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DOI
10.1016/j.proeng.2016.06.195

Publication date
2016

Document Version
Final published version

Published in
Procedia Engineering

Citation (APA)
Ubbens, H. H., Dwight, R. P., Sciacchitano, A., & Timmer, N. (2016). Some Results on Bobsleigh Aerodynamics. *Procedia Engineering*, *147*, 92-97. https://doi.org/10.1016/j.proeng.2016.06.195

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 147 (2016) 92 – 97

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Some results on bobsleigh aerodynamics

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Abstract

Bobsleighs races nowadays are decided upon hundredths of a second. As the margins are that small the aerodynamics of a bobsleigh can play a significant role in a race outcome. This paper investigates the influence of the gap between the nose and the rear cowling of a two-man bobsleigh. The paper especially focusses on the misalignment between both cowling parts due to lateral rotation in a track bend. CFD analyses and wind tunnel tests have shown that the rotation of the nose increases the drag due to an enlarged frontal area and due to adverse effects of the airstream flowing into the cavity. The results are used to define an area of investigation to alter the gap geometry which may lead to reduced drag when the bobsleigh parts are misaligned.

Peer-review under responsibility of the organizing committee of ISEA 2016

Keywords: Bobsleigh, cowling misalignment, aerodynamics, CFD, wind tunnel tests

1. Introduction

For a long time sleighs have been used as a means of transportation. After the addition of a steering mechanism to the steel frame in the late 19^{th} century, the sport of bobsleighing was born. In this sport, also known as the Formula 1 of the Winter Games, speeds of over $150 km/hr$ are reached in races where the winner leads the pack by only hundredths of a second [1]. In order to create an advantage over the competitors slight geometrical changes to a bobsleigh can increase the performance.

The design of modern bobsleighs is strictly regulated by the rules imposed by the International Bobsleigh & Skeleton Federation (IBSF) [2]. These rules are mainly imposed to guarantee the safety of the athletes but they also reduce the possibility of an unfair competition as larger teams have more resources to design and improve the bobsleigh. However, there is some freedom left in the design in order to gain marginal advantages over the competitors, as suggested by Dabnichki [3]. However, most of the research performed investigates the bobsleigh as a single body where in real-life the cowling consist of two parts connected by means of a pivot axis. During a race both parts are misaligned most of the time due to the track configuration. When the front and rear cowling are misaligned the frontal area is increased and the gap between both parts is increased both resulting in an increase in aerodynamic drag. This paper describes an investigation into the effect of the misalignment between front and rear cowling on the aerodynamic drag of a two-man bobsleigh. The results are being used to define a project in which the influence of the gap configuration on the aerodynamic drag will be assessed.

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Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.195

2. The sport of bobsleighing

In 1924, a year after the IBSF was founded, the sport of bobsleighing took its first appearance in the Winter Olympics in Chamonix, France [4]. When the stakes of winning became higher, strong and large athletes were deployed for the competition. After the inclusion of a weight limit, to avoid this game changing case, the sport as it is known today was born. Research has been performed to increase the performance and speeds of the sleighs by improving the geometry and materials, understanding the forces acting on the bobsleigh and improving the aerodynamic characteristics of the bobsleigh.

2.1. The bobsleigh

The first and most important design feature of the bobsleigh is that it provides safety to the athletes. In order to satisfy this requirement a set of strict regulations is imposed by the IBSF on the geometry of a bobsleigh [2]. These regulations describe the exact shape of a bobsleigh with marginal room for modifications.

The most characteristic aspect of a bobsleigh is the two-part configuration where the frame is connected pivotally. The nose of the bobsleigh is able to rotate with respect to the aft body which ensure more gradual and faster cornering during a race. The entire body is required to have a convex shape containing front and rear bumpers to provide a safety buffer in the case contact is made with the track walls. These bumpers are usually integrated in the cowling design in order to reduce unfavourable aerodynamic interactions in the junctions.

In order to minimise a gravitational advantage during a race a weight limit is imposed on the bobsleigh. During the race the only force which is able to accelerate the bobsleigh is the gravitational force due to the combined weight of the sleigh and its crew. A two-man bobsleigh must weigh at least $170kg$ excluding the crew. A maximum weight of $340kg$ or $390kg$ is imposed on the bobsleigh including the athletes and other equipment for women and men respectively in the two-man discipline.

2.2. Forces acting on a bobsleigh

A bobsleigh race comprises a downhill course of about 1200-1650m length which can be divided into three phases: the start, the drive phase and the finish [2,5]. At the start phase the athletes push-off, increase the speed and get into the sleigh. After this ‘loading’ the gravitational force is the only accelerating force acting on the bobsleigh while the ice friction and aerodynamic drag forces oppose this acceleration. Next to the pilot skills the geometry of the bobsleigh is therefore of utmost importance to enable good race performance. During this drive phase the bobsleigh will encounter a collection of elements with varying difficulty. At the finish the final time is set and the sleigh must be decelerated by an uphill stretch and a brake.

Two cases of forces acting on the bobsleigh can be identified along a track. The case where the bobsleigh travels a straight line and the case where the bobsleigh encounters a turn. In a straight line the bobsleigh can be seen as a symmetrical body where forces only act in the longitudinal direction. In order to increase the performance the weight must be maximised while the ice friction and aerodynamic drag have to be minimised. When the bobsleigh travels through a turn in the track the bobsleigh encounters a centrifugal force pushing the sleigh outwards and the pilot needs to steer the bobsleigh in order to hold the best line. This steering, where the runners are rotated to create a moment over the bobsleigh, exerts an extra resistive force that slows down the bobsleigh [3].

2.3. Aerodynamics

The best bobsleigh performance is achieved when the resistive forces, as discussed before, are minimised. A large part of this resistive force is caused by the aerodynamic drag of the bobsleigh. This drag force consists of two main sources: the skin friction and the pressure drag force [6,7]. The drag on bluff bodies, non-streamlined bodies as bobsleighs, is dominated by the shape of the geometry and influenced by flow separation, hence the pressure drag is the largest drag component [6–8].

When a moving bobsleigh is investigated it can be seen that a pressure difference is present between the flow in front of the body and the flow trailing the sleigh, caused by flow separation [8,9]. At regions of high curvature and sudden geometrical changes - such as the gap between the cowling parts, pilot helmet and the rear end of the bobsleigh cavity - the flow encounters a high adverse pressure gradient causing the onset of separation and the formation of a low-pressure wake. The flow over the rear cowling is partly sucked into the cavity due to this low-pressure wake resulting in the formation of trailing vortices which increase the drag significantly.

The misalignment of both cowling parts around the pivot point is expected to influence the drag in two ways. First of all the rotated nose creates an increased frontal area and secondly the flow entering the nose through the gap influences the pressure in the nose and cavity resulting in a larger wake.

3. Methodology

In order to analyse the aerodynamic drag of the bobsleigh, a model has been investigated with the use of computational fluid dynamics (CFD). This model showed the effect of a rotated nose on the aerodynamic drag. Wind tunnel tests were used to support the test results from the CFD analysis. Further the influence of the gap on the aerodynamics was investigates next to the flow around and inside the bobsleigh.

3.1. Bobsleigh models

Several bobsleigh models have been used for both the CFD and the wind tunnels tests. The first bobsleigh model was a Singer two-man bobsleigh, which was used in both CFD analysis (performed by the design engineering company Modesi [10]) and wind tunnel tests in the framework of the Dutch InnoSportNL Topbob project [10,11]. This project was carried out to support the Dutch bobsleigh team by improving the bobsleigh design and performance.

The second model was derived from a full scale bobsleigh 3D scan performed by the Queen Mary University of London and adapted by Oscar Lewis [12]. The model, as can be seen in Figure 1, was used to investigate the influence of the gap and to visualise the flow stream over and inside the cavity as well. The detail view of Figure 1a shows that the nose has a sharp trailing edge to prevent separation and the rear cowling leading edge is blunt in order to have a better flow guidance over the cowling. The influence of the nose rotation on the frontal area and the flow field and therefore the drag area was investigated using this model as well. A wind tunnel model with scale 1:3 was printed from this scan.

The third model was a simplified circular bobsleigh model with a 62.5*mm* radius. This model was used to investigate the effect of the nose rotation on the aerodynamic drag. For simplicity and in order to reduce the interference effects no bumpers were attached to this model.

3.2. Wind tunnel tests

The CFD calculations can be supported with the use of wind tunnel tests. The outcome of three tests performed at the low speed wind tunnels of the German-Dutch Wind Tunnels (DNW) and the Delft University of Technology are used to verify the CFD results. The tests at DNW used the full-scale Singer two-man bobsleigh, including the crew, in the wind tunnel. The test was performed in the framework of the Topbob project [11].

Two tests were performed in the low-speed lab of the Delft University of Technology. These tests were conducted to have a basic understanding of the different parameters, particularly the nose rotation, that affect the aerodynamic drag of a bobsleigh. The two scale models were used for these tests. The second model (Lewis [12]) was tested in the $1.80\text{x}1.25\text{x}2.60m^3$ Low-Turbulence-Tunnel (LTT) and the simplified model in the open jet $0.4\text{x}0.4m^2$ tunnel.

Next to balance measurements to calculate the drag, particle image velocimetry (PIV) was used to investigate the flow behaviour around the rotated nose of the simplified model as well. A planar PIV set-up with a Quantel Evergreen

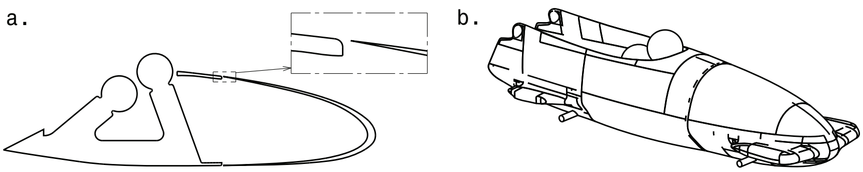

Fig. 1. (a) 2D bobsleigh model with gap; (b) 3D bobsleigh model [12]

200 Nd:YAG laser was used with a 200mJ pulse at a 15Hz maximum repetition rate to enlighten the particles in the flow. The camera used to capture the images was a 2$Mpix$ Imperx Bobcat IGV-B1610. The resolution of this type of camera is 1628x1236 with a pixel size of 4.4μm. A focal length of 75mm and an fstop of 8 were found for optimal data collection.

4. Results

When the nose of the bobsleigh is rotated with respect to the rear body the frontal area (S) increases. With an increase in frontal area the drag (D) is increased as well as becomes eminent from the drag equation (Equation (1) [6]).

$$D = C_D \frac{1}{2} \rho U^2 S \tag{1}$$

When the nose of the second bobsleigh model (by Lewis [12]) is rotated 5° due to a track bend, the frontal area, and hence the drag, is increased by 1.9%. A 10° rotation will lead to a drag increase of 4.8% and a 20° rotation will increase the drag for 7.8%.

Together with the increased frontal area, the flow entering the cowling is expected to increase the drag. When the streamlines over the cowling are investigated the influence of the nose rotation can directly be noticed (Figures 2 and 3 [10]). The 5° and 10° nose rotations show two main differences in flow behaviour in the nose and behind the pilot. In these CFD analyses the colour coding of the streamlines represent the velocity distribution. Next to the velocity streamlines the colour coding on the bobsleigh nose and pilot helmet represents the pressure at these locations. As expected the stagnation areas, were the highest pressure occurs, are found at the frontal area of the head of the pilot and the nose of the bobsleigh.

Analysis of the flow inside the bobsleigh shows that the circulation in the nose increases with larger nose rotation. With a higher degree of rotation a larger portion of air can flow into the bobsleigh which largely influences the inner bobsleigh flow behaviour. In the nose of the bobsleigh the circulation is aggravated resulting in a growth of the wake. Next to the circulation in the nose it can also be seen that the degree of circulation behind the pilot is increased. As a consequence of a larger part of the airstream entering the bobsleigh nose, the pressure inside the wake will decrease causing a larger pressure difference between the wake and the flow over the cowling. This pressure difference results

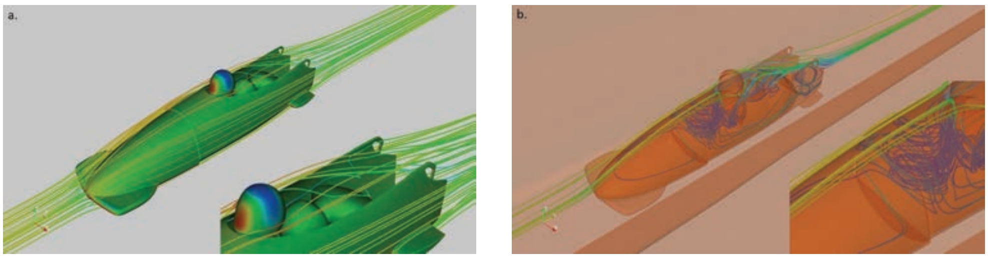

Fig. 2. (a) Streamlines at 5°nose rotation; (b) cavity flow behaviour at 5°nose rotation. [10]

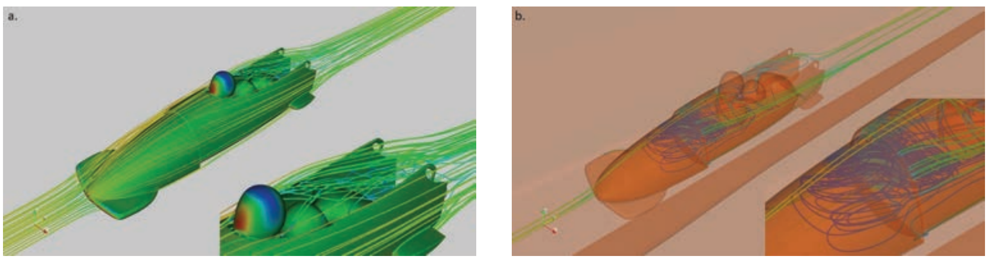

Fig. 3. (a) Streamlines at 10°nose rotation; (b) cavity flow behaviour at 10°nose rotation. [10]

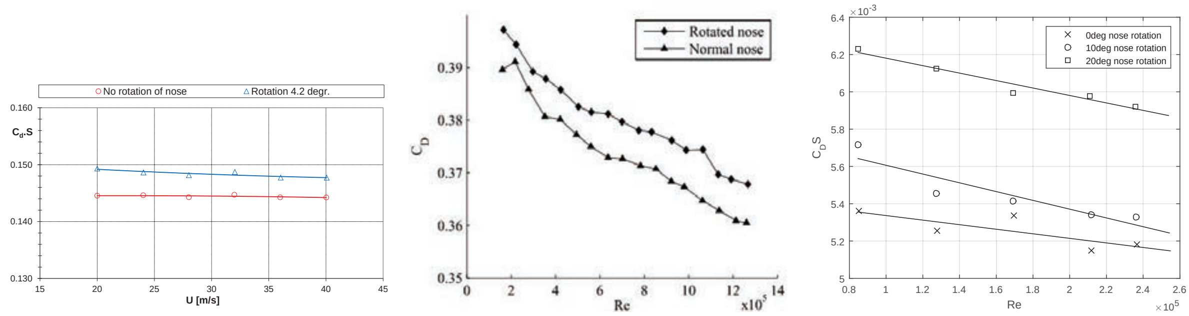

Fig. 4. Measured effect of the nose rotation on drag for the (a) full-scale bobsleigh in the DNW low-speed wind tunnel [11]; (b) scale-model in the Delft University LTT [12]; (c) simplified model in the Delft University of Technology open jet 0.4x0.4m^2 tunnel.

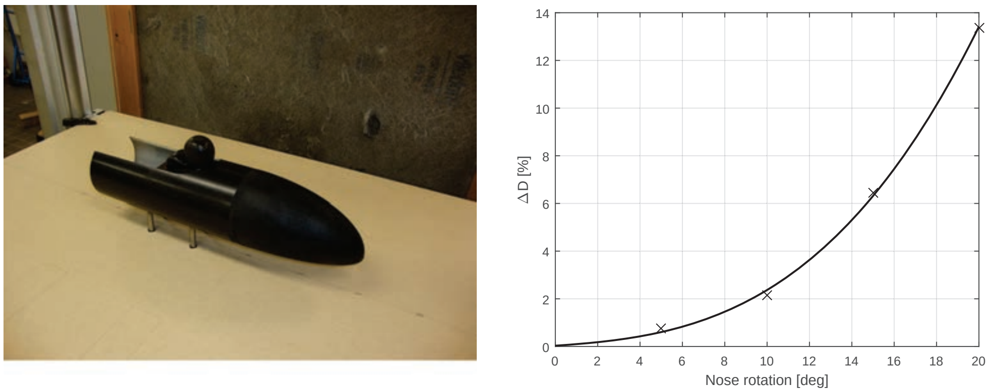

Fig. 5. (a) Simplified wind tunnel test set-up; (b) drag increase with nose rotation for $Re = 1.58 \cdot 10^5$.

in a suction force of the bobsleigh cavity on the flow over the cowling. The streamlines over the sidewalls bend over the walls into the cavity inducing vortices in the cavity and in the wake. Over the back of the brakeman a larger area of recirculation, due to the increased nose rotation, can be seen which enlarges the strength of the trailing vortices and therefore the wake trailing the bobsleigh. The flow behaviour shows higher instability and stronger circulation for larger nose rotation angles, which indicates a higher drag force.

The wind tunnel tests were used to verify the CFD results and it was found that a nose rotation increases the drag as can be seen in Figure 4. Both tests - which are on different scales - show a similar increase in drag area for increasing nose rotation as expected from the CFD calculations.

The simplified wind tunnel model exhibits a linear increase of frontal area with nose rotation, which basically, established from the drag equation (Equation (1)), causes the drag to increase linearly as well. Yet, the measurements (Figure 5b) show a quadratic increase with nose rotation, indicating that secondary effects of gap flow have an additional impact on drag.

Next to balance measurements the flow around the bobsleigh is investigated using PIV. The nose rotation is visualised from a top view in Figure 6. The flow behaviour is analysed from 10mm in front to 50mm behind the plane of rotation with a freestream air velocity of 20m/s and a 10° nose rotation at the widest part of the bobsleigh.

Figure 6a shows that a separation bubble appears behind the rotated nose after which the flow reattaches to the body. In the separated region right after the rotated nose circulation appears and backflow causes air to enter the bobsleigh nose. Figure 6b focusses on the streamlines at the rotated part and clearly shows the flow entering the nose which impacts the drag.

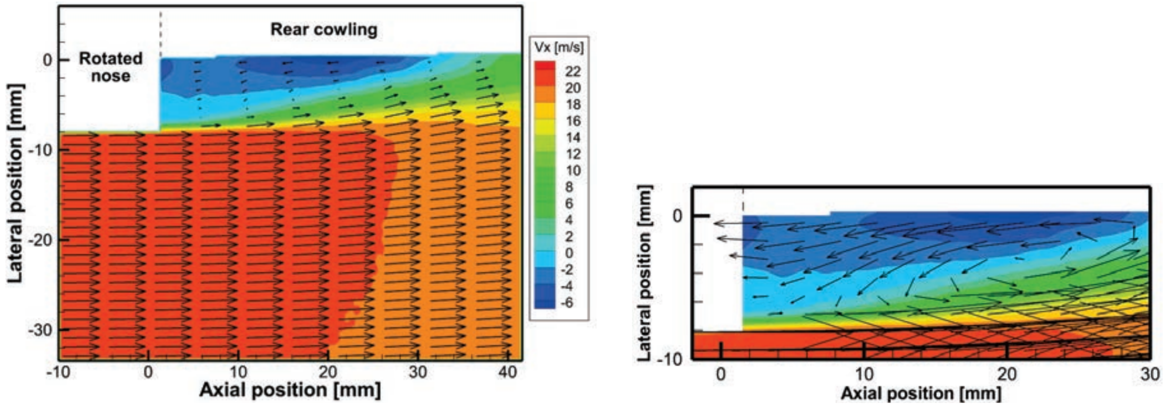

Fig. 6. (a) PIV analysis of 10° bobsleigh nose rotation at $20m/s$; (b) Detail view of the backflow entering the bobsleigh nose at 10° nose rotation and $20m/s$.

5. Conclusions and recommendations

Full-scale and model experiments in a wind tunnel show that the drag of a bobsleigh increases with nose rotation. This increase seems to originate - at least for the flow around the simplified model - from two sources: the increase of frontal area and secondary effects of flow entering the rear cowling through the gap. The growth of the wake due to this gap flow causes the circulation over the back of the brakeman to increase and aggravates the vortices trailing the bobsleigh.

Further research will focus on shape optimisation to reduce the effect of nose rotation, both with respect to frontal area increase and to the aerodynamics of gap flow.

References

[1] IBSF, Bobsleigh infographic, [Online] `http://www.ibsf.org/en/our-sports/bobsleigh-info-graphics`, 2015.
[2] International Bobsleigh Rules, International Bobsleigh & Skeleton Federation, 2014.
[3] P. Dabnichki, Bobsleigh performance characteristics for winning design, Procedia Engineering 112 (2015) 436–442.
[4] IBSF, Bobsleigh history, [Online] `http://www.ibsf.org/en/our-sports/bobsleigh-history`, 2015.
[5] P. Dabnichki, F. Motallebi and E. Avital, Advanced bobsleigh design. Part 1: body protection, injury prevention and performance improvement, Proceedings of the Institution of Mechanical Engeineers, Part L: Journal of Materials:Design and Applications 218 (2004) 129–137.
[6] J. D. Anderson Jr., Fundamentals of Aerodynamics, fourth ed., McGraw-Hill, 2005.
[7] R. G. J. Flay, Bluff Body Aerodynamics, in: Y. Tamura, A. Kareem (Eds.), Advanced Structural Wind Engineering, Springer Japan, 2013, pp. 59–84.
[8] A. Winkler and A. Pernpeintner, Improving the Performance of a Bobsleigh by Aerodynamic Optimization, The Engineering of Sport 7 2 (2008) 329–338.
[9] H. Chowdhury, F. Alam, S. Arena and I. Mustary, An experimental study of airflow behaviour around a standard 2-man bobsleigh, Procedia Engineering 60 (2013) 479–484.
[10] Modesi, CFD calculations in the framework of the Dutch InnoSportNL Topbob project, 2009. [Restricted publication].
[11] W. A. Timmer, Wind tunnel test results in the framework of the Dutch InnoSportNL Topbob project, 2009. [Restricted publication].
[12] O. Lewis, Aerodynamic analysis of a 2-man bobsleigh, Master of Science thesis, Delft University of Technology - Faculty of Aerospace Engineering, 2006.