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Design and construction of an open-circuit wind tunnel with specific measurement equipment for cycling

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Abstract

In order to overcome resistance a cyclist has to deliver a total power output of which 90% is necessary to overcome the aerodynamic drag [1,2]. In order to perform research in this aerodynamic drag a wind tunnel has been built by the Belgium company Flanders' Bike Valley. This wind tunnel is designed using classical design rules and with specific cycling requirements an open-circuit wind tunnel is designed. This wind tunnel, containing a test section in which two cyclist can be positioned in succession, contains three main measurement systems to investigate the aerodynamic drag of a cyclist. A balance is used for the measurements of aerodynamic forces acting on the model, a bikefitting test is included to have a perfect fit between cyclist and bike and finally a PIV system is installed to investigate the flow behaviour.

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1. Introduction

Rules and regulations of the Union Cycliste International (UCI) bound the design spectrum of sports engineers concerning the global shapes of bicycles and cycling gear. As about 90% of the total power output delivered by the cyclist is needed to overcome the aerodynamic drag the focus lies on the reduction of this resistive force [1,2]. In order to gain profits the aerodynamics and attitudes of cyclists and their gear must be investigated.

Examinations of the aerodynamics (on both macro and microscopic scales) of cycling clothing and bicycles and the attitude of the athletes on their bikes are part of the research goals of Flanders' Bike Valley. This cluster collaboration therefore invested in building a cycling wind tunnel. Next to the wind tunnel tests the company, which is founded by Ridley Race Productions, BioRacer, Lazer Sport, Voxdale and Flanders' Drive, strives for open innovation in the cycling industry. By hosting an incubation centre Flanders' Bike Valley encourages the joint go-to-market strategies of multiple companies to bring new and innovative products on the market.

This paper will discuss the detail design of the Flanders' Bike Valley wind tunnel and focuses especially on the test section with its measurement devices.

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2. Design of the wind tunnel

The design of a wind tunnel starts with determining the top-level requirements and the size of the test section [3]. The test section size and shape determine the overall size and the power input of the wind tunnel.

2.1. Requirements

A wind tunnel can be classified by its type, specialisation, size, operating speed, etcetera, and requirements for the design were given within these classes. From a conceptual wind tunnel study performed in 2012 it became clear that an open-circuit wind tunnel would be optimal for the given requirements. An open-circuit wind tunnel has an inlet and an exit and uses atmospheric air through the wind tunnel. Open-circuit wind tunnels save construction costs and a lot of space as a return circuit is not needed. This type of wind tunnel is usually placed in a sealed building and for that reason it can be seen as a closed-circuit wind tunnel with a less efficient return circuit [4].

The wind tunnel test section must be able to host multiple cyclists in line and the hydraulic diameter of the test section must be at least $2.2m$. This minimum cross-sectional dimension ensures that the blockage factor will not exceed 10%, which is a maximum for liable results [3]. This blockage factor is defined by dividing the frontal area of the test object by the cross-sectional area of the test section.

The maximum speed of the wind tunnel is reached in the test section and was required to be $30m/s$. This velocity is substantially higher than a cyclist reaches in normal conditions (ca. $15m/s$ in time trial mode), but in order to extend the versatility of the wind tunnel the upper speed limit is increased. This versatility creates a possibility for the wind tunnel, which is intended for cycling research, to be used in multidisciplinary research areas. Further it is aimed to have a laminar flow with a turbulence intensity below 0.1% as suggested by [3].

2.2. Wind tunnel configuration

The design of a wind tunnel is an iterative process which starts with dimensioning the test section. The test section was designed to be squared with a width of $2.5m$. A circular test section shows better flow properties, but the construction and mounting of the test object is more straightforward in a straight walled tunnel. The $2.5m$ width leads to a blockage factor of 6.1%, with a frontal area of $0.38m^2$ for an average cyclist in time trial position, in the test section [1]. A larger blockage factor leads to increased uncertainty with the formulation of the blockage correction factor. A lower blockage factor would be favourable; however, a lower blockage would mean a larger test section and therefore a larger wind tunnel which was impossible within the space constraints.

The requirement to include more than one cyclist in the test section resulted in a test section length of $6.5m$. With this test section size the wind tunnel is capable op hosting two cyclists in succession. At the inlet and outlet of the test section $1.25m$ and $1.5m$ respectively of empty space is needed to stabilise the flow and to ‘close’ the separated region behind the second cyclist [3,4].

The part of the wind tunnel preceding the test section serves the purpose of ‘catching’, stabilising and accelerating the flow. The flow enters the inlet of the wind tunnel and is captured by a bellmouth intake. This elliptical intake, with an axis ratio of 1:3, increases the intake efficiency and prevents *vena contracta*. This phenomena describes the excessive contraction of the flow in the inlet of a straight duct which increases the energy losses in the flow and can initiate separation [5].

The flow entering the wind tunnel is subjected to turbulence and velocity variations and has to be stabilised in order to produce a laminar flow in the test section. After the inlet the settling chamber is positioned which hosts flow manipulators to produce a steady and uniform flow. Honeycomb structures and screens are used in wind tunnels to manipulate the flow. A combination of both is preferred since the honeycomb structure is most effective in reducing swirl and lateral irregularities in the flow and screens are more effective in reducing the axial turbulence [6,7]. These flow straighteners produce a pressure drop, which causes additional drag, and are therefore placed in the settling chamber. The low velocity in this wind tunnel section causes these disadvantageous effects to be minimised.

Several screens are placed behind the aluminium honeycomb structure in the $4m$ long settling chamber. The number of screens is depending on the level of turbulence that has to be reached in the test section. A screen produces a pressure drop which contributes in the reduction of velocity variations and turbulence and after the screen the static pressure returns to constant without an appreciable loss in total pressure [6]. This pressure drop is depending on the