Budapest University of Technology and Economics

Department of Fluid Mechanics

Building Aerodynamics

Measurement with application of oil streak method

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Literature survey

The employable oil streak method is used for flow visualization in wind tunnel modelling. It presents the flow field qualitatively well, in case of steady flows.

The chosen material mixture has to be applied on the area of interest, then the model has to be rapidly inserted into the test section. Due to the shear stress of the air and the gravity, the compound will follow the streamlines and will show the surface pattern.

In order to obtain evaluable figures, the proper viscosity of the fluid indispensable. On slant or vertical surfaces, the effect of gravity will dominate, therefore the mixture has to possess sufficiently high viscosity to be able to represent the flow. On the other hand, it cannot exceed the limit, from where the speed of the air is not capable to move the oil, hence reveal the flow's shape. Further requirement against the material is that the measurement time should remain in the acceptable range, which is usually up to 1 minute.

Altogether, we can declare that for vertical faces, it is an extremely complex task to find an appropriate material combination when the investigated rate of flow below 160 km/h.

Fortunately, in the technical literature, we can encounter experimented mixtures of which just have to select the suitable one for the actual project.

The most commonly used material is the paraffin. It has fitting viscosity – if not appropriate, it can be changed by engine-oil or naphthene in the required direction -, but messy to clean up afterwards the investigation.

Another substance, which can be applied is the poly-glycol with the usage of fluorescent dye. It's a versatile material, which can be found in many areas from medicine to industrial manufacturing. The main advantage of it is it solvable by water, which makes the cleaning much easier. However, it has lower viscosity compared to the paraffin.

Generally speaking, the utilization of a colouring material significantly helps the interpretation of the flow pattern. The applied colour depends mainly on the background, thus the white colorant, for example, the titanium dioxide can be used broadly. To further enhance the visibility, we can apply ultraviolet illumination, which also could help to detect the incidental contaminations in the wind tunnel.

Afterwards, we chose the suitable material mash, it becomes necessary to test the needful proportion between the oil and the colorant. This ratio depends on, for instance, the surface roughness of the investigated model and the dissolution limit of the blend. In the professional literature, we can find guidelines for the recommended rate.

The majority of the sources propose around 1:3 colorant-oil proportion. According to an unclassified 1962 NATO document [1] - which deals with flow visualization in wind tunnels using indicators – a practicable solution could be the anthracene-oil mixture in 1:3 ratio. This blend's disadvantage is that it is colourless in sunlight, thus it is necessary to use ultraviolet radiation, in which it exhibits blue.

Furthermore, it suggests the mash of titanium dioxide and oil in the same proportion as the previous mixture and the accidental usage of linseed oil in the same amount as the colorant.

We can find further useful information in Kristóf Hári's BSc dissertation [2]. The author unfolds in it that the appropriate mixture also depends on the temperature and flow velocity. He also mentions a rule of thumb that the well applicable solution comprises one and a half dl oil, which two-third is paraffin and one third is instrument oil and 3 coffee-spoon titanium dioxide.

This chapter was written by the usage of sources [3], [4] and [5].

Test of the suitable mixture

There were available paraffin and titanium dioxide at the department's laboratory, thus we chose to investigate a mixture, which includes these. Our starting-point was the recipe delineated by Kristóf Hári [2].

In order to ensure the appropriate boundary layer profile, we fabricated from Styrofoam a parallelepiped for the test, which filled the whole cross-section of the NPL wind tunnel in the horizontal direction. Unfortunately, the paraffin slowly but surely dissolves the Styrofoam, hence the top of it – where the trial happened - had to cover by an aluminium sheet. There are other advantages of the metal plate, for example, it facilitates the cleaning and increases the weight of the model as well. To eliminate the scratches on the sheet, which could influence the flow pattern, we covered the disc with a matte black foil.

To determine the applied amount of components, we used a gram accuracy balance. After a couple of trials, we successfully identified the best mixture. **It contains 87-gram paraffin, 6-gram titanium dioxide and six press of chain oil**. At this point, it is important to emphasize, that the mash has to be intensely mixed for an appropriate amount of time, in order to avoid the formation of two phases. This time duration is around five minutes.

A flow pattern, which measured by the described ratio is presented in Fig. 1.

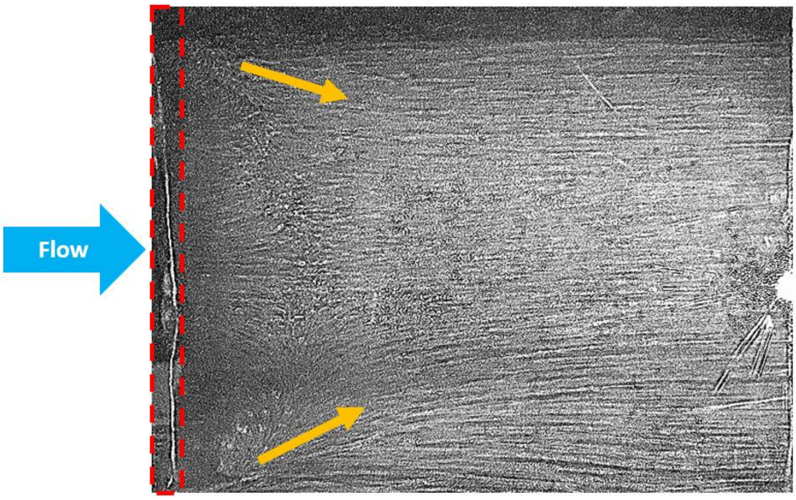


Fig.1: Flow pattern on the test model (wind direction from left)

We can observe a narrow separation bubble (within the red dashed rectangle) at the leading edge of the model. In addition, the streamlines in the first third of the model directed slightly inward of the domain (see orange arrows).

Investigation of a cubic building

Fig. 2 illustrates the investigated building model, which was attached to the base used for the test (on the left) and the technique of the anointing and its amount (on the right).

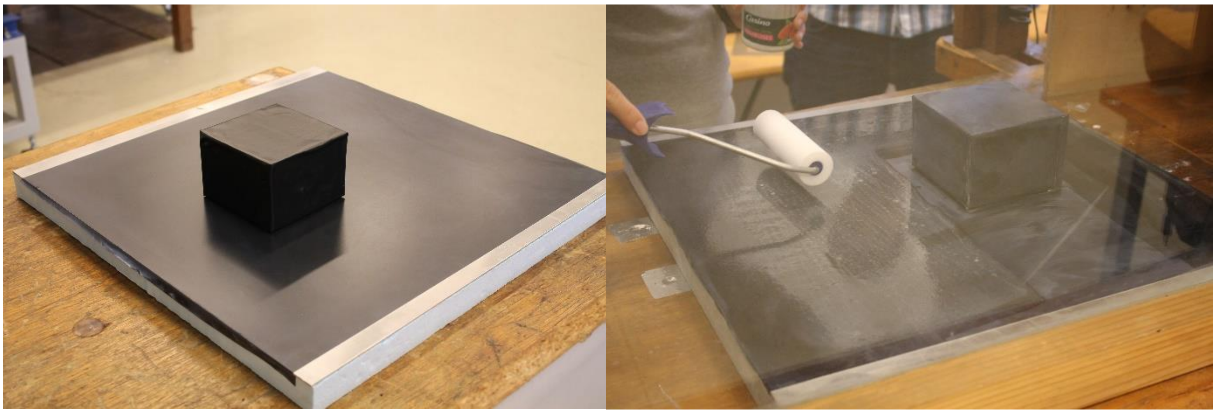


Fig.2: Cubic building model on the base (left), anointing of the model (right)

Measurements were carried out at two different wind velocities (7,4 m/s and 11,2 m/s) with two building position. The first was, which can be seen in Fig.2 i.e. when the front wall is perpendicular to the wind direction and the second one when it was in 45° angle to the wind.

Fig. 3 shows the comparison of the pattern at lower and higher wind velocity from a top view. The flow field is similar in both cases, but we can observe behind the building on the vortices (red dashed curved arrows), that the mixture is working better at the higher velocity. Both pictures represent well the horseshoe vortex (shown in dotted orange), moreover, we can see an interesting phenomenon, that at the higher velocity the vortex has a little tip in the middle. The separation bubble behind the building and at the top (end of separation shown by blue dashed line) of it clearly visible and the size of it easily estimable. Two smaller vortices can be found on the top after the trailing edge, too (pointed by the green arrow)

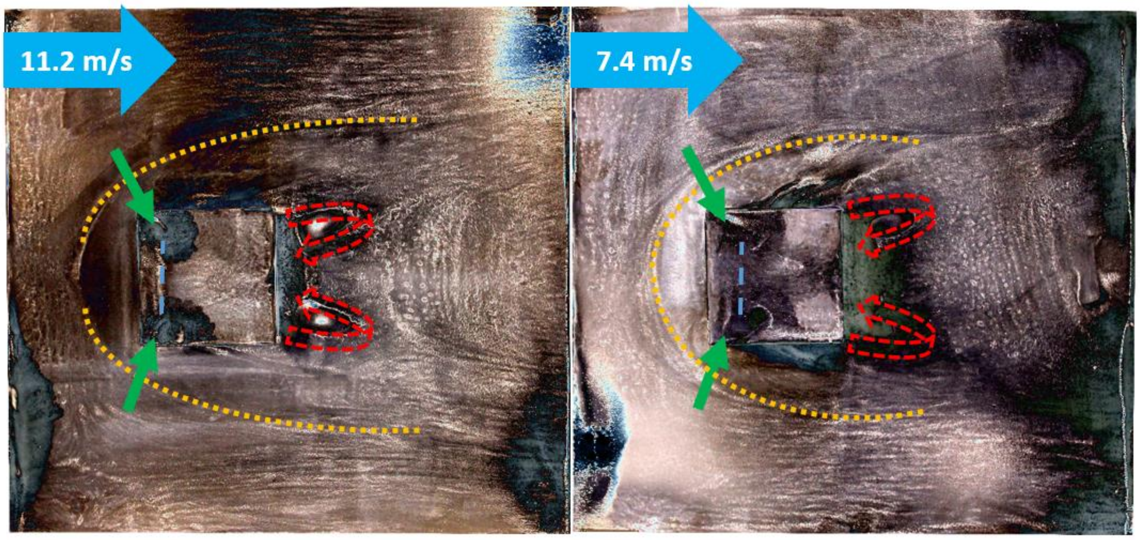


Fig.3: Top view of the model with wind direction from the left, 11,2 m/s (left), 7,4 m/s (right)

We can investigate a little more in detail the building in Fig. 4, in an axonometric view.

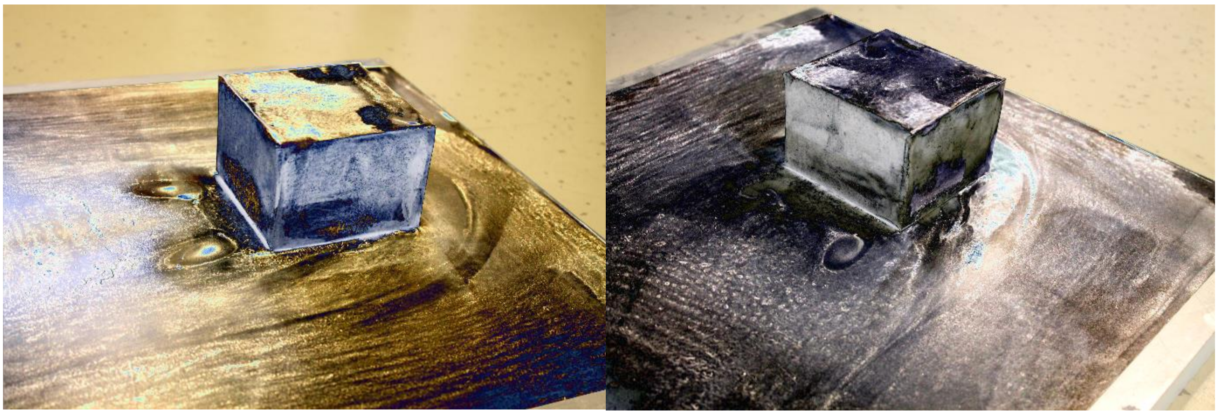


Fig.4: Axonometric view of the building, 11,2 m/s (left), 7,4 m/s (right)

Fig. 5 exhibits the results of the measurement when the model was rotated to 45° to the wind direction. The vortex detachment zone is easily observable both at the front (orange dotted line) and the top (dashed red line) of the building. The size of the separation bubble, unfortunately, cannot see perfectly, because of the fast drying in the middle back, but if we follow the two vortices' (shown by dashed green arrows) boundary it can be imagined. In this case, the higher velocity also gives a more interpretable picture.

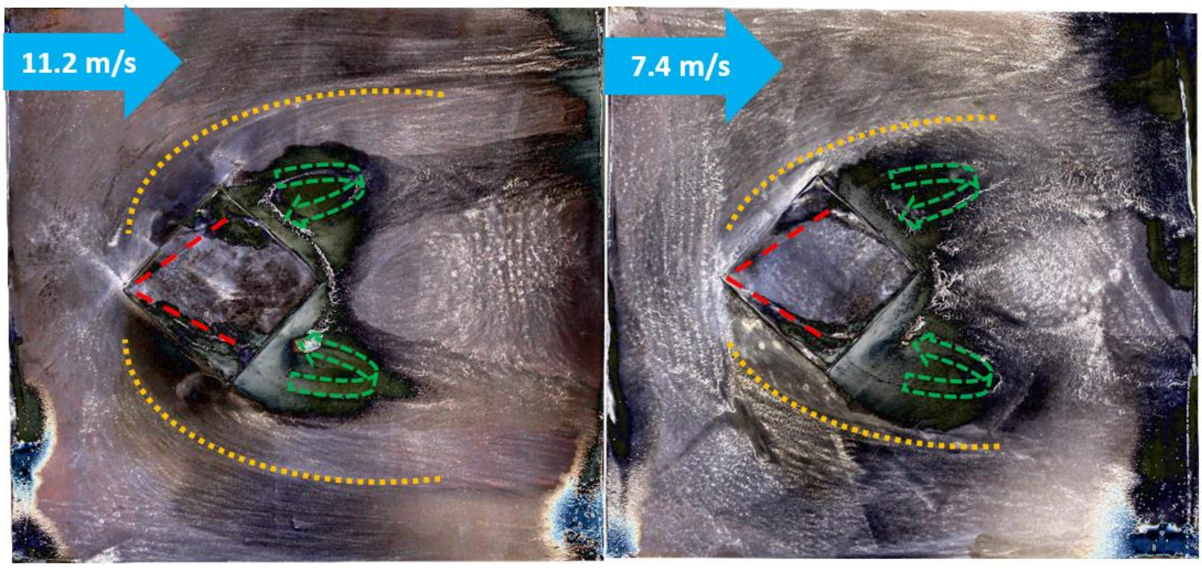


Fig.5: 45° angle of attack from top, 11,2 m/s (left), 7,4 m/s (right)

The aforementioned flow formations can be viewed in more detailed in Fig. 6. The path of the delta wing vortex on the roof of the building can be viewed more picturesque. The separation bubble at the back of the house, in case of the 11,2 m/s wind velocity looks much larger, than it is because the wind continuously transported the oil firm instead of drying it.

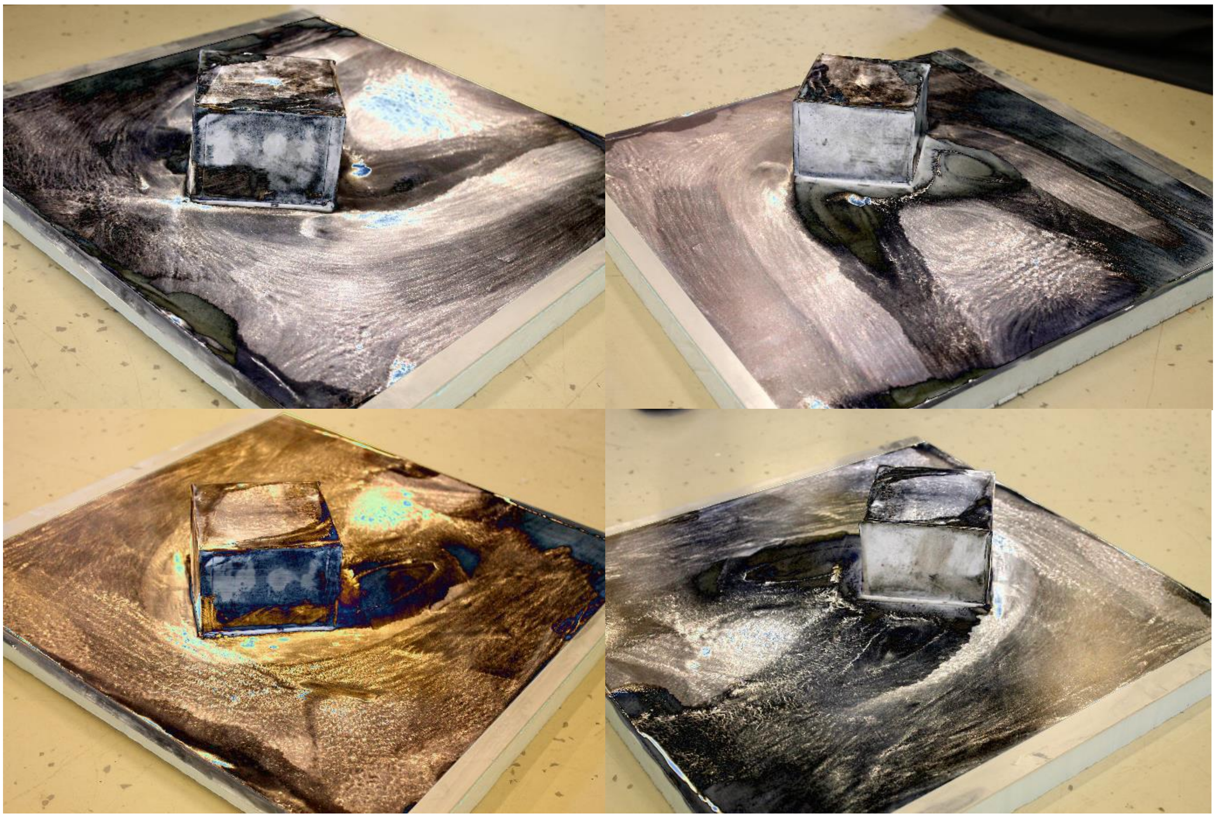
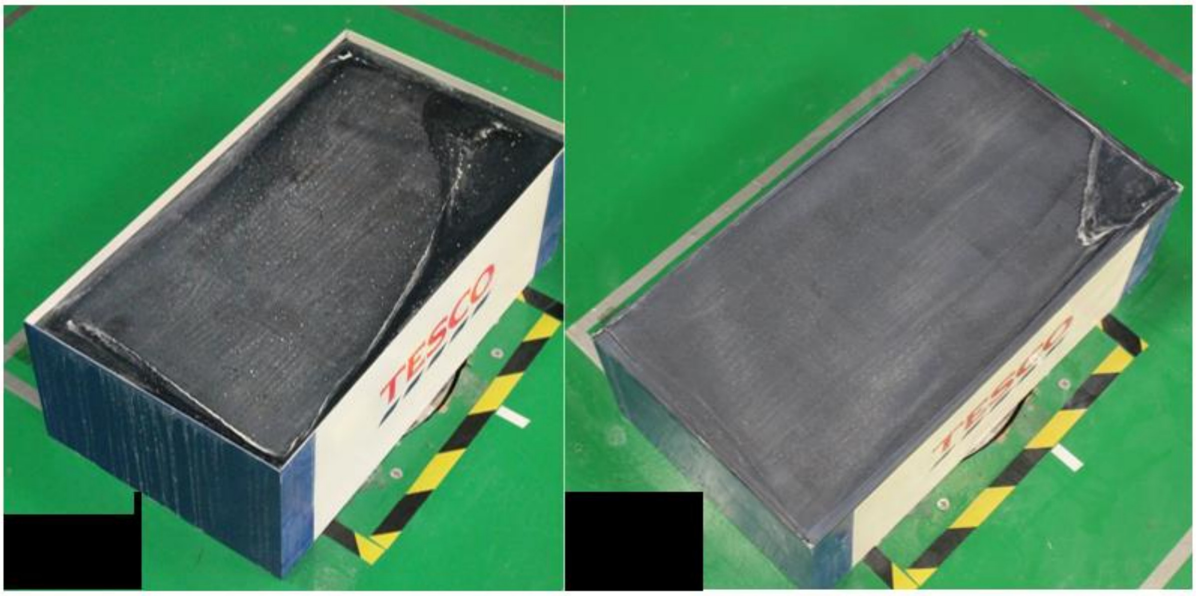


Fig.6: 45° angle of attack from front and back, 11,2 m/s (top), 7,4 m/s (bottom)

Investigation of a Tesco with parallelepiped shape



The ultimate goal of the measurement was the inspection of a Tesco's two configurations. Fig. 7 illustrates the formations, which were studied.

Fig.7: Investigated configurations, with verge on the top (left), without verge (right)

The difference between them is the presence of a gap on the top in one case. This clearance was achieved by a foil coated aluminium plate, which position was regulated by its support's height.

The examination was carried out at 20 m/s wind velocity at the big wind tunnel. Due to the high speed, it was necessary to anchorage properly the model, therefore we applied screws. The other consequence of the larger wind speed is that we had to use even more mixture to be able to follow the streamlines. To be easier to imagine or estimate the needful amount of fluid, I present Fig. 8, which shows the anointing process.

Fig.8: Anointing process

Both layouts were studied for three different angles of attack. One which was perpendicular to the wider side, one which was perpendicular to the narrower side and one, which was between these two positions i.e. in 45° angle.

Fig. 9 represents the results of the experiments, when the wind arrived from the narrower side, namely from the left.

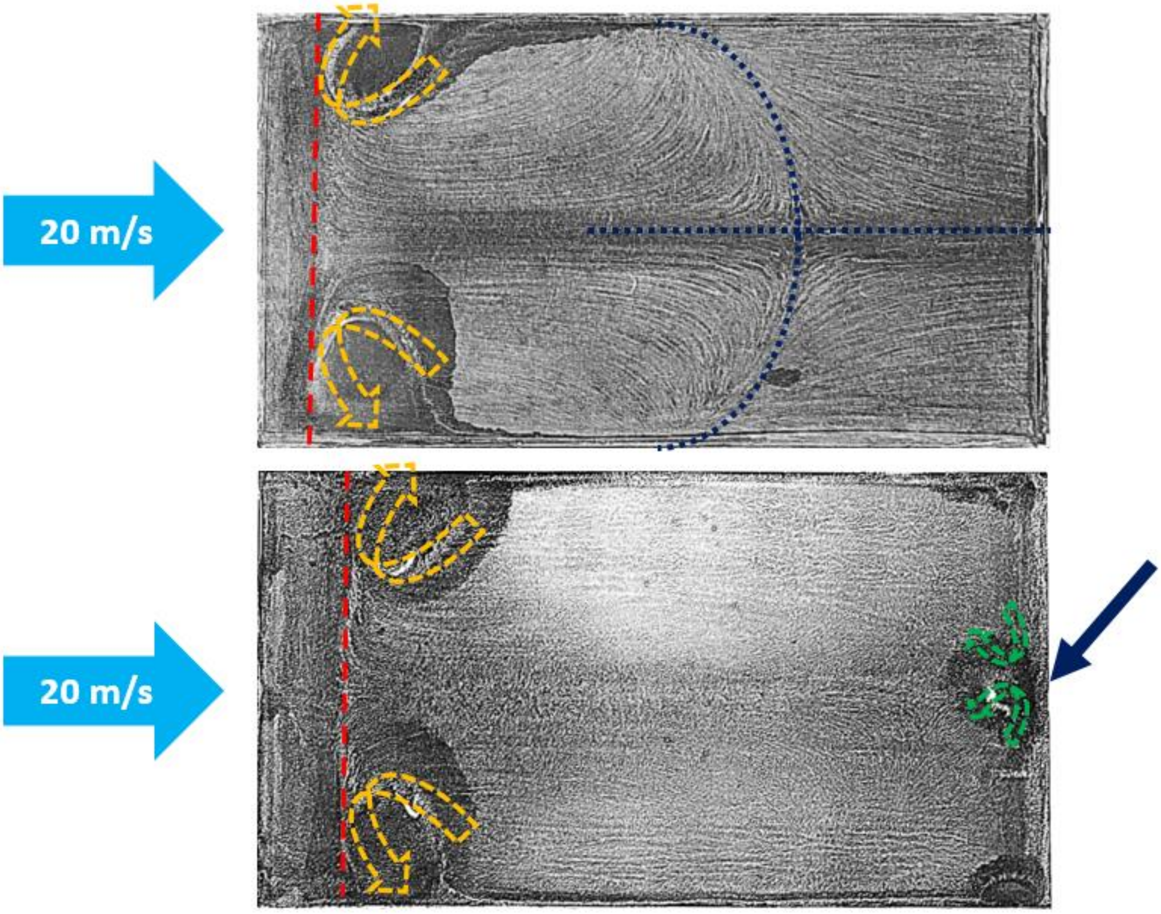


Fig.9: Top view of the building, wind from left, without verge (top), with verge (bottom)

The formations appear similar at first glance, but we can discover several subtle deviations. With the verge, the separation bubble at the leading edge of the building's top is almost double size, compared to the flat roof (see dashed red line). We can observe two vortices in both cases (shown by orange arrows), which rotates counter, the upper one clockwise, while the lower one counter-clockwise. The size of them similar, but the effect of them not. In the top picture, we can clearly see a semi-circle like curve, which links the two vortices. The impact of the vortices on the flat roof spreads till this arc, wherein the middle we can notice a saddle point like formation (see dotted blue line). From this line, the streamlines are following the direction of the far field. In contrast, the version with the verge isn't contained this size structures. The effect of vortices is relatively limited. However, we can remark a patch in the middle, close to the trailing edge (shown by blue arrow), which origin can be led back to the presence of the side and back wall (flow direction of mixture shown with green dashed arrows).

The results of the investigation, when the whole model was rotated by 90° can be seen in Fig. 10.

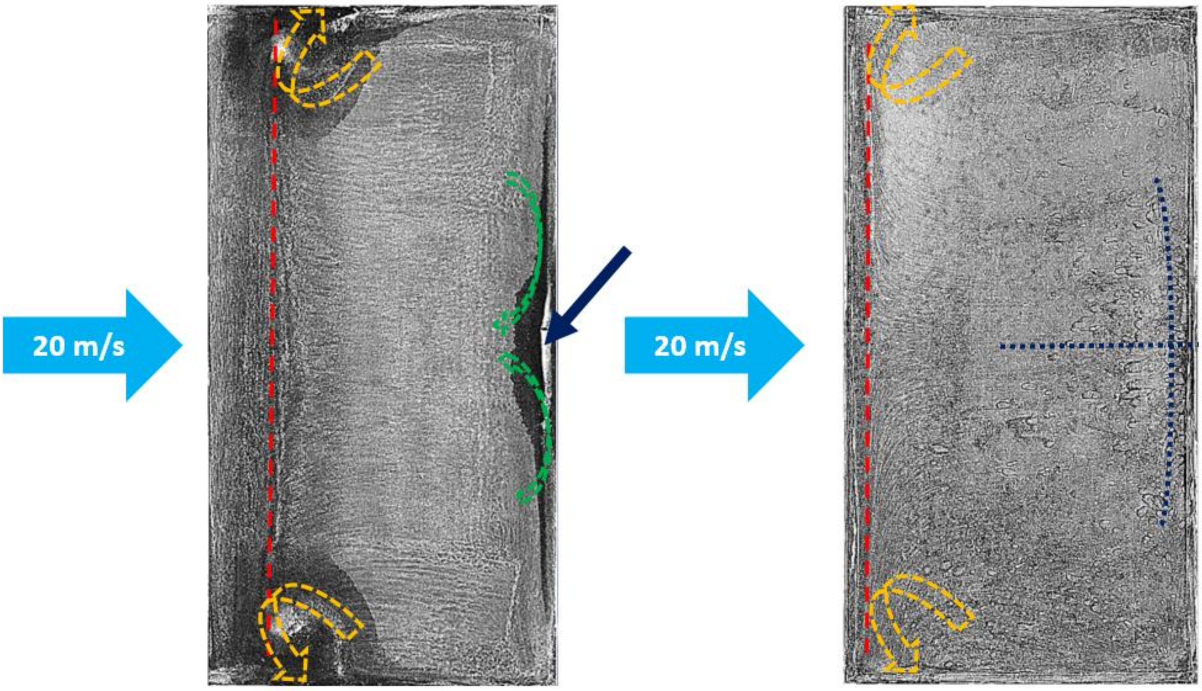


Fig.10: Top view of the building, wind from left, without verge (right), with verge (left)

Quickly noticeable, that the flow has less effect on the flat roof. The structures are the same in both pictures, but the sizes are less significant. We can declare, that the basic build-up of the phenomenon is the same as visible in Fig. 9. (Because of that, the same graphical elements are applied) We can identify the counter-rotating vortices and the wider separation bubble. In addition, the effect of the verge at the trailing edge also remarkable, but in this case it is elongated (green dashed arrow).

The final examined layout can be viewed in Fig. 11. The flow left a similar mark on both roofs, but because with the verge it is more visible, I will start the analysis on that.

The formation corresponding the pattern, which we could discover on the previously discussed cubic building's top when it stood in 45° to the wind direction. The interesting thing about this formation that it is asymmetrical, due to the geometry of the model. We can clearly see a continually expanding channel (shown by dashed red line), which directed toward the top right corner, where the mixture is collected in a vortex (shown with orange arrow). Nevertheless, we cannot see the entire another branch of the delta wing vortex, which led to the bottom left corner because of the shortness of the roof.

Owing to the verge, the oil remained on the top and accumulated in the top right. We can find the analogous phenomenon on the other picture as well. The difference is its size, which arises from the smoothness of the roof.

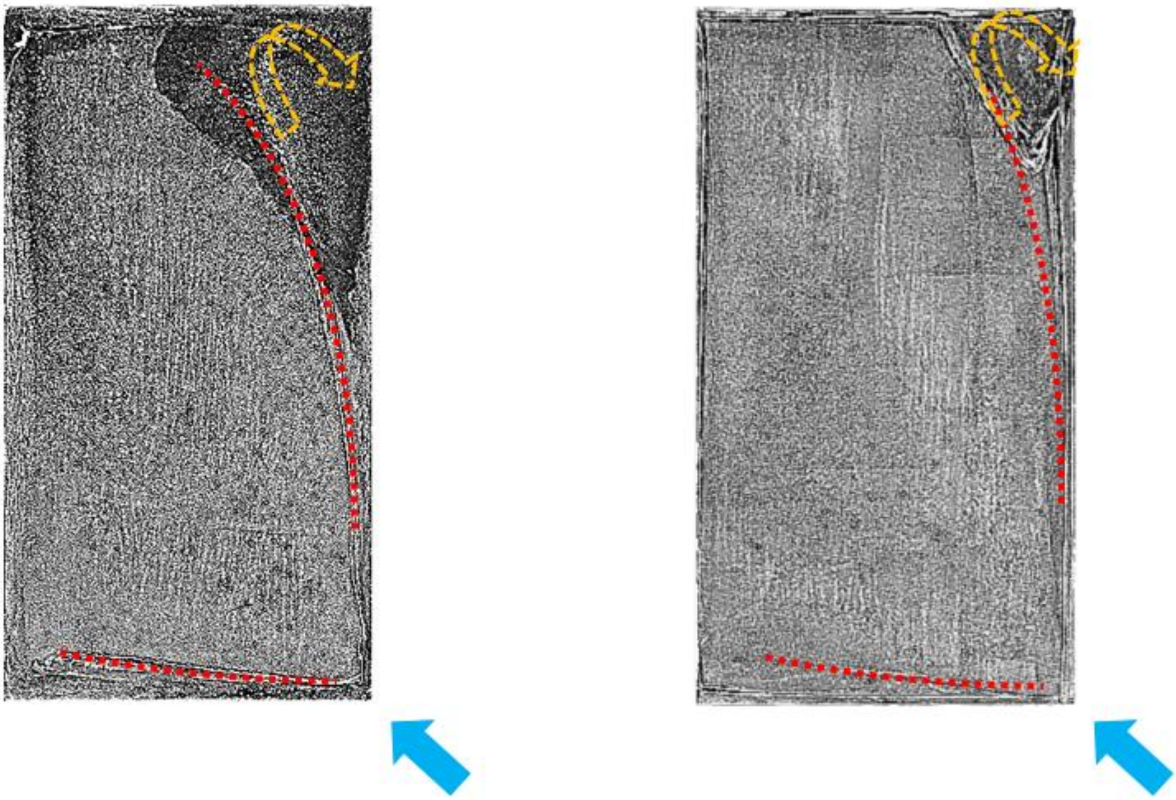


Fig.11: Top view of the building, wind from the bottom right corner, without verge (right), with verge (left)

Sources

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[2] Kristóf, H.: *Airfoil segment investigation with Laser Doppler Velocimetry in an NPL wind tunnel*. BSc dissertation, 2013. URL: *http://www.ara.bme.hu/~nagy/_oktatas/diploma/MEAS_%28AIRFOIL%29_Hari_Kristof_%282009%29_BSc.pdf*

[3] Barlow, J. B., Rae, W. H., Pope, A.: *Low-Speed Wind Tunnel Testing.* John Wiley & Sons, Part 5, 1966.

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