

DESIGN AND CONSTRUCTION OF A LOW SPEED WIND TUNNEL

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Abstract. This article presents some aspects of the design and the construction details of a subsonic low speed wind tunnel in the Aeronautical Engineering Course at Federal University of Uberlândia – UFU. This wind tunnel has been designed to achieve 90 m/s in the working section with low intensity turbulence level (0.2%) making it available for research in areas such as low speed aerodynamics (flight and terrestrial vehicles), sport activities, civil engineering applications, fundamental research in Fluid Mechanics and other possibilities. In order to accomplish such objectives a very detailed design was carried on through the use of CFD analyzes and theoretical and semi-empirical methods in order to improve the flow quality over the wind tunnel sections. A very careful attention has been focused to the design of the fan blades and the electrical engine assembly, which has been inserted in a “pusher” configuration. Flow control and stabilization also take place through the use of screens, honeycombs and corner-vanes, all of them optimized. The design and construction of each wind tunnel section has been presented and discussed shedding light to the most relevant technical aspects. The qualification of the wind tunnel is taking place in the next months and further results will be shared with scientific community.

Keywords: wind tunnel, low speed, aerodynamics, flow control, turbulence

1. INTRODUCTION

The practice of low-speed experimental aerodynamics has continued to evolve and continues to be a cornerstone in the development for a wide range of vehicles and other devices that must perform their functions in the face of forces imposed by strong flows of air or water. It was believed that in the 1970s and in the early 1980s that the use of wind tunnels, especially in the subsonic regime, would rapidly disappear as computational fluid dynamics (CFD) would become a more attractive option to obtain data, since it would be better in cost-effectiveness. Computational simulations improved since then but they have not come close to reaching a level sufficient to replace the need for experimental data in development projects.

The investigative methods leading to quantitative predictions have been a combination of experiment and theory, with computational methods becoming a new tool of increasing consequence, however experimental explorations remain the mainstay for obtaining data for designers' refined and final decisions across a broad range of applications. A primary tool of experimental aerodynamics is the wind tunnel. A well designed wind tunnel could supply technical information for a large number of engineering applications such as external aerodynamics (flow over terrestrial and aerial vehicles), civil engineering (flow over bridges, buildings, cables, etc.), sport activities (flow over cyclists, design of volley and basket balls, wind sails, etc.), fundamental fluid dynamics (laminar and turbulent flow over simple and complex geometries) and an extensive frame of other options in industry.

To achieve such level of applicability, there are two basic types of wind tunnels and two basic test-section configurations. The two basic types are open circuit and closed circuit – Fig. 1(a) and (b). The two basic test-section configurations are open test section and closed test section, which are respectively a free boundary test-section (opened to atmospheric condition) and an enclosed test-section (surrounded by walls).

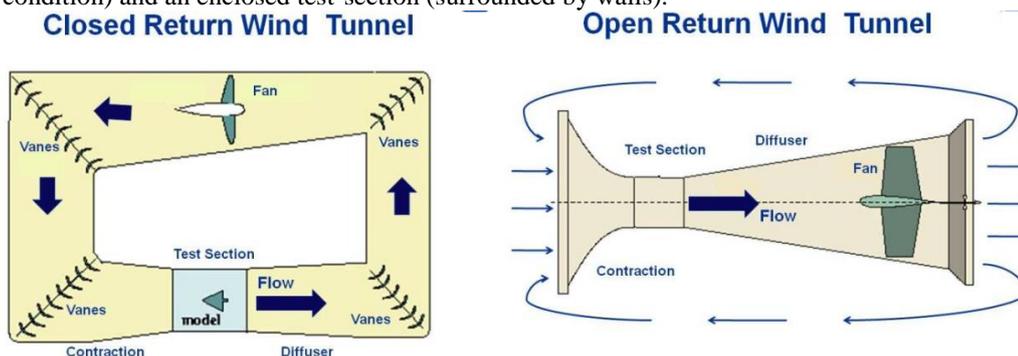


Figure 1- (a) Closed circuit tunnel (left) (b) Open circuit tunnel (right) – www.nasa.gov.

The advantages of open return wind tunnels are the construction cost (less than closed circuit), the possibility to run internal combustion engines and extensively use of smoke for flow visualization without the need to purge. The disadvantages are: harder than closed circuit to obtain high-quality flow; wind and cold weather might affect operation; requires more energy to run if the tunnel has a high utilization rate; in general tend to be noisy.

The advantages of closed return wind tunnels are: through the use of corner turning vanes and screens the quality of the flow can be well controlled; independent of other activities in the building and weather conditions; less energy required for high utilization rates; less environmental noise when operating. The disadvantages are the higher initial costs (due to return ducts and corner turning vanes), the necessity to purge the tunnel if smoke is extensively used and some method of cooling for high utilization of the tunnel.

This paper is intended to describe some aspects of the design and the construction details of a subsonic low speed wind. This wind tunnel has been designed to achieve 90 m/s in the working section with low intensity turbulence level. In order to accomplish such objectives a very detailed design was carried on through the use of CFD analyzes and theoretical and semi-empirical methods in order to improve the flow quality over the wind tunnel sections. A very careful attention has been focused in the design of the fan blades and the electrical engine assembly. Flow control and stabilization also take place through the use of screens, honeycombs and corner-vanes, all of them optimized for the best characteristics of the main flow. The design and construction of each wind tunnel section has been presented and discussed shedding light to the technical aspects.

2. WIND TUNNEL DESIGN

It is well known several references for wind tunnel design in open literature. However, care must be taken when considering aspects of low turbulence intensity, flow control and smoothness as well as cost requirements. Some “golden” rules may apply with subtle corrections and/or adjustments for each specific design. The following main references have been consulted for designing a low speed wind tunnel, Muncey & Pote 1956, Mehta & Bradshaw 1979, Barlow, Rae & Pope 1999, Cattafesta et al.(2010), Bell & Mehta (1989), Bell & Mehta (1988), Lindgren & Johansson (2002), among others.

2.1 Wind Tunnel Requirements

The main requirements for the wind tunnel were specified at the beginning as: low-speed (subsonic at Mach 0.26) wind tunnel for research and educational purposes, closed-circuit with flow passive control (corner-vanes and stabilization chamber). The main characteristics are described below:

- Closed-circuit wind tunnel with approximately 30 meters length and 10 meters width. The first drawings suggested a major section chamber of order 5 m x 5 m.
- The wind tunnel material could be either treated naval-wood or steel plates for covering the side of sections. Requirements for superficial treatment have been placed with polishing at surfaces and covering of any screw and/or slot present in each section. The whole structure (skeleton) could be either wood and/or metal rods – fuselage type construction.
- The maximum air speed at test chamber must reach 90 m/s with a prescribed turbulence level of 0,2 %.
- Minimum flow velocity: 5 m/s
- Test chamber dimensions: 1.2 m x 1.7 m (2.04m²), with 3.0 m length.
- Acrylic access doors.
- Include a stabilization chamber with screens and honeycombs for flow control (laminar flow).
- Contraction ratio between 9:1 and 12:1 in order to reach speed requirements.
- Minimum accessories: two pitot tubes; fixed (used as reference) and movable, all of them connected with a digital manometer.
- Drive System: Triphase 8 poles, 380 V e 350 hp equipped with an air or water cooling system, and fairing integrated in order to reduce flow disturbance.
- Engine Speed control: through frequency inverter.
- Fan Blades: 8 blades of composite material, with approximately 3 m diameter and adjustable pitch.
- The set drive system-blades must be cooled in order to avoid temperature increase in the internal flow. The drive system must be structural isolated from other sections of the tunnel, in order to avoid vibration.

Figure 2 shows a schematic view of the closed-circuit wind tunnel. Some aspects of the wind tunnel design are described in the following sections.

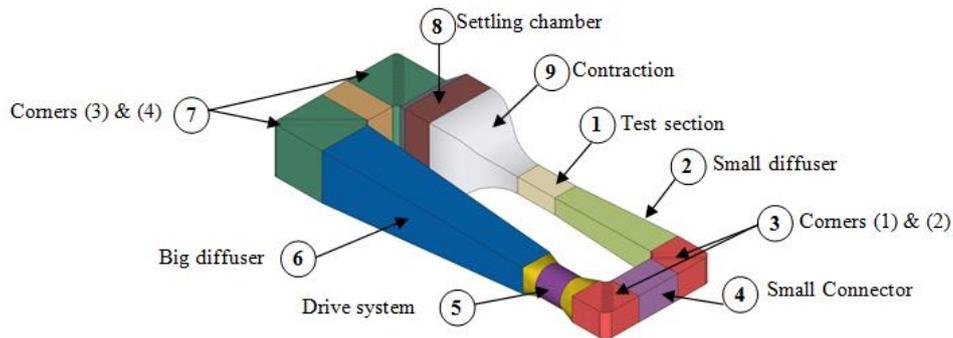


Figure 2. Closed-circuit wind tunnel – schematic.

2.2 Test Section

The test section with dimensions 1.70 m x 1.20 m x 3.0 m has been constructed according to the requirements; including a large access door made of acrylic for facilitate visualization techniques. It is important to emphasize that the other lateral panels could be replaced at any time with acrylic panels and/or other specific material. The test section illumination is completed with LED lamps over the floor and ceiling throughout the whole length. At the floor there is the aerodynamic balance access platform, which is a circular disk of dimension 1 m – Figure 4(a).

2.3 Diffusers

The wind tunnel is equipped with two diffusers. The first one, just after the test section has 1.2 x 1.7 m² at inlet and 1.85 x 1.85 m² at the exit with a length of 7.5 m – Figure 3. At the end of this diffuser is installed a safety screen in order to avoid any misleading part from test section to be carried to the drive system. The second diffuser is installed after the drive system and has 15 m length with exit dimensions of 3.7 x 3.7 m². Again, a second safety screen is placed at the end of this diffuser in order to retain any part lost from the drive system assembly. The diffuser expansion factor must be well evaluated in order to avoid flow detachment - Mehta & Bradshaw 1979.

2.4 Corners

The corners of a closed circuit wind tunnel require special attention since it has the important task to turn 90° the flow. In order to accomplish this task two sets of corners have been designed and built. The first set are the corners after the test section with dimensions of 1.85 x 1.85 m², and the second set are the corners after the long diffuser with dimensions of 3.7 x 3.7 m² – Figure 5. Both set of corners have been integrated with corner vanes specially designed to induce the flow curvature at the bend. The shape of the corner vane has been improved from the work of Lindgren & Johansson (2002) – Figure 5.

2.5 Drive System

In order to keep up with a flow velocity of 90 m/s at the test section the drive system proposed take into account an electrical engine with 350 hp equipped with an air cooling system. This engine is assembled with 8 fan blades with approximately 1 m long and fully streamlined with the flow through the use of fairings. The air cooling system is forced by use of two additional small centrifugal blowers through ducts inside the main fairing – Figure 6. An important design choice for this component was the engine blade mounting which has been selected to be in a “pusher” configuration. The whole drive system is completely segregated from the wind tunnel (i.e. there is no hard and/or physical connection between the engine and the wind tunnel structure) in order to avoid vibration in the structure and impact in the flow uniformity.

2.6 Contraction

The design contraction ratio achieved was 12:1 in order to meet the velocity requirements. More than that, according to Mehta & Bradshaw 1979, the design of a contraction is aimed to reach a uniform and steady stream at its outlet, and requires the avoidance of flow separation. Here, it has been selected a tradeoff between contraction length and contraction ratio. Since it has been invested in the inclusion of a settling chamber (including honeycombs and screens) it is expected that a higher contraction ratio could take place without jeopardizing the flow uniformity. Figure 4 (c) shows the front view of the contraction. The contraction curve has been designed to reach a 1st and 2nd derivative at the inlet and outlet. Also, the selected curve was applied to a tridimensional CFD model in order to verify the development of the boundary layer into the test section. For brevity, these results will be not shown here.

2.7 Settling Chamber

Despite the size of the contraction, it has been selected to incorporate in the design a set of honeycombs and screens to form the settling chamber. Before the contraction there is a large screen at the end of the bigger diffuser with two main objectives: to stop any part lost from the drive system and also to add uniformity into the flow. In the expansion from the corner (4) up to the contraction is placed the settling chamber with a set of an aluminum honeycomb and screens. The design and sizing of cell to the screen and honeycomb have been carried out to reduce swirl and lateral mean velocity variations with a certain pressure drop.

3. WIND TUNNEL CONSTRUCTION

The big challenge after the wind tunnel design is doubtless the wind tunnel construction, moreover, to select and to choose the right manufacturing techniques in order to reach the goals set at the beginning. It means that the workforce responsible to build the equipment must have professional experience in constructing some similar parts. The wind tunnel construction, as mentioned before, as chosen to be as an aircraft fuselage, with main spars and ribs of steel covered by a skin of naval wood (treated for humidity and high level of surface finishing). A high qualified group of technicians has been selected to weld the tunnel parts and to fix each part of the naval wood panels. By assuming this, the way the chance of cracks or bad welds is diminished. The welding method was the “MIG” with 2 mm width.

During the construction process, the smaller diffuser - Fig. 3(a) - was the first part built, considering its simplicity (one of the simplest parts of the tunnel). The small steel connection parts were cut by water jet, granting a great precision. The material used for all the structural parts of the tunnel, including the referred one, was the SAE1020 Steel with bars of 50 x 100 mm.



Figure 3. Smaller diffuser (a) (left) and its internal finishing details (b) (right).

The test section was the second part to be built, a special attention was given to fix the 18 mm Naval MDF's on the main structure, using PVC glue that has a rubber base, this way the vibration transferred to the MDF's was reduced, contributing to maintain the flow laminar. In addition, each wood panel was screwed in the spars and ribs throughout the whole section. Internally, each screw is covered with plastic resin in order to meet the surface finishing requirements. In order to avoid slots at the upper and lower corners (connection between the side wall panels) in all the connections it was used a composite based on PVC to seal the tunnel.

As requirement, the test section will have a polycarbonate door (transparent) hinged on three points and automatic actuated by an electric motor. An additional simple door will be placed at the end of the test section in order to make easy the access into this chamber every time it is needed. Figure 4 (a), (b) and (c) shows the test section, the smaller diffuser and the contraction next to each other.

One of the most complex parts to build was the contraction. Since the contraction curves assume a prescribed curvature function, the placing of the Naval MDF's took around 4 weeks, to bend them without distortions require time and caution. This was an extensive work (almost artisanal, developed by an experienced carpenter/woodworker). The contraction part is shown below in Fig. 4 (c).



Figure 4. Test section (a) (left), test section aligned with the smaller diffuser (b) (middle) and the contraction (c) (right).

Another section that deserved especial attention was the corners; they were built as one piece connected to the middle part between them (connectors), 2 parts in total (“C1”, “C2”, “C3” and “C4” connections). A correct design of this part is quite important in order to impose a better flow control for bending it at 90°. It was possible to achieve a better strength and dimensional control with metal structure and wood panel. As cited before, it was used additional flow control by using corner turning vanes placed rightly to direct the flow. The material of the turning vanes is mainly fiberglass, in order to have good superficial finishing and light weight. Sets of turning vanes were placed at both small corners (just after the section test) and at the big corners (after the long diffuser).

The curves “C3” and “C4” (after the long diffuser) and the profile of the turning vanes are shown in Figure 5.



Figure 5. Curves C3-C4 without the turning vanes (a) (left) and Turning vane profile (b) (right).

The drive system was the main concern in this design and construction, since it is the “heart” of the wind tunnel. The electrical engine weight is around 2 tons (2.000 kg) and required especial attention to install it. It was built a segregated steel support for the motor in order to avoid vibration transmission to the tunnel, especially when starting the motor and at higher velocities. The drive system section has stator vanes to remove swirl from the blades (8 blades of composite material turning at around 900 rpm) and to reduce the turbulence in the long diffuser. It was designed an aerodynamic fairing to the electrical engine which, together with the pusher configuration, achieves a better flow quality and more efficiency. Figure 6 (a), (b) and (c) shows the steel support and the motor installed on it, the drive system section, and the fairing (mold) for the electrical engine.

The drive system also comprises a hub with 8 fan blades made of composite material (fiberglass) for propelling the air. This set of blades is pitch adjustable by means of a standard mechanism created especially for this purpose. The adjustment of the pitch allows the engine to operate at safely margins minimizing the operational and maintenance costs during work life of this wind tunnel. The drive system is completely accessible via a maintenance door and the engine could be rapidly removed from this set if necessary.

The blades (number of 8) used in the drive system were built using glass fiber, as shown in Figure 7. The blades have been designed through the B.E.T (Blade Element Theory) for achieving efficiency of order 80% throughout the operational envelope of this wind tunnel.



Figure 6. Motor support (a) (left), drive system section (b) (middle) and mold for the engine cover (c) (right).

Finally, it is important to emphasize that all the structure steel parts of the tunnel were coated with anti-corrosion paint in order to have a higher durability. The wood panels were cleaned off and sealed after the construction. No “bumps” and/or surface deviation is allowable for the whole wind tunnel sections.



Figure 7 – Mold for the blades – composite material.

4. CONCLUDING & REMARKS

As presented throughout the sections, the wind tunnel design is somewhat not standard procedure and depends very strongly on variables such as infrastructure (space dimensions), flow speed requirements and mainly cost for production. The first two variables are quite sensitive to the need of educational and research purposes and can be dealt with rationale through the phases of design, however the last variable impose hard limitations to the design. In fact, cost of equipment's and parts such as drive system can really push back the design for simpler configurations. Based on that, one of the most important phases of the design is not technical but economical. A complete “part-cost” list must be specified at the beginning for initial estimates and a detailed specification must follow by establishing contacts and in voice calls, thus refining the estimates and providing more realistic cost estimation for the whole wind tunnel conception. This wind tunnel has been built in 12 months with a specialized team of technicians which followed the original design point by point. This wind tunnel is the main equipment in the CPAERO – Centro de Pesquisa em Aerodinâmica Experimental (Experimental Aerodynamics Research Center) at the Aeronautical Engineering Course at Federal University of Uberlândia – Minas Gerais. An experimental validation of the flow inside the wind tunnel sections is envisaged for the 2nd semester of 2016 and the data will be further shared with the academic community.

5. Acknowledgements

The authors would like to thank the FINEP (0138/11) for funding the wind tunnel design and the administration of Federal University of Uberlândia (UFU) for all support during the phases of this project. Also, the authors recognize the support of Fundação de Amparo a Pesquisa do Estado de Minas Gerais – FAPEMIG.

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