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Bobsleigh performance characteristics for winning design

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Abstract

Bobsleigh is one of the fastest and most exciting winter sport where winning margin are very slim. It is also a sport highly dependent on technology. In this work we review the technology areas likely to bring the biggest advantage to the teams and present some developments in critical areas identified. The areas reviewed are unsteady aerodynamics of the sled, ice friction and runner development, dynamic structural response and ergonomics. It is demonstrated that these three areas provide opportunity to gain performance improvement with infringing the design constraints stipulated by the regulatory body FIBT and without comprising athletes' safety.

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1. Introduction

Success in winter sports has always been strongly linked to the technological advancements in equipment development. A spectacular example was presented at the Nagano Olympics when the introduction of the "clap" skate led to all the records being broken and Dutch skaters wining all titles [1]. Ski sponsors and manufacturers invest in technology more than £600m pa leading to introduction of smart skis. Investment in sport equipment development is not any more just about exposure but also represent cutting edge research and their implementation in other areas including medicine and aerospace is highly beneficial.

Bobsleigh is one of the fastest winter sports that brings much excitement with victories achieved by the narrowest of margins. At the 1998 Olympics, the British and French teams shared the bronze medal. This means that their times were within 0.01 s (0.04% of the total time) over six km distance. Such small time differences put pressure on the teams to seek superior design solutions to gain competitive advantage. Tracks vary in their design, as they need

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to follow to some extent the natural slopes. However, the sports' rules dictate that tracks should be approximately 1.5 km, with a total vertical drop of approximately 120 m. Average gradients should be approximately 8.6% with a maximum slope of 15% [2]. A standard bobsleigh run is divided into three main stages: start, drive and finish. The crew starts by pushing the sled as the clock is triggered by a photocell at 15 m from the start line. Beyond the loading point when the entire crew had entered the sled the result is entirely dependent on both driver's skills and crucially sleds' performance. Speeds can reach 135 km/h and g-forces of 5 g [2]. Bobsleighs have four runners, two front and two rear runners (Fig.1 below). Men competition is for two and four-man and female have only two-woman crews. The minimum allowed weight is 170 kg for two- and 210 kg for four-man bob. Maximum weight (incl. crew) for two-man is 390 kg (350 for two-women) and four-man - 630 kg. The maximum weight may be achieved by ballast firmly fixed to the bob. The drive is to avoid ultra-light sleds manned by very heavy crews. Sleds have steering and a suspension system which together with the shape and aerodynamics of the sled are strictly regulated.

Bobsleigh technology is advanced and the development is of interest to scientific and commercial institutions. NASA was closely involved in crucial aspect of the equipment development (runners and aerodynamics) for the US Olympic teams. The teams have also very close relationship with the NASCAR team owner Jeff Bodine. The German teams that traditionally dominate the sport mostly due to their superior sleds all built by a state owned company working closely with academic institutions. Ironically recently other teams have performed better using other German competitive manufacturers showing that the process is dynamic and no one can rely on eternal superiority. The Swiss sleds are also built by a contractually bound state supported company that can only supply the Swiss teams. The development is supported by ETH Zurich that re-designed the Swiss sled for the 2010 Olympics. In the UK teams have been relying on the support of Formula 1 teams and aerospace companies such as BAE.

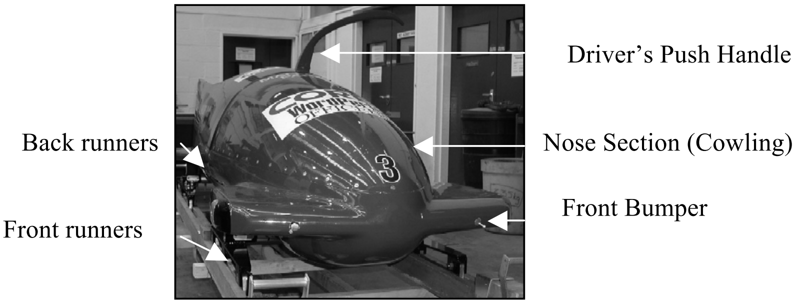

Fig. 1. Front View of a Two-Man Bobsleigh with Driver's Push Handle in Starting Position

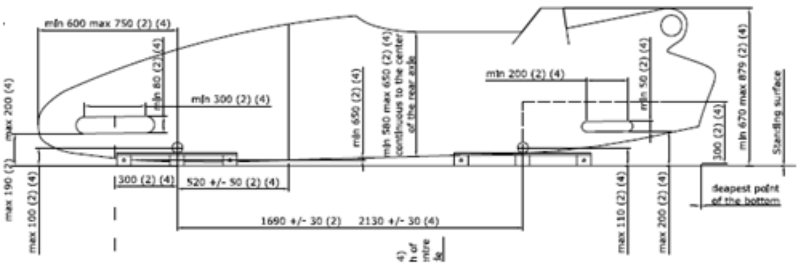

Fig. 2. Bobsleigh shape regulations as per FIBT rules.

2. Critical areas in bobsleigh design

The driving force behind a bobsleigh run is the gravity. Tracks are devised with spectacular curves that attract both thrill seekers and world class athletes. The sport is used by the Royal Air Force (RAF) in the UK for team training and character building. During the run athletes endure up to 5g gravity load as per the FIBT regulations [2] in addition to regular dynamic forces of up to 10g on the tracks we measured. The predominant concern of the regulatory body is safety as the sport is hazardous and sleds run down the track with speed sometimes exceeding 130 km/h. Hence many of the technical regulation are placed with the explicit aim to limit or even reduce the speed of the sleigh and reduce the risk of fatalities. We shall only point out that the frontal area and front bumpers are intentionally prescribed in order to increase the drag and that bobsleigh cannot have any suspension (passive or active) apart from the leaf spring in the front. Further to this there is no proper steering as the front runners are used to alter the friction and generate a lateral rotation but this is not by any means a proper steering. Those features certainly have the most limiting effect on the sled's speed. Hence, in order to achieve performance one need to deal with these restrictions that become in effect optimisation constraints. As a result we produced an analysis with the participation of sport experts and racing cars manufacturers in order to identify most critical issue affecting the ride and ways to address them.

Hence the key areas that could bring highest benefit without any rule infringement were identified as:

1. Improvement of the sled aerodynamics;
2. Runners design enhanced by better understanding of ice/metal contact, and
3. Dynamic response of the sled to the loads high g-loads.

In order to achieve these improvements the following project aims were formulated:

1. To develop a computational model of the coupled aerodynamic/solid body problem.
2. To develop an adaptable structure under high g-loads.
3. To develop a model for ice/metal interaction considering geometry, metal and ambient temperature, material properties incl. conductivity and hydrodynamic drag.
4. To develop procedure to match runners' properties to the associated track conditions.

One should note that the cost of sled testing and development is almost prohibitive so the theoretical development cannot always be implemented directly. Further to this the drivers and crew need time to adjust to the riding dynamics and introduction of any modification need to be completed by the mid-stage of the Olympic training cycle to allow time for adjustment and performance improvement. Hence we adopted step by step improvements.

3. Research topics explored

Once the areas of interests were identified, the research team conducted investigatory work on both fundamental issues related to the development and potential design innovations. The effect of the innovation was then assessed in terms of compliance with the regulations and its potential acceptance rejection by experts and athletes.

3.1. Ice metal contact

Although most studies on bobsleigh have been devoted to aerodynamics the right selection of runners can win the day. At the same moment gliding performance is most hardly affected by the weather conditions such as sunshine or snowfall on the ice. More established factors such as air temperature and humidity play vital role. During the bobsleigh run, the initial dynamic energy in the runner is converted to kinematic one, as it slopes downhill. However, a great amount of the initial energy is used to overcome the aerodynamic drag and the frictional forces of the runner's blades with the ice. In speed skating athlete the total frictional loss is roughly estimated to be 75% due to air drag and 25% due to the ice friction [3]. As bobsleighs are streamlined the percentage loss due to ice friction is higher and we estimate it in certain scenarios to be around 40%. Furthermore, the initial speed the crew achieves contributes significantly to the final speed of the bobsleigh and since at the start aerodynamic drag is negligible due to the very low speed, then the ice friction plays a more important role during this part of the race. Our tests have shown that a change of friction coefficient from 0.004 to 0.006 decreases the average sliding speed by 0.3m/sec or equivalent to be out of the top six. Consequently, optimizing the design of the blades to reduce friction is an important for the overall racing performance of bobsleighs. Research indicates that a very thin film of water is created on the surface of ice, which acts as a lubricant. Initially it was believed the film was created due to pressure melting [4] but current view is that frictional heating is the dominant mechanism [5, 6, 7, 8]. Such heating will melt a thin layer of ice acting as a lubricant. The main parameters affecting ice friction are ice temperature, sliding speed and material parameters (heat transfer coefficient, elastic parameters, etc.). It was showed [3] that the friction coefficient is reduced as sliding speed increases, since more heat is generated creating a thicker lubricant film. Ice temperature is considered greatest influence on the ice friction. For artificial ice the minimum friction coefficient is at around -7^{o}C [4]. Fig.1 presents the mechanism, as temperature increases, thicker layer of ice is melted that results in lowering of friction coefficient. However ice deforms more resulting in an increase of the friction coefficient. Combining these dominant mechanisms an optimum coefficient was achieved for certain ice temperature as illustrated in Fig.3. As per the FIBT rules the teams can only use standard runners by a FIBT nominated supplier and can only alter the curvature and the degree of surface finishing. They both have altered performance significantly as the main parameters were surface finishing, edge corner and the Gaussian curvature of the runner. We have refrained from studying the influence of water content. However, an additional factor that was found to affect the ice properties was the atmospheric pressure although we are not certain whether the correlation is direct and not through already established factors such as total temperature (modified for humidity and wind speed).

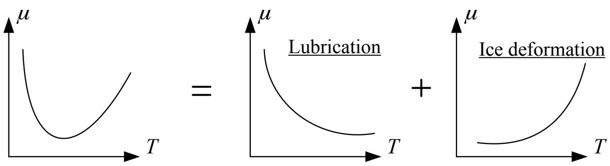

Fig. 3. Variation of ice friction coefficient with temperature.

We cannot claim the credit as in competitive bobsleigh it was already a common practice to use more curved blades when the ice temperature is very low and less curved ones when the ice temperature is higher. We used thermal imaging to track the run and observed that in cases of very cold ice, achieving a more localized contact with a curved blade helped to distribute the generated frictional heat over a smaller area, resulting to the fast creation of the lubricant film in agreement with published results [37]. When the ice temperature was towards the melting point, a curved blade like the aforementioned localized the contact and since the ice is not sufficiently stiff, the resulting higher penetration of the blade increased the friction coefficient, exactly as Fig.3 illustrates. Further to this appropriate selection of the finishing of the front and back runners affects the steering time and curve followed.

3.2. Structural response under dynamic loads

Each track in different competitions has a different signature in terms of dynamic interactions between sleds and track. Certain tracks present “rougher ride” and other higher speeds. We have collected dynamic data to allow us to simulate sleds loading on different tracks and used it to look into the dynamic response of the structure. The results we obtained we somewhat surprising on the deformation part and presented us with some very good ideas. We illustrate the structure’s oscillation and deformation under 10g dynamic load. We noticed that certain critical parts undergo large deformations affecting sled’s overall performance.

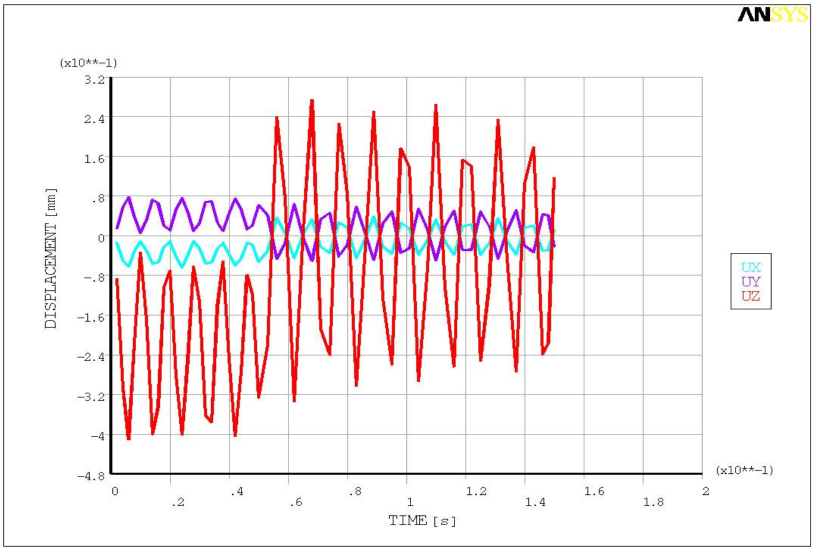

Fig. 4. FEA model demonstrating the dynamic node oscillations of the bumper

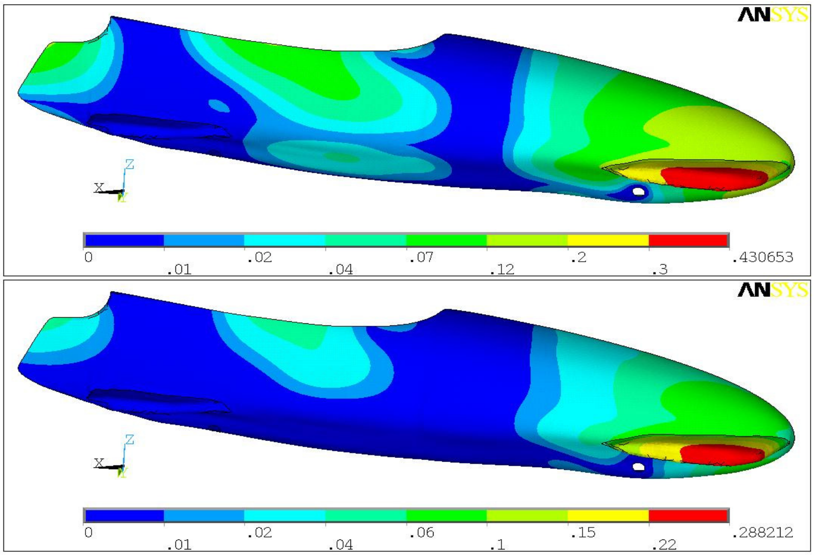

Fig. 5 Sled deformation under high g loads.

The reader can see some detail in some earlier publications [9, 10].

3.3. Aerodynamics

Although there have been numerous works on bobsleigh aerodynamics we set the trend on understanding the crew/sled interaction and its influence on the sled aerodynamics and on the understanding the alterations in aerodynamic performance due to sled deformation. As already discussed it is difficult to .re-design an entire sled and achieve success as it takes time for the driver and crew to develop a bond with this new piece of equipment. However, we made best progress on the double women sled as the rearrangement of the crew positions and internal padding. The figures below show the way we modified the sled in two steps, i.e. shape modification and cavity alterations to follow.

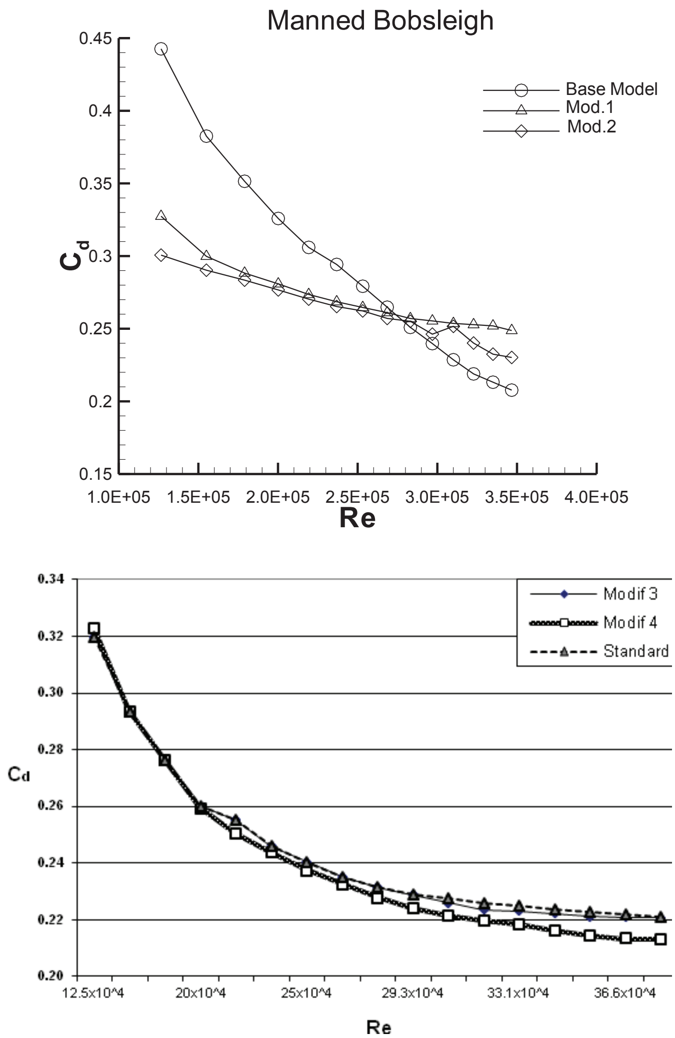

Fig. 5. (a) Bobsleigh drag resistance (C_d) vs Reynolds number (Re) standard model (Base) vs modifications (b) Comparison between different internal padding modifications and the bobsleigh without any padding

As can be seen from Fig 5a the sled was modified and although it showed slightly inferior performance at the very high end of speed spectrum it still performs better overall when the track speed profile is taken into consideration. The track profiling is therefore an essential part of the aerodynamic optimisation and is to be addressed in some upcoming works. Earlier results are also available in [11, 12, 13].

4. Sport technology and its influence on general science and technology

Sport technology is frequently perceived as solely a recipient of advanced technological developments from other fields of science and engineering. To some extent this perception was created in the early part and last decade of the twentieth century when the vast drop in defence expenditure prompted a lot of high tech companies to licence their developments to the fledging sport manufacturers. However, this is not the case any more as sport developments and research now influencing science and engineering. W Development of methods for assessing and achieving optimal performance under changing and sometimes severe environmental conditions has considerable promise for a variety of applications with potential benefits ranging from energy savings to safety improvements. Elasto-hydrodynamic lubrication contact problems, specifically at low temperatures, have not been explored in sufficient depth and such research is gaining importance with the advancing exploration of the arctic areas.. These problems, however, are of great practical importance and have a wide spectrum of engineering applications. Indeed NASA and US Defence Ministry declared structural responses at low temperatures as a priority research area.

Further to this some approaches we used for the improvement of the aerodynamic performance had common features with high profile projects such as the morphing wing one by MIT.

5. Conclusions and Future Work

Over the last two decades we and our esteemed competitors have been gaining deeper insight into the physics and engineering of the track sports. The sled performance and safety have both improved considerably aided not in a small part by the advanced design of the competitive tracks. However, there are still three areas of outstanding interest to us as outlined below, that we believe if appropriately addressed will bring further improvement in sleds handling:

- Structural dynamic response and its influence on the sled navigation;
- Unsteady effects and a possibility to improve aerodynamic performance by adapting the structure;
- Drivers navigation, information processing and

The first two areas we are already addressing while the driver performance requires advanced cognitive analysis and physiological testing while making competitive runs which is both technically challenging and a safety concern. Unfortunately simulators are quite limited in replicating the real track conditions hence we are not very clear on the coordination and response time as well the way driver processes and memorises the track profile and characteristics and how he/she responds to changes in conditions such as visibility, ice condition, track status. This remains a challenge we are not able to address at this point of time and in our opinion the virtual reality approaches had some limited success.

Future work will focus on in-depth analysis of structural response of the sled and its influence on sled's performance and building sled prototypes with a superior aerodynamic performance under unsteady conditions.

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