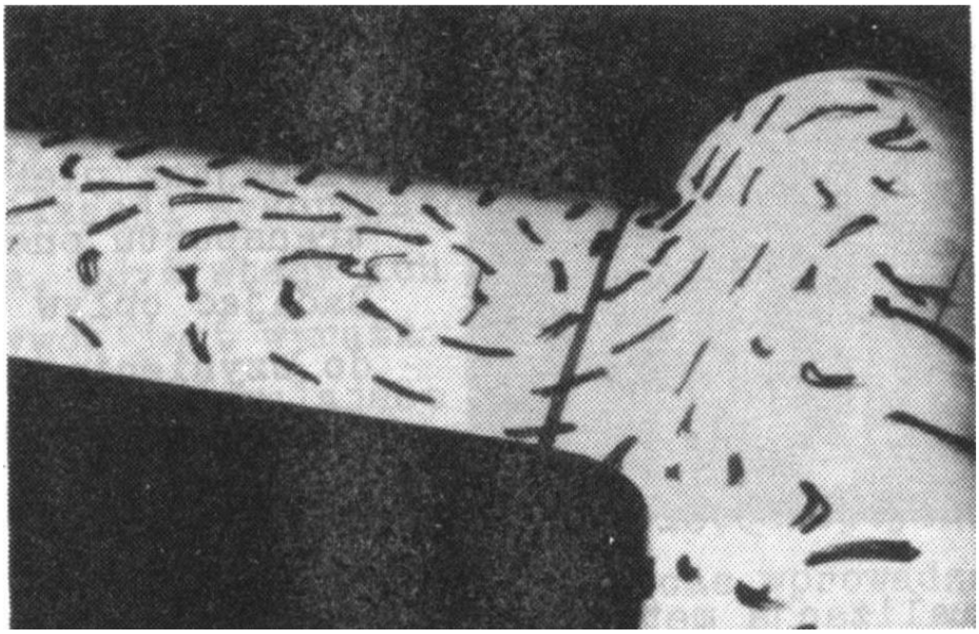

Figure 4 Flow in the blending zone of body and wing.

The method of “directional markers” is restricted to the surface of the immersed body but it can also be employed inside the flow field. Tufts (markers) are attached to a metal wire oriented perpendicularly to the flow direction. In this way we can visualise flow at a required cross-section. Example is shown in the fig.5, where wingtip vortices are visible in case of “delta” wing.

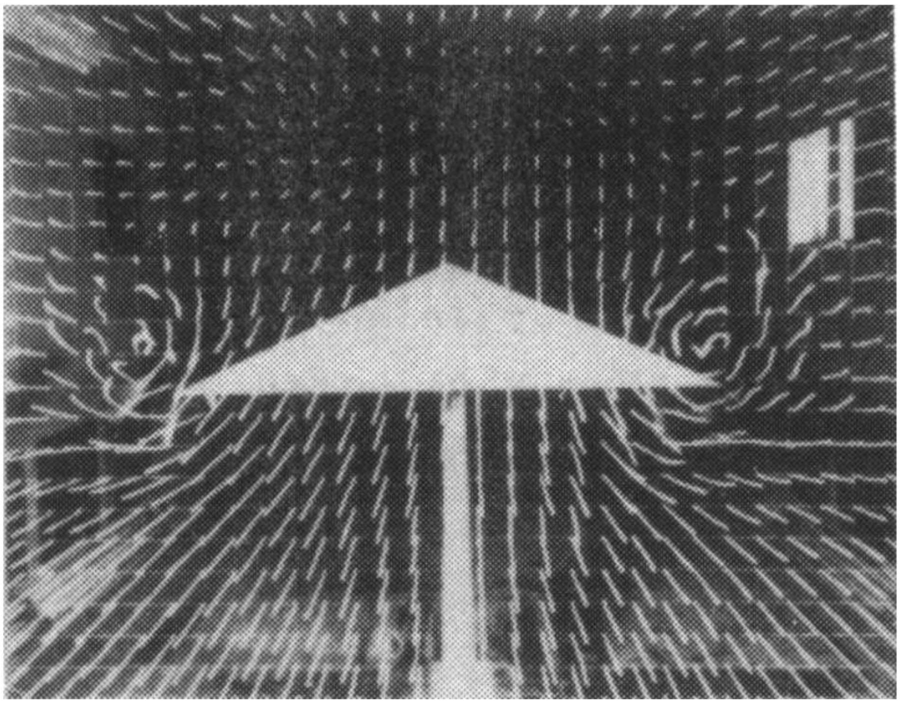

Figure 5 Wingtip vortices visualisation behind the "delta" wing.

2.6. Surface visualisation – saltation method

Some quantitative conclusions can be made by employing surface visualisation method called saltation (erosion) method with calibrated sand. The principle of this method relies on the phenomenon of erosion of rigid particles (grains of sand). The grains are removed when the flow velocity reaches critical value – corresponding to the first phase of pneumatic transport. When we deal with the flow around certain body we obtain non-uniform velocity field. Saltation of sand will happen only in regions, where the local flow velocity will be equal or higher than the critical velocity for the phenomenon. Knowing the critical velocity value and velocity of undisturbed flow one may determine lines of constant velocity ratio. Repeating experiment with different flow velocities and using differently coloured sand one can obtain a map of the flow (as in fig.6).

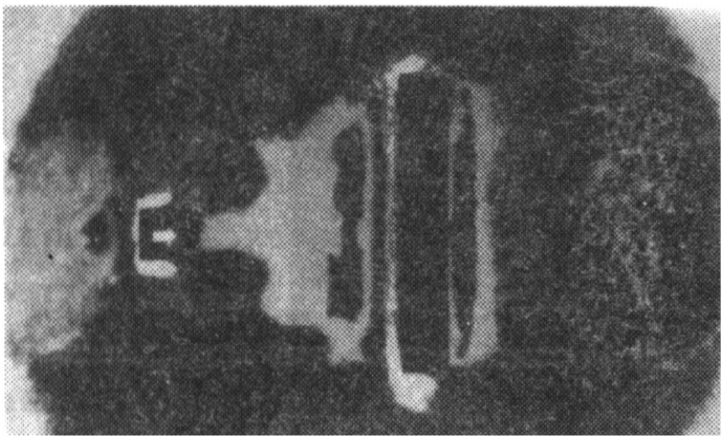

Figure 6 Visualisation with saltation method.

The method of oil film and saltation are especially useful in research devoted to flows in urban areas. One can determine zones of inconvenience (from the perspective of pollution or zones with unpleasantly high velocities).

Oil film method employed to aerofoil profiles can provide information about transitional zone, separation zone and zone where laminar bubbles exist – see fig. 7.

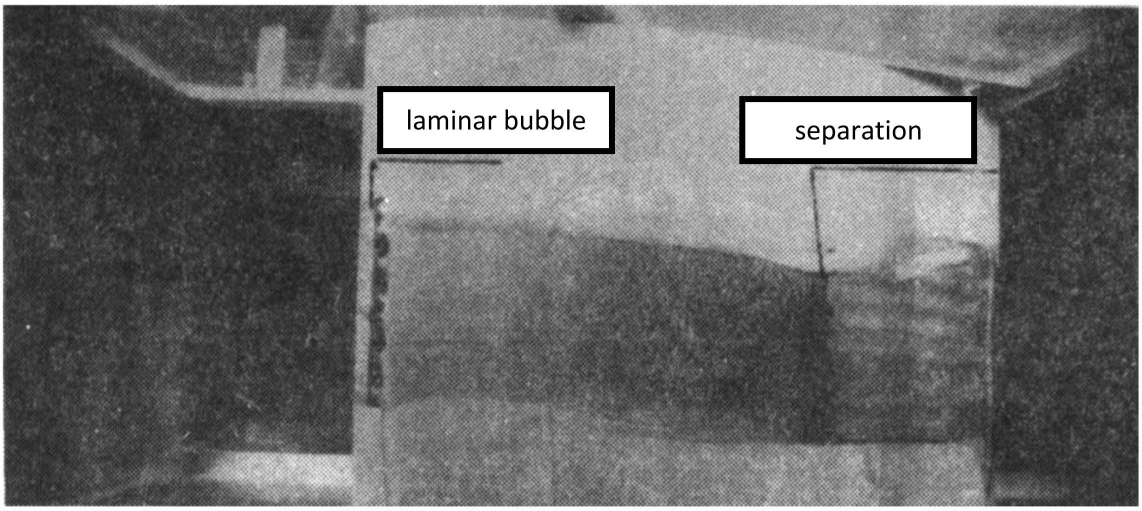

Figure 7 Oil visualisation of separation on the aerofoil profile (top view).

3. Experimental setup and exercise

3.1. Streakline visualisation

Visualisation is performed in smoke tunnel. The scheme of this tunnel is presented in fig. 8. Investigated model (1) is placed inside rectangular test-section. Flow in the tunnel is generated by the fan (2), sucking air from the environment through the inlet (3). In front of the test-section piping system injecting smoke is installed (4). Smoke is produced in generator (5) by burning oil. Oil is injected to generator from the reservoir (6) onto heater (7).

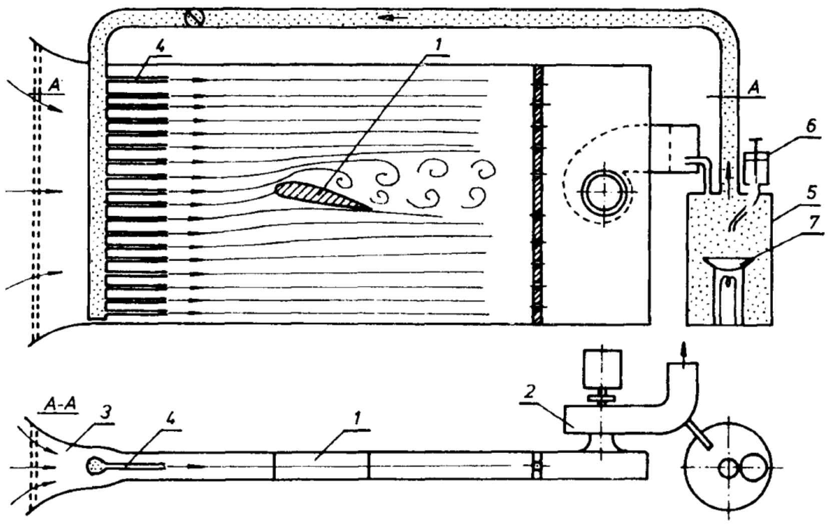

Figure 8 Scheme of the smoke tunnel

3.2. Pathline visualisation

Visualisation is performed in closed-loop water channel (fig.9). Flow is produced by waterwheel (1). Different flow velocities in the test-section (2) can be obtained by changing the rotational speed of the wheel.   Water free-surface is being covered with dust/flakes allowing to observe flow field.

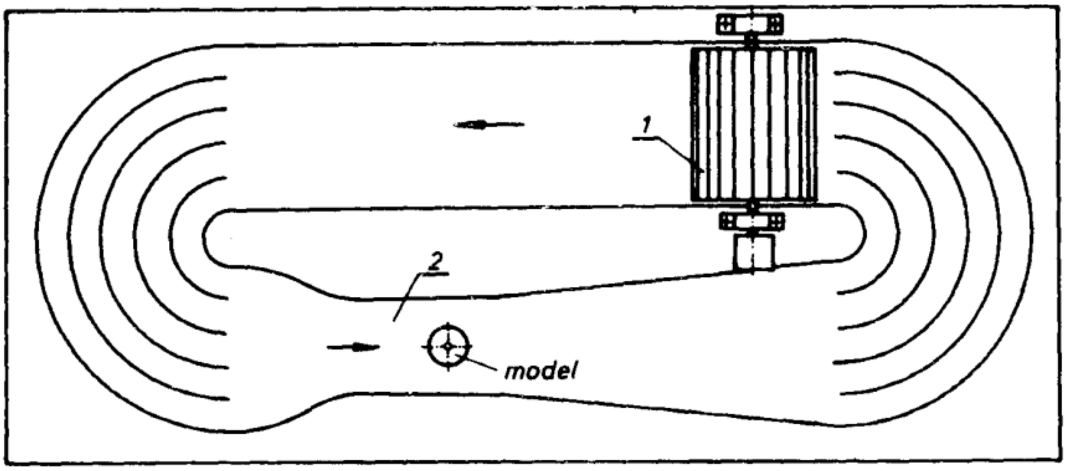

Figure 9 Scheme of water channel.