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Procedia Engineering 13 (2011) 376–381

Engineering Procedia

5th Asia-Pacific Congress on Sports Technology (APCST)

Aerodynamic study of ski jumping suits

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Received 20 April 2011; revised 15 May 2011; accepted 16 May 2011

Abstract

Advancements of science and technology have progressively been implemented in speed sports especially in ski jumping. Aerodynamics plays a vital role in the overall performance of ski jumping. Although some studies have been conducted on the skier's body and ski positions, scant or no study on aerodynamic behaviors of the ski suits and skier has been reported in the open literature. Therefore, the primary objectives of this study are to design and develop a full scale experimental setup and evaluate the aerodynamic performance of skier and ski jumping suits with different fits along with skies, boots, goggles, helmet and gloves. The results indicated that the tight fit suit provides an extra aerodynamics advantage over a normal fit suit. As a result the jumping length can be increased to win the competition.

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Selection and peer-review under responsibility of RMIT University

Keywords: Wind tunnel; full scale test; aerodynamic drag; lift; ski jumping; suits; experimental measurement

1. Introduction

Ski jumping is one of the most complex, scientifically challenging and spectacular acrobatic winter sports. 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. Therefore, aerodynamics knowledge is paramount factor for the increasing high performance achievement in modern ski jumping. In addition to physical parameters, the length of ski jump can be enhanced by appropriately designed equipment (e.g. ski, helmet, goggles, suit, hand gloves, boots etc.). The aerodynamic forces experienced

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doi:10.1016/j.proeng.2011.05.101

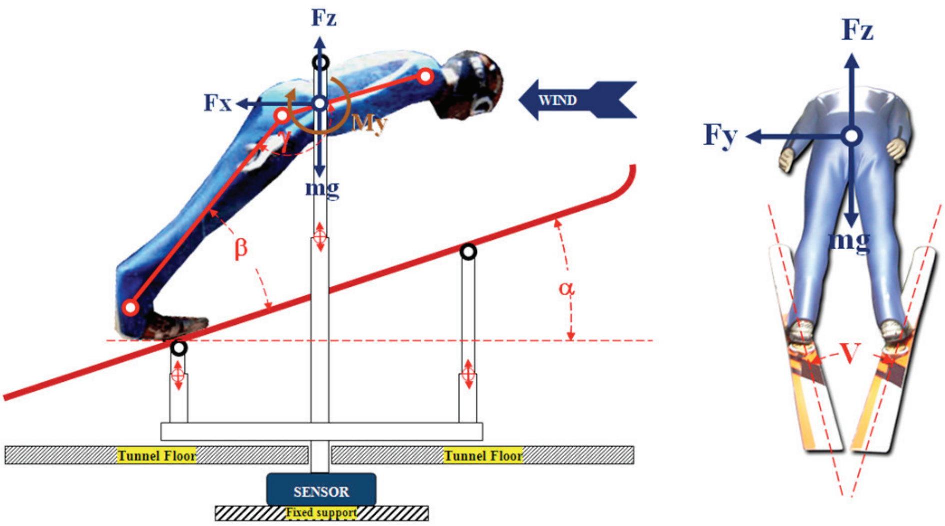
by the skier directly depends on the projected frontal area of the skier's body, body position in flight, equipment and their positions and features.

The effects of ski suits made of various materials on aerodynamic performance of the athlete have not been well studied or understood. Recently studies by Chowdhury *et al.* [1, 2] reviled that the knowledge of textile materials in high speed and high performance sports including ski jumping as well as skier body position is crucial for the positive outcome of the event. In order to understand, the aerodynamic role of ski jumping suits, it is also utmost important to comprehend the aerodynamic behaviors of the skier and skis in flight as the magnitude of aerodynamic forces are significantly larger compared to the aerodynamic forces generated by the ski suits. Although some aerodynamic work on high performance textiles have been conducted for some other sports suits like cycling suits, scant scientific information is available on full scale aerodynamic studies of skier and ski jumping suits in the open literature except a very limited studies by Mueller *et al.* [3] and Seo *et al.* [4]. According to the simulation approach used by Muller and Schmolzer [5] the jump length would increase by 1.8 m when the lift can be increased by 1% throughout the whole flight while jump length can be decreased by 1.2 m with an increase of drag by 1%. Meile *et al.* [6] tested ski jumping suits with scaled model and mentioned that at the first glance, the effect of these minor changes may seem negligible. Nevertheless, the consequences on the increased jump length by few meters could be a decisive advantage. From the competitive point of view this is very essential, because a few percent of improvement in lift may lead to larger jump lengths and, therefore, decide over winning or losing in World Cup competitions. So the effort put into the development of appropriate suits is justified. The influence of the suit might be of competitive relevance, as the observed small differences may have decisive influence on the length of the flight trajectory. As mentioned earlier, the effects of ski suit on aerodynamic performance of the athlete in full scale have not been studied and/or little understood. Therefore, the primary objectives of this study as part of a larger project are to design and develop and evaluate a full scale testing methodology using mannequin or real athlete along with all associated ski gears.

2. Methods

As mentioned previously, scant information about the full scale aerodynamic testing methodology for the skier and ski suits is not available in public domain. Till to date, two experimental setups have been reported by Mueller *et al.* [3] and Seo *et al.* [4] in the open literature. However, these experimental setups have some drawbacks as either of these setups does not allow simultaneously measure all 6 components of forces and moments or the mounting devices have significant interference to the airflow and subsequently lead to incorrect forces and moments measurements. For example, the experimental setup developed by Seo *et al.* [4] cannot be rigidly mounted. In this setup, there is a stability problem. Forces and moments cannot be measured with a real athlete. Also measurements can significantly be affected due to the instability of the system as it uses flexible wire. Beside this, Muller [3, 7] developed a relatively better experimental setup for full scale testing of real athletes. But in this setup, a support was placed in front of the test subject. As a result, the measurement is affected due to this front support. Therefore, we propose a new setup that has been carefully designed for the use in RMIT Industrial Wind Tunnel by carefully analyzing all advantages and disadvantages of the existing two systems for the full scale measurement of dummy or real athlete with all ski gears including ski suits. The developed setup is robust, safe and the supporting structures have minimum interference to the aerodynamic properties of dummy or athlete with ski gears. Using this methodology and setup, it is possible to quantify the small variation in aerodynamic properties that might cause by various features of ski jumping. The full scale testing of ski suits made of materials with different surface structure can easily be refined 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 the suits with minimum changes in the experimental setup. The RMIT Industrial Wind Tunnel is appropriate for the full scale experimental setup as it has the rectangular test section with dimensions of 3 m width, 2 m height and 9 m length. The tunnel's cross sectional area is 6 square meters. It 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.

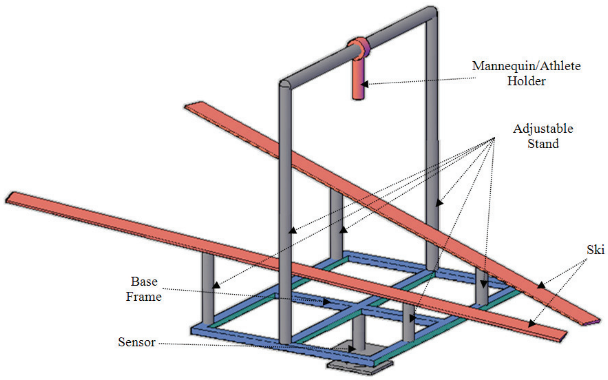
Figure 1 shows the various parameters associated with ski jumping. Here, Fx (D), Fy (L), Fz (S) and My denote drag force, lift force, side force and pitching moment respectively. Also α, β, γ and V stand for of ski angle relative to horizontal plane, body position angle, hip angle and angle between two skis respectively. The ski angle (α) can be varied from -15° to +15°, the hip angle (β) can be varied from 120° to 160°, and the body position angle (γ) can be adjusted from 10° to 70°. Additionally, the V-Angle of the ski can be varied at angles from 0° to 35°. These angle adjustments cover most of the possible variations of an athlete in real ski jumping.



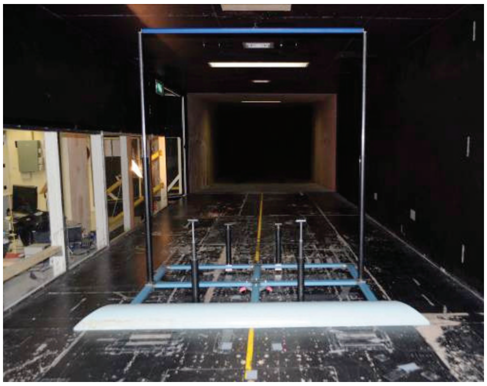
(a) (b)

Fig. 1. A schematic of experimental setup: (a) side view; (b) rear view

The full scale experimental setup has been designed to accommodate the athlete/mannequin with all associated equipment (e.g. ski, suit, boots, goggles, helmet, hand-gloves, etc). A special safety harness was also made for the extra safety of the athlete at high speed testing. A CAD model of the experimental setup is shown in Figure 2(a). The base of the rig was made of high strength steel frame. Six adjustable (articulated) circular steel pipe stands were used to fix the skis and adjust the angles between the ski and horizontal plane up to ±15º by varying the heights. A special mounting device was connected with the structure at joining line of the mass centre of the whole structure. The mounting device is connected to a 6 component force sensor. The sensor has a sensitivity of 0.05% over a range of 0 to 1000 N axial forces which is capable to measure accurately all 3 forces and 3 moments under a range of wind speeds (from 10 km/h to 140 km/h). The adjustable mannequin can be used for the aerodynamic evaluation of ski jumping suits. The articulation and pivotal points of the mannequin are shown in Figure 1. In order to reposition the mannequin and other equipment for the repeatable data acquisition, two fixed cameras were used. Overlapping the images taken by these cameras digitally, the mannequin and other accessories were repositioned to their exact relative previous positions. The mannequin was used for the replication of the athlete body position in flight. However, the mannequin can easily be replaced with a real athlete using this setup developed at RMIT University. 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. Figure 2(b) shows the experimental setup installed in RMIT Industrial Wind Tunnel.



(a)



(b)

Fig. 2. (a) CAD model of the experimental setup; (b) Full scale setup installed in RMIT Industrial Wind Tunnel for testing

With a view to evaluate the robustness and suitability of the newly developed full scale experimental setup and testing methodology, an articulated mannequin and two ski jumping suits (Suit-1 and Suit-2) have been used. Tests were conducted for a range of wind speeds starting from 80 km/h to 110 km/h to with different configurations as shown in Figure 3 as the take off speeds for long jump varies from 90 to 100 km/h. Both suits are made of the same fabric manufactured by Spinno according to the FIS regulations and the body measurement of the mannequin used. Maximum allowance about 5 cm has been provided in Suit-1 but no allowance is implemented in Suit-2. As a result, Suit-2 is tight fit suit for the mannequin. Skin tight Suit-1 had less wrinkle when put on the plastic mannequin. But because of the 5 cm allowance wrinkles were observed on Suit-2. All tests were carried out at a fixed position of $\alpha = 12.5°$, $\beta = 42.5°$, $\gamma = 160°$, V = 20°. These values are based on the field results data analyzed by Schmölzer and. Müller [4], further processing was done to find out the percent contribution of time for different body parts (legs, trunk, arms) during the total duration of flight time which is 3.63 s. As this configuration contributes for the larger part of the flight, the tests are carried out with these values.

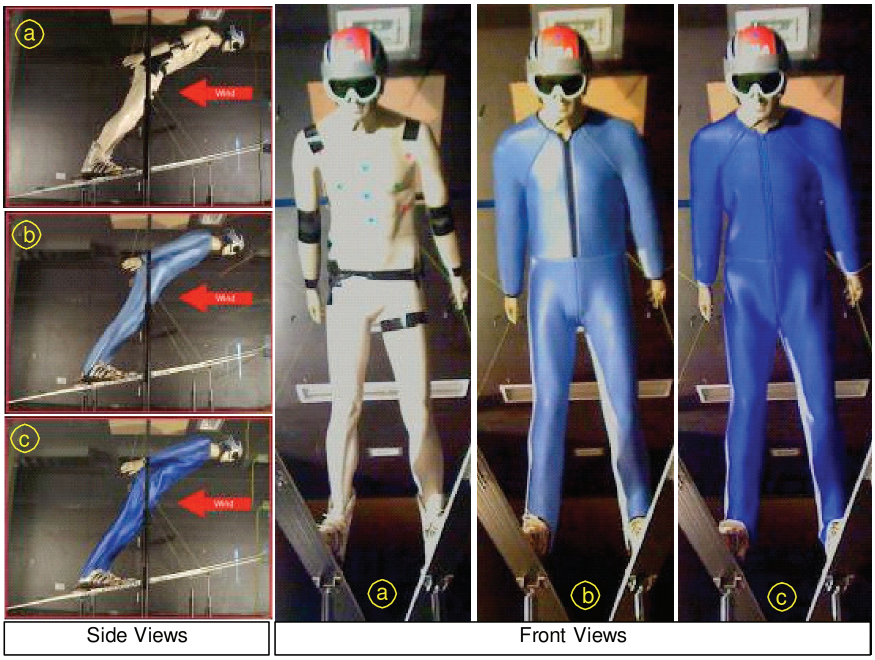


Fig. 3. Different test configurations

3. Results and Discussion

All forces (3 components) and moments (3 components) of were measured simultaneously. However, only the drag (D) and lift (L) forces and their corresponding non dimensional coefficients C_D and C_L are included in this paper. The C_D and C_L are calculated using the formulae: $C_D = \frac{D}{\frac{1}{2}\rho V^2 A}$ and $C_L = \frac{L}{\frac{1}{2}\rho V^2 A}$ respectively; where, D, L, ρ, V and A are drag force, lift force, density of the fluid, velocity of the object relative to the fluid and the reference area respectively. The C_D, C_L and L/D variation with speed are shown in Figure 4(a), (b) and (c) respectively. The figures illustrate the aerodynamic parameters for the bare mannequin (without any suit) and the mannequin with 2 suits.

Projected frontal areas were measured for each configuration and were found 0.525 m^2, 0.584 m^2 and 0.596 m^2 for bare manikin, mannequin with Suit-1 and mannequin with Suit-2 respectively. Frontal area increased about 11% and 14% with Suit-1 and Suit-2 respectively compared to the bare manikin. Because of the tightness of the Suit-1 the projected frontal area is 2% less than that with Suit-2.

With an increase of wind speed, the mannequin with Suit-1 and Suit-2 experiences higher drag and lift compared to the drag and lift of the mannequin without any suit. However, the increment of lift is significantly higher compared to the drag increment at high speeds. Data clearly indicates that both suits have significant advantages over lift to drag ratio compared to the ratio of lift to drag of the mannequin without any suit (see Figure 4(c)). A little variation in drag and lift for Suit-1 and Suit-2 can be observed because of the different fit of the suits. The data shows that Suit-1 (skin tight suit) has greater values of *L/D* values. As a result, jumper can get more aerodynamic benefit with the skin tight suit. Thus a little aerodynamic benefit can be harnessed to win international competitions.

Result also shows that with Suit-1 the average drag area (*D*) was decreased by 1.8% but lift area (*L*) increased by 4.3% compared to Suit-2. The resultant jump length can be increased by about 8 m by using the simulation approach formulated by Muller and Schmolzer [5].

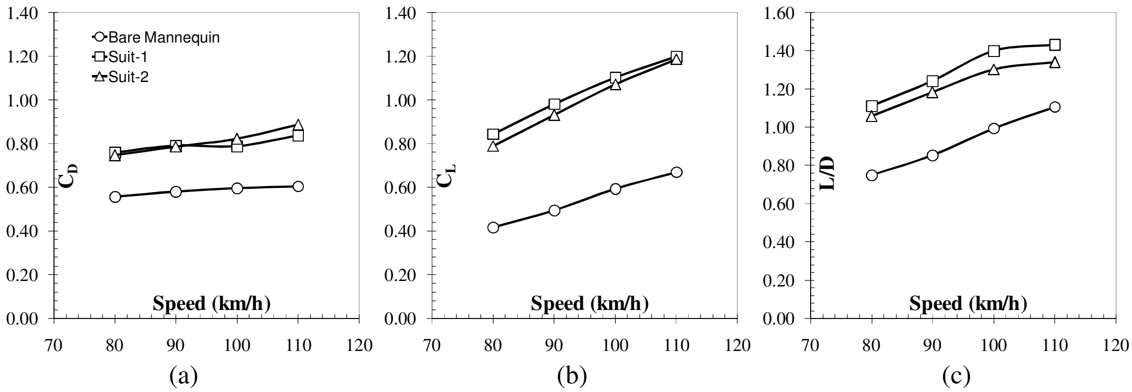


Fig. 4. C_D, C_L and *L/D* variation with speed for different configurations.

4. Conclusions

- A robust and reliable full scale experimental setup and methodology has also been developed and calibrated.
- The developed system allows experimental evaluation of drag and lift for all types of ski gears as well as real athletes and dummy.
- Tight fit suit can provide an aerodynamic advantage over a loose suit to win a race.
- The developed system can be used as a tool for the airflow visualizations of the ski jumping.
- The RMIT University developed full scale setup can be used as an essential training tool since it allows athletes to be trained both psychologically and physically in a more control environment.

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