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INSTRUMENTS FOR THE EVALUATION OF THE AERODYNAMIC PERFORMANCE OF WIND TUNNELS

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Abstract: *Wind tunnels are installations which generate air flow around a model or one of its components in the test room in order to perform aerodynamic experiments. The current article aims at reviewing the experimental wind tunnels as well as the visualization techniques used.*

Keywords: *wind tunnel, visualization technique, test room, air flow quality*

1. INTRODUCTION

Wind tunnels are installations which generate air flow around a model or one of its components in the test room in order to perform aerodynamic experiments measured by a set of sensors. According to the way in which the air flow is entrained, wind tunnels classify in open-circuit and closed-circuit wind tunnels while experiment duration classifies them in continuous-flow and intermittent-flow wind tunnels (with vacuum storage tank, with pressure tank). Depending on the speed reached in the test room area, these installations fall in different categories as follows: low-speed subsonic wind tunnels (M ≤ 0,5); high-speed subsonic wind tunnels (0,5 ≤ M ≤ 0,9); transonic wind tunnels (0,9 ≤ M ≤ 1,3); supersonic wind tunnels (1,3 ≤ M ≤ 5,0); hypersonic wind tunnels (M > 5,0).

1.1. Subsonic wind tunnels.

These wind tunnels are mostly continuous- flow and of incompressible flow speed. They are shaped like variable section tubes (convergent-divergent) and can be closed-circuit or open-circuit ones; see figures 1.1 and 1.2 [1]. The closed-circuit subsonic wind tunnel has some advantages: superior air flow, low operating costs, mostly uniform flow in the test room, the fan compensates only for the air flow losses, silent performance unlike the open-circuit wind tunnels. Its disadvantages are the high construction costs, the need of air cooling installations and the dumping of the exhaust waste.

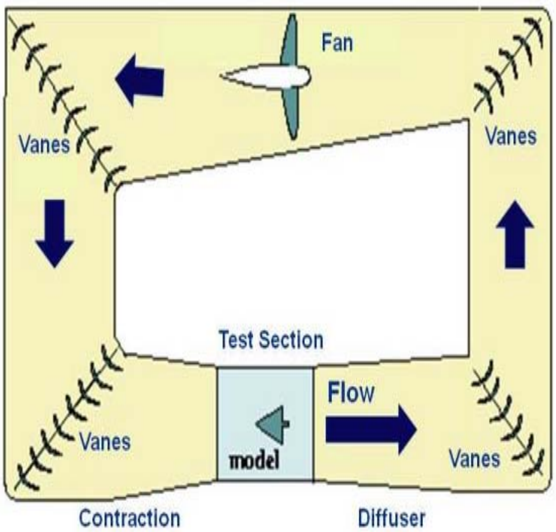

Fig. 1.1 Closed-circuit wind tunnel

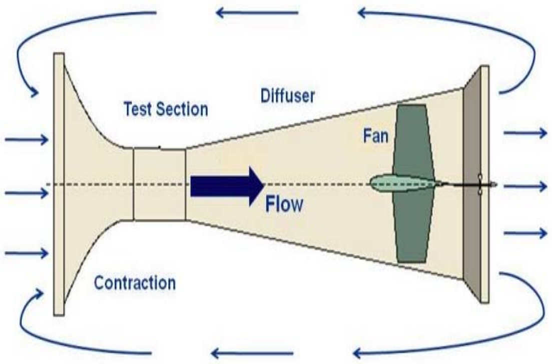

Fig.1.2 Open-circuit wind tunnel

1.2. High-speed subsonic wind tunnels. Due to the high speed of the flow, the air warms up and influences the precision of the experiment if appropriate measures are not taken. Therefore, a cooling installation is needed. The simplest option is evacuating some of the warm air at the entrance of the collector and collecting cold air behind the diffuser from the outside environment.

1.3. Transonic tunnels. They may be continuous-flow, closed-circuit wind tunnels or intermittent-flow, open-circuit wind tunnels. Reynolds numbers must be around $6x10^6$ for 0,1% turbulence in order to obtain data as similar to the one in real flight conditions as possible. When Mach numbers are close to 1, the blockage or choking effect occurs in the wind tunnels with solid wall test area. This is characterized by the fact that, in spite of the rise of the compression level, the Mach number does not grow anymore, which leads to the impossibility of experimenting with a Mach number close or equal to the unit; see figure 1.3.

1.4. Supersonic tunnels. According to their way of functioning, these installations fall in two categories: intermittent-flow wind tunnels and continuous-flow wind tunnels. The intermittent-flow wind tunnels classify in wind tunnels with vacuum storage tank, wind tunnels with pressure tanks, and combined wind tunnels. They can function as transonic ones as well. Due to the speed conditions, the current and future requirements impose $Re>6x10^6$ Reynolds numbers which can only be achieved through pressure variation. Consequently, wind tunnels with pressure tanks (up to 10 atm.) are largely used.

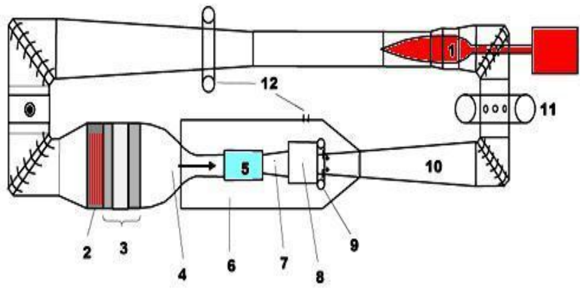

Fig. 1.3 Open transonic wind tunnel [2, 3]

1 – main compressor; 2 – heat exchanger; 3 – honeycomb and screens; 4 – first and second (flexible) nozzles; 5 – test section with ventilated walls (allow mass flow out from test section to establish transonic regimes); 6 – plenum chamber (adjusts pressure in the test section); 7 – reentry flaps (return mass to the main circuit); 8 – second throat (forces shock formation top revent flow disturbances from moving backward into the test section); 9 – injectors (provide extra momentum to the main flow, saving main compressor power requirements); 10 – diffuser (decelerates the flow); 11 – blow-off (exhausts mass flow injected); 12 – plenum extraction and re-admission ports.

1.5 Hypersonic tunnels. Such wind tunnels have been required by the field of aerospace. An intercontinental ballistic missile can reach a 10,000 km distance during flight M=22. At such speeds, dissociation, ionization and formation of compounds such as the nitric oxide occur. Ionization can lead to magnetic field interaction and the acting forces during the flight can change. The research method in the hypersonic field employs hypersonic wind tunnels which use air or helium to reach $M > 5$ by means of retention in diffusers. Once these Mach numbers are reached, the decrease in temperature is so significant that the work area is in danger of liquefying. If air is being used as working area, it is previously heated to prevent liquefaction after retention. If helium is used though, problems disappear as it liquefies at much lower temperatures than air. Therefore, $M = 30$ can be achieved with no heating.

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2. THE WIND TUNNEL. COMPONENT PARTS

As shown in figure 2.1, the components of the wind tunnels are the following:

The confuser is placed before the test section and has the task of increasing air flow velocity up to value V_c and of decreasing turbulence in the test room. There are several types of confusers, with main geometrical characteristics of a confuser with section variation in one plane and double curvature and curvilinear generators.

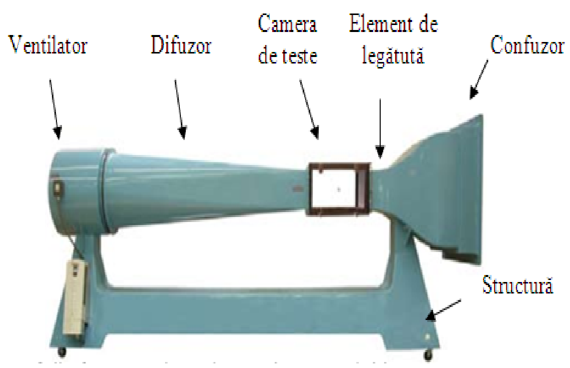


Fig. 2.1 Components of a didactic subsonic wind tunnel [4]

The test room is where the model for studying is placed and the usual natural conditions are created. In the transversal section, the test room can take different shapes depending on the tunnel destination, the most often used being the rectangular and circular ones while octagonal and elliptical ones are rarer.

The diffuser is placed in continuation of the experiment chamber and it needs to be created so as not to allow air flow detachment from its walls.

Turbulence reduction screens are used to reduce air flow turbulence and to favorably lead the flow towards other important components such as the confuser.

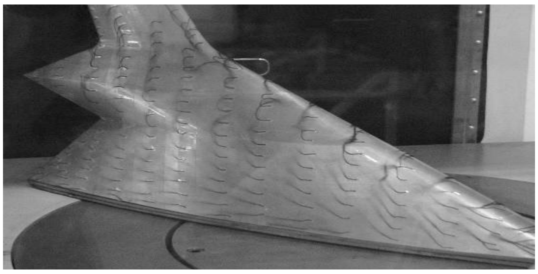
The blower/ The fan is the power source of the installation which ensures air circulation through the tunnel. The axial ones are commonly used with classical wind tunnels. In order to reduce vortices generated by the blower's rotor, two identical blowers spinning in opposite directions are sometimes mounted consecutively. Turbulence reduction screens and different profiles are often introduced along the wind tunnel circuit. They are mounted the farthest from the test room. If the speed of the blower is constant, the air flow is adjusted by means of a vane.

Connecting elements are generally needed in closed-circuit wind tunnels and they connect the main component parts. They are mainly curvatures and pieces ensuring passage from one section to another such as is the passage from the circular section of the blower to the rectangular flow section.

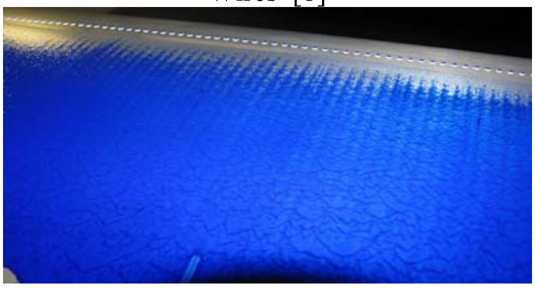
3. VISUALISATION TECHNIQUES IN WIND TUNNELS

Visualization of the experimental air flow is necessary for collecting an image of the flow around the model as well as for testing flow theories. Suitable visualization techniques can help in visualizing light flows (for example, vortices) or heavy flows characterized by tack effects (for example, boundary layer flows, and separation areas).

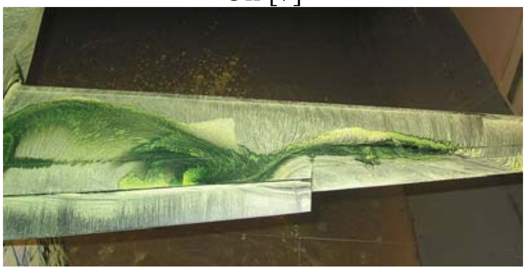
Smoke [9]



Wires [8]



Oil [7]

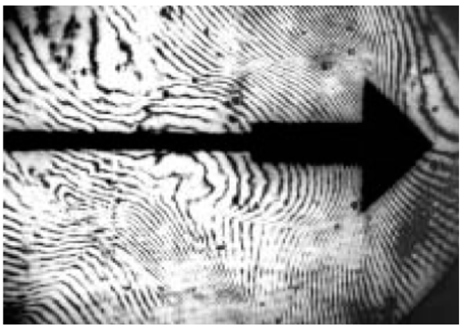


Powder [7]

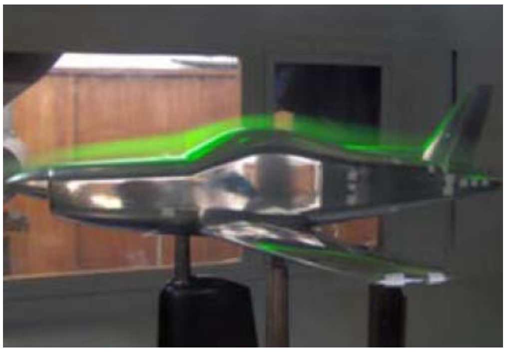
Fig. 3.1. Non-optical visualization techniques

Visualization of the flows in the test room can be achieved through two techniques: non-optical and optical. Non-optical methods make use of a series of agents such as smoke, fluorescent coloring agents, powder, gas blobs, fiber piles, oil, and colored wires [5, 6, 7].

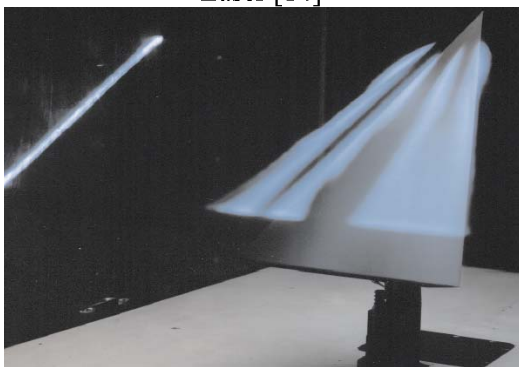
Visualization through optical methods is performed with specific markers (smoke particles, oil drops) and image illumination and image recording devices (cameras) see figure 3.2. The optical methods are used to view compressible flows by means of the following main means: shadows, Schlieren imaging, interferometry, and velocimetry with laser and Doppler Effect [10, 11, 12, 13, 14, 15].



Interferometry [13]



Laser [14]



Doppler Effect [15]

Fig. 3.2. Optical visualization techniques

4. STANDARDS REGARDING AIR FLOW QUALITY

To generalize and validate test results, a set of norms and recommendations have been issued, such as those of SAE (*Society of Automotive Engineering*) which have been published in wind tunnel testing reports, namely SAE J2071 JUN94 norms , [16]. The minimum recommendations for obtaining the proper quality of the air flow in the test room (open) of a wind tunnel are the following:

- *Angular aberration in relation to plane* xOy : $\Delta\alpha \leq \pm 0.5°$;

The angle between the air flow direction and the transversal plane xOy is considered to be positive for upward deviations;

- *Angular aberration in relation to plane* xOz : $\Delta\beta \leq \pm 0.5°$;

The angle between the air flow direction and the longitudinal plane xOz is considered to be positive for left to right deviations;

- *Uniformity of flow speed distribution:* $\Delta v \leq 1.0$ % ,defined as:
-

$$\Delta v = 100 \frac{v - v_\infty}{v_\infty} \; [\%] \qquad (1)$$

where: v - local speed (from its measurement point);
v_∞ - reference speed;

- *Degree of turbulence*: $T \leq 0.5\,\%$;
- *Uniformity of pressure distribution along the direction of the air flow,* $Ox : \Delta p < 0.01$; defined as:

$$\Delta p = \frac{p_x - p_\infty}{q_\infty} \qquad (2)$$

- *Length of the constant pressure area:* $(\Delta l / L) \geq 1.0$;
according to length L, specific to the model for study;
- *The thickness,* δ^* *[mm],of the boundary layer in motion:* $\leq 10\%$;
according to the value of the minimum distance between the model for testing and the walls of the test room.

5. CONCLUSIONS & ACKNOWLEDGMENTS

Wind tunnels are experimental installations for didactic and research activities meant to confirm the results obtained through theoretical and/or numerical methods CFD. The reliability of results provided by the wind tunnels is directly proportional to the quality of the air flow generated, to the precision of data collection equipment, to the quality of the design of the test element (the experimental model) and, last, but not least, to the methods used in the experimental process.

Test results generally depend on a set of parameters from the test room as follows: the air flow quality, the reference dynamic pressure, the way in which the boundary layer is formed, the geometry of the test room, and the blocking rate.

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