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A century of wind tunnels since Eiffel

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ABSTRACT

Fly higher, faster, preserve the life of test pilots and passengers, many challenges faced by man since the dawn of the twentieth century, with aviation pioneers. Contemporary of the first aerial exploits, wind tunnels, artificially recreating conditions encountered during the flight, have powerfully contributed to the progress of aeronautics.
But the use of wind tunnels is not limited to aviation. The research for better performance, coupled with concern for energy saving, encourages manufacturers of ground vehicles to perform aerodynamic tests. Buildings and bridge structures are also concerned.
This article deals principally with the wind tunnels built at ONERA during the last century. Somme wind tunnels outside ONERA, even outside France, are also evocated when their characteristics do not exist at ONERA.

1. From birth to first evolutions

1.1. Wind tunnel definition

Wind tunnels are facilities (circular, elliptical or rectangular tunnels) in which the wind is produced by fans or by compressed air to study and measure the action of the air flow around a solid. The test section is the part of the circuit where the solid is studied. Invented in the late nineteenth century, these aerodynamic laboratories took off in the early twentieth century. The method is based on the principle of relativity enunciated by Isaac Newton in 1687: the forces exerted on a solid immersed in a fluid and the fluid are the same either the solid moves with a certain speed through the fluid at rest, or the fluid moves, with the same relative velocity to the solid that it is immobile.

In French, wind tunnel is still designated by the term “soufflerie”, which was correct for the first facilities, since a fan was blowing air upstream (relative to the direction of flow) of the test-section. The first evolution was to suck air downstream of the test section. The precursors of the other countries in the science of flight use terms that do not prejudge whether the direction of the air is moving in the circuit: *wind tunnel* in English, *Windkanal* in German, *galleria aerodinamica* in Italian, and *aerodinamicheskaya truba* in Russian [1]. Anyway, wind tunnels have largely contributed to the development of aviation, reducing the number of accidents, thus saving the lives of pilots and maintaining the equipment. They also allowed replacing the “flair” of the pioneers by the “art” of the engineers, according to the beautiful sentence by Gustave Eiffel.

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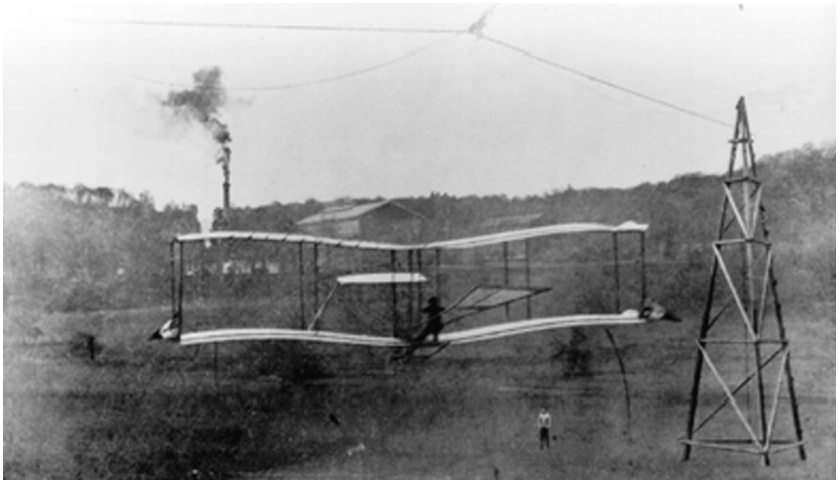

Fig. 1. *Aérodrome* of Captain Ferdinand Ferber in Chalais–Meudon (© ONERA).

1.2. Competitors for ground investigation

The wind tunnel is a very convenient experimental investigation mean, which has surpassed the alternative methods based on the direct movement of the solid in the air. However, at the beginning of the twentieth century, there was no consensus. Indeed Armand de Gramont, Duke of Guiche, who was measuring the distribution of pressure on a wing fixed on a moving car, was a detractor of Eiffel, who was using a wind tunnel. He even challenges the work of Eiffel and disapproves the transposition of the results obtained in his wind tunnel to the reality of airplanes in flight. To definitively close the controversy about the equivalence between real and relative movements – although the question had been already solved in the middle of the 19th century through the experiences of Duchemin, solving the paradox of du Buat [1] – Eiffel requests the intervention of the great mathematician Henri Poincaré. Shortly before the death of Poincaré in 1912, Eiffel received a note in line with his expectations: "There is no reason that the forces exerted on the plate by a uniform air flow differ from those that would occur if this plate is moving in a calm air". Poincaré adds: "it is clear that only the relative movement is significant" [2].

Below are described these alternative processes existing at the beginning of the 20th century:

– Horizontal rectilinear motion
- in 1901, a flight testing was performed by the German company Siemens on a train traveling at 160 km/h,
- in 1909, thanks to a 1.4-km private railway track, the AeroTechnical engineering Institute (IAT) of Saint-Cyr-l'École tested wings;
- during the first decade of the twentieth century, Armand de Gramont, duke of Guiche, tested wings in his car [2].

– Vertical rectilinear motion
- in 1908, before the building of its first wind tunnel, Gustave Eiffel conceived a very ingenious drop test machine to study the drag of solids [2,3]. He installed the device on the eponymous tower's second floor, taking advantage of its 115 m in height. His first studies, awarded by the French Academy of Sciences in 1908, allowed him to found the fundamental laws of air resistance. In this period, with the growth of aviation, Eiffel brought new ideas and his knowledge of aerodynamics led him to understand the efforts of the air on a solid.

– Combination of the horizontal and vertical motions
- In 1904, Ferdinand Ferber in Meudon performed a device by taking advantage of the effects of gravity to move a plane along a cable. His plane, suspended from a sliding carriage along a tensioned cable between pylons (see Fig. 1). Gustave Eiffel had also considered such a device, called *aérodrome*, from the first floor of the tower, prior to the realization of its wind tunnel.

– Circular motion:

In 1906, the AeroTechnical engineering Institute (IAT) of Saint-Cyr-l'École tested solids attached to the ends of rotary arms. This way allows access to tangential speeds all the more important that the arm is long and the speed great.

1.3. The blowing wind tunnels and the introduction of the collector

Even if the first wind tunnel known in Great Britain operated by compressed air ejector (Venham Francis, 1871, then that Horatio Phillips, 1884), the following wind tunnels used the air moved by a fan disposed upstream of the wind tunnel's test section (see Fig. 2a): Charles Renard (France, 1896), Hiram Maxim (Great Britain, 1896), Konstantin Tsiolkovsky (Russia,

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