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Experimental Evaluation of Ski Suit Performance

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Abstract

In today's sport, a combined effort of individual skill, science & technological advancement and rigorous training is important for the success. In addition, athletes need both simulated and field training to be prepared physically and mentally. It is especially important for technically challenging sports like ski jumping where aerodynamics play a vital role. To achieve aerodynamic efficiency (manipulate drag and lift), the ski jumper's body postures, position & profile of the skis and other associated gears need to be optimised. Due to the short duration of ski jumping, a wind tunnel environment is an effective tool for both aerodynamic optimisation and training. This paper describes a design of a wind tunnel experimental rig that can be used as a training simulator as well as for the aerodynamic optimisation of the ski jumper's body posture and jumping suits. Using the developed full scale experimental rig, the aerodynamic performance of two ski jumping suits with an articulated mannequin was evaluated and presented in this paper.

Introduction

Ski-jumping is one of the most complex acrobatic winter sports. In ski jumping jumpers go down a hill with a take-off ramp with a goal to travel as far as possible. Points are allocated predominantly for the length; however, some points are also allocated for style on a scale from 1 to 20 skipping the highest and the lowest marks allocated by 5 judges. The skis used for ski jumping are wide and long with parallel sides. Ski jumping consists of four main phases: a) In-run, b) Take-off, c) In-flight, and d) Landing. During the in-run and take-off phases ski-jumper tries to reach maximum velocity. In the flight phase, the ski-jumper wishes to keep favourable body position in relation to wind direction to maximise the lift and minimise the drag to achieve the maximum jump distance possible. In landing phase, the aerodynamic drag is maximised and lift is minimised to achieve safe and artistic landing. It is no doubt that several factors including the initial ski jumper's body position, the magnitude and the direction of the velocity vector and the magnitude of the aerodynamic drag and lift forces determine the trajectory of the ski jumper hence the total distance of the jump. Modern V-technique pioneered by Jan Boklöw of Sweden is used by elite level skiers to maximise the lift and minimise the drag. This technique can increase the distance of the take-off hill by about 10 percent compared to the previous technique with parallel skis. Therefore, aerodynamics has become an important factor for increasing demands of high performance in modern ski jumping.

In addition to physical parameters, the length of ski jumping can be enhanced by appropriately designed equipment (eg, ski, helmet, goggles, suit, hand gloves, boots etc). The aerodynamic forces experienced by the skier directly depends on the projected frontal area of the athlete's body, body position in flight, equipment and their positions and features. A series of studies has been undertaken by Müller et al. [8-9], Meile et al. [7], Murakami et al. [10], Ito et al.[5], Remizov [11], Schmölzer & Müller [12], Schwameder [13], Seo et al. [14], Virmavirta et al. [15-16], Watanabe & Watanabe [17] predominantly looking at the biomechanical, body position and ski aspects of the ski jumper on aerodynamic effects using simulation, wind tunnel and in situ measurements. It is beyond doubt that these aspects are extremely important to understand the flight trajectory of the ski jumper. The effects of ski garments on aerodynamic performance of the athlete have not been studied and/or little understood. The use of textile materials in high performance sports including ski jumping can play a pivotal role in the outcome of the event. Since the early work of Brownlie [2] and Kyle et al. [6] in the 1980s and more recently studies by Chowdhury et al. [3-4] on the aerodynamic effects of sport clothing, systematic progress has resulted in aerodynamic apparel being associated with success at the highest elite levels; for example, in sprint, speed skating, cycling and ski jumping as reported recently. Considerations in this aerodynamic performance include the textiles (woven or knitted), seam and fastener placement and air permeability. Elite competition usually involves very short winning time margins in events that often have much longer timescales, making aerodynamic drag during the event significant in the outcome.

As the total duration of the flight trajectory for ski jumping is very short (~ 4 seconds), the ski jumper needs to optimise the body and ski positions very quickly. In order to be near perfect in optimisation, elite level skiers need to undergo a series of training and practice jumps. However, the process is time consuming, expensive and nature dependent. Moreover, it is extremely difficult to get effective feedback from the real world jumping due to the short span of flight time. The athletes and coaches spend enormous amount of time and effort on improving the flight style, body and ski position for the aerodynamic improvements. As mentioned earlier, a series of complex body positions need to be adjusted during the entire flight. For example, immediately after the take-off, posture changes need extremely sensitive pitching moment to be balanced. In order to maximize the desired jump length, the jumper has to vary the angle of attack during the flight and also the configuration of body parts and the skis. During the initial phase, the drag acts particularly disadvantageous against the nearly horizontal motion in reducing the flight velocity. At the later phases, the flight becomes steeper and the vertical component of the drag (against gravity) supports raising the flight path. Simultaneously, the lift component in the horizontal direction increases and is beneficial for larger jump lengths. Of course, the optimum flight style differs significantly from one jumper to the other due to anthropometrical differences and due to individually different motor abilities [12]. Therefore, a full scale wind tunnel aerodynamic performance evaluation in a more controlled environment is extremely desirable and appropriate option. Jumpers can have ample opportunities to feel, adjust and become familiar with the optimised positions and styles. Although several full scale experimental setups in wind tunnels by Müller [8], Ito et al. [5] and Seo et al. [14] have been reported in the literature, none of these setups is perfect for the comprehensive evaluation of aerodynamic performance of the ski jumper, ski and ski suits. Details of two of these experimental setups will be discussed later.

The primary objectives of this work as part of a larger project are to develop a full scale experimental aerodynamic performance evaluation methodology and experimental set up for dummy and real athletes using large wind to determine the aerodynamic effects of skier, ski suits and other ski gears.

Development of Full Scale Experimental Setup and Methodology

The development of a full scale ski jumping simulation using a wind tunnel is cumbersome, time consuming and expensive. There is extremely limited information on full scale ski jumping experimental setups available in the public domain. To date, two experimental setups have been reported by Müller et al. [8] and Seo et al. [14]. However, these experimental setups have significant drawbacks as neither of these setups allows simultaneously measurement of all 6 components of forces and moments or the mounting devices have significant interference to flow and subsequently lead to incorrect force and moment measurements. For example, the experimental setup developed by Seo et al. [14] cannot be rigidly mounted (see Figure 1). As a result there is a stability problem. Forces and moments cannot be measured with a real ski jumper. Measurements can be significantly affected due to the instability of the system as it uses flexible wire. Beside this, Müller [8] has developed a relatively better experimental setup for full scale testing with a real ski jumper (see Figure 2). In this setup, a support which is placed in front of the test subject will affect the measurement. Therefore, a new setup has been designed in RMIT University by carefully analysing all advantages and disadvantages of the existing two systems for the full scale measurement with a dummy or real ski jumper and ski gears including ski jumping suit. The developed setup is robust, safe and the supporting structures have minimum interference to aerodynamics of dummy, jumper and ski gear. Using this methodology and setup, it is possible to quantify the small variation in aerodynamic properties that might be caused by various features of ski jumping. The newly developed system and experimental set up is shown in Figures 3 to 5.

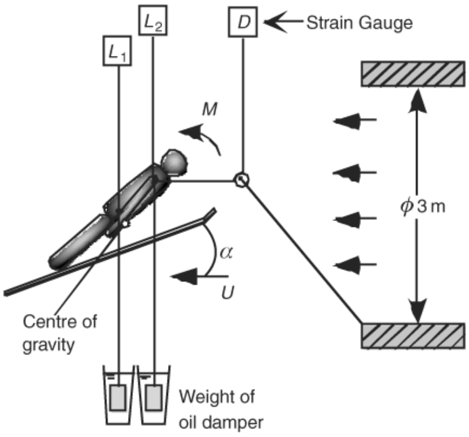

Figure 1: Schematic of experimental set up in wind tunnel [14]

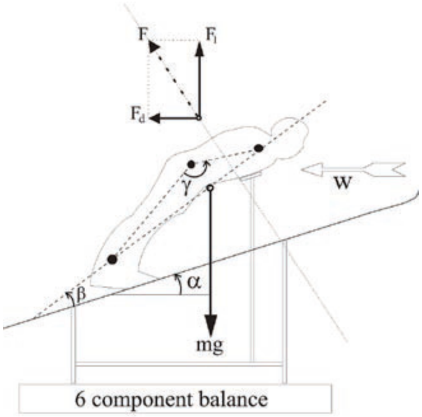

Figure 2: Schematic of full scale experimental set up in wind tunnel [8]

The RMIT Industrial Wind Tunnel was used for the newly developed full scale experimental setup for the aerodynamic performance evaluation. The tunnel is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 km/h. The rectangular test section dimensions are 3 m wide, 2 m high and 9 m long. More details about the RMIT Industrial Wind Tunnel can be found in Alam et al. [1].

As mentioned earlier, the full scale experimental setup (rig) has been designed to accommodate the real ski jumper with all equipment (e.g., skis, suit, boots, goggles, helmet, and hand gloves). A special safety harness was also made for the extra safety of the athlete at high speeds. A CAD model of the experimental rig is shown in Figure 3. The base of the rig was made of high strength steel frame. Six adjustable circular steel pipe stands have been used to fix the skis and adjust the angles between the skis and horizontal plane up to ±15º by varying the heights. A special mounting device has been connected with the structure at joining line of the mass centre of the whole structure. The mounting device goes to a 6 component force sensor (type JR-3). The sensor has a sensitivity of 0.05% over a range of 0 to 1000 N axial forces which is capable to measure very accurately all 3 forces and 3 moments under a range of speeds (10 km/h to 140 km/h). A mannequin with adjustable body parts can be used for the aerodynamic assessment of ski jumping suits. The articulation and pivotal points of the mannequin are shown in Figure 4. In order to reposition the mannequin and other equipment for repeatable data acquisition, two fixed cameras have been used. At first two photographs were taken as reference positions from front and side. Overlapping the images taken by these digital cameras, the mannequin and other accessories can be repositioned to the previously referenced position. The mannequin can be used for the replication of the jumper's body position in flight. However, the mannequin can easily be replaced by the real jumper into this setup. The force sensor is connected to a wind tunnel data acquisition computer port and special software is used to capture all 6 component forces and moments simultaneously. The data acquisition system also allows real time data display and associated data related information. The data acquisition can be both time averaged and/or instantaneous (time dependent).

Figures 4 and 5 show the various parameters associated with ski-jumping. Here, Fx, Fy, Fz and My denote drag force, lift force, side force and pitching moment respectively. Also α, β, γ and V stand for of ski angle relative to horizontal plane, body position angle, hip angle and angle between two skis respectively. The ski angle (α) can be varied from -15° to +15°, the hip angle (γ) can be varied from 120° to 160° and the body position angle (β) can be adjusted from 10° to 70°. Additionally, the V-Angle between the skis can be varied at angles from 0° to 35°. These angle adjustments cover the majority of the possible variations in real ski jumping.

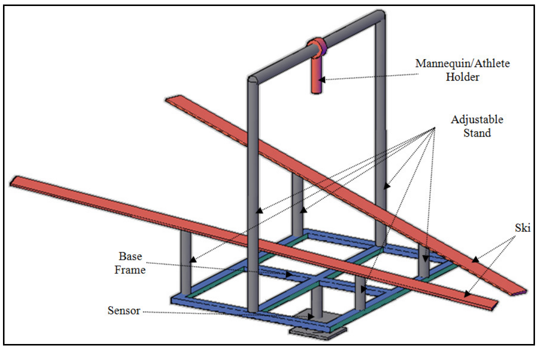

Figure 3: CAD model of the experimental rig

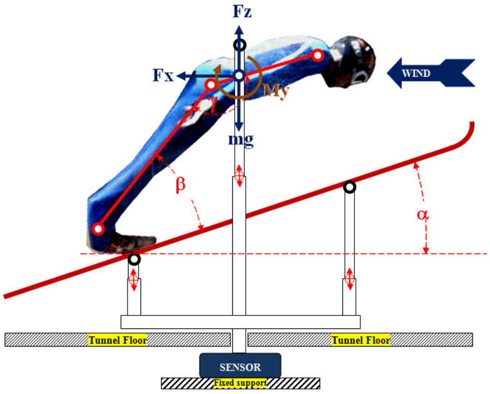

Figure 4: A schematic of experimental setup (side view)

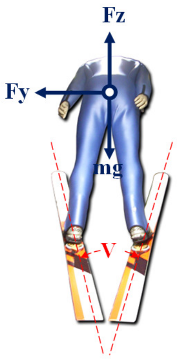

Figure 5: A schematic of experimental setup (rear view)

As mentioned earlier, the experimental setup (rig) can be used for the aerodynamic performance evaluation of both full scale mannequin and real ski jumper with all the accessories including the ski suits, skis, boots, helmets, goggles and hand-gloves. The rig can be used for ski jumping training as well.

Aerodynamic Evaluation of Ski Jumping Suit

As mentioned previously, the aerodynamic performance of ski suits is not available in the public domain. Although it is believed that with the appropriate design and materials in compliance with the existing rules and regulations of the governing bodies, the performance can be enhanced significantly as mentioned by Chowdhury et al. [3-4]. The full scale testing of ski suits made of materials with different surface morphology can easily be evaluated using the proposed experimental development. Ideally, the mannequin would be the appropriate tool for this kind of study. The instrumented mannequin allows easy fitting and unfitting different ski jumping suits with minimum changes to the experimental setup.

In order to understand the comprehensive aerodynamic behaviour of ski jumping suit, it is extremely important to study at macro scale first by decomposing the body into parts cylindrical in shape. Study needs to be undertaken to understand the effects of materials surface morphology, seams and zips on aerodynamic drag and lift as many body parts predominantly generate only drag or drag and lift simultaneously. As the aerodynamic forces generated by the suits are an order of magnitude less compared to the full body and skis, the full scale testing may not be as useful as cylindrical testing. However, once a suit is designed and optimised, it can be used for full scale testing using mannequin or a real athlete either in wind tunnel or real world jumping.

In order to perform a macro scale aerodynamic evaluation of any sports suits, a cylindrical method has also been developed at RMIT. Details about this method can be found in Chowdhury et al. [4]. Based on macro scale test results, one optimised suit has been developed. The optimised suit along with a standard suit purchased from the shelf has been selected for full scale test using the developed rig. The structure with and without the mannequin was tested under a range of speeds (20 km/h to 110 km/h) typically experienced by the ski jumper during in run and in flight. The standard jump suit and the optimised suit were also tested under the same test conditions and speeds. The aerodynamic drag and lift coefficients (C_D and C_L) for the bare mannequin and the mannequin with 2 suits are shown in Figures 6 and 7. All these test were carried out at a fixed position with α=10°, β=20°, γ=160° and V=30°.

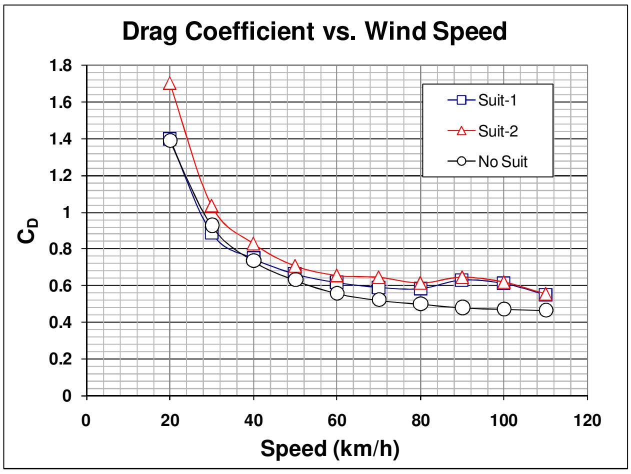

Figure 6: Drag coefficient variation with speeds

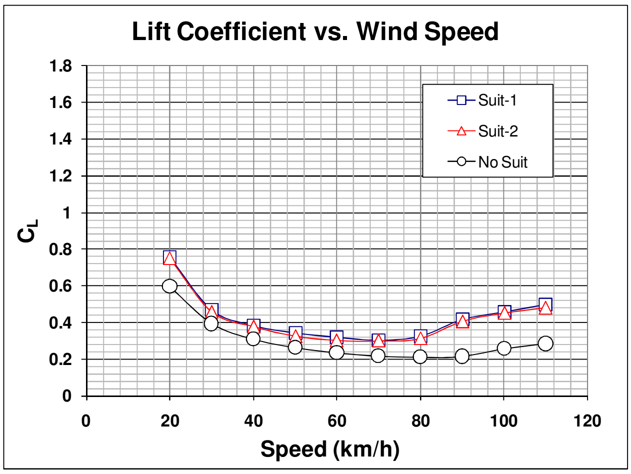

Figure 7: Lift coefficient variation with speeds

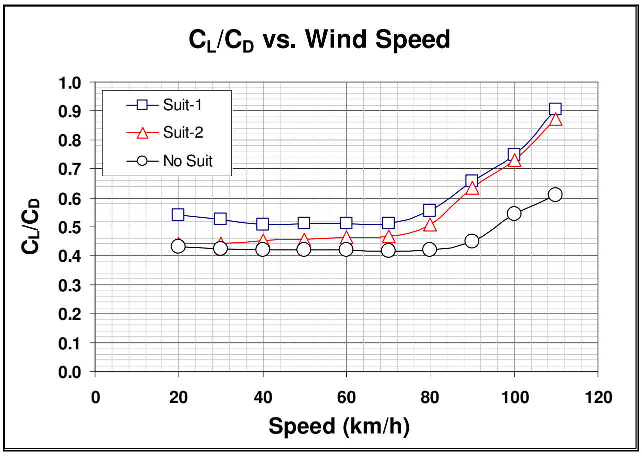

Figure 8: C_L/C_D variation with speeds

The ratio of C_L/C_D indicates that the mannequin (without suit) and the mannequin with suit-1 have no significant advantages below 80 km/h and 70 km/h respectively. Both suits and the mannequin generate significantly more lift than drag at speeds over 80 km/h. However, the suit-2 (modified) generates more lift than drag at all speeds tested (see Figure 8).

Concluding Remarks

The following conclusions were made from the work presented here:

- A robust and reliable full scale experimental setup and methodology for ski jumping aerodynamic performance evaluation has been developed.
- The developed system allows experimental evaluation of drag and lift for all types of ski gears as well as real ski jumper or dummy.
- The developed system can be used as a tool for airflow visualisation of the ski jump
- For jumper's training, the RMIT developed set up will be extremely useful as it allows jumpers psychologically and physically to be trained in a more controlled environment.

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