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The influence of aerodynamic drag in the flight phase of long-jump performance

J. P. Sachini Jayaneththi[1], A.W.Suraj Chandana[2]

[1](Department of Sports Sciences and Physical Education, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka, P.O. Box 02, Belihuloya, Sri Lanka)

[2](Department of Sports Sciences and Physical Education, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka, P.O. Box 02, Belihuloya, Sri Lanka)

Abstract:
Background*: Three different air dynamics are employed when performing the long jump and each has a different impact on performance. In a variety of sporting events, aerodynamic forces have a considerable impact on strategy and performance records. This study is aimed at determining how much wind and air resistance contributed to long jump performance. Investigations were conducted on the relationship between the Drag force (D) and time for various flying techniques.*
Materials and Methods*:Six male senior long jumpers' best performances at a national competition in Sri Lanka were considered for this study. Two of each technique's best performers were used to analyze (Kinovea 9.5 software) all three of the techniques. Two cameras were used to record the performances in the frontal and sagittal planes (100 Hz). The coordinates of each athlete's Centre of Gravity were examined for each frame from the take-off through the landing phase. Separately, the frontal plane and sagittal planes were used to complete the space calibration to get the frontal surface area of the body for each frame.*
Results*: The study calculated the aero drag force using the equations of Reynolds number and aerodynamic force. The drag force for each time frame for the three techniques fluctuated approximately between 7N to 11N.* ***Conclusion:****This leads to reduce the horizontal flight distance.*
Key Word*: Air resistance, body surface area, frontal plane, wind velocity*

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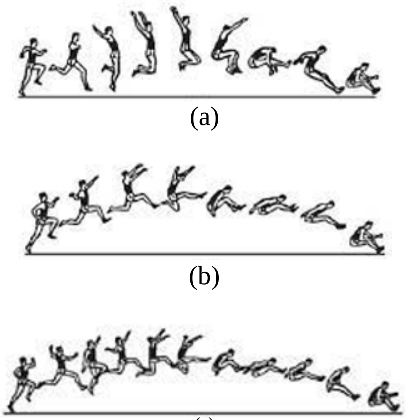
I. Introduction

The long jump is a field event in track and field sports where players combine their speed, strength, power, and balance to achieve the horizontal displacement. The flight distance is dependent not only on the take-off parameter but also it's depended on the flight technique and landing technique used by athletes (Smith & Lees, 2005).Athletes who leap long distances commonly employ the Hang, Hitch Kick, and Sail/Stride jump techniques (Figure 1) (Kamnardsiria, et al., 2015).Due to variations in the movements of the arms and legs, these three approaches behave differently with angular momentum (Hong & Bartlett, 2008; Wu, Wu, Lin, & Wang, 2003).

The sail entails quickly contacting the toes after take-off. This permits the body to fly longer with take-off momentum. The hang technique extends the body and keeps airborne for as long as possible. Both arms and legs are stretched to the greatest extent feasible, and the posture is maintained until the jumper achieves the highest height. Hitch-kick, also known as ascending or running in the air, athletes rotates their arms and legs to maintain balance during flight.

The performance of the long jump is impacted by arm and leg mobility during flight.The arm and leg swing used to enhance the leaping distance (Tsuboi, 2010).There has to determine the excessive force generated by changing the body segments such as arm and leg swinging.Another benefit of arm motion would be that it accelerates the body's canter of gravity (CG), increases the vertical ground reaction force's peak magnitude, and adds more downward force on the body, which promotes the generation of greater muscle force (Smith,1985).A considerable force is produced when the body's parts are moved, such as when the arms and legs swing.

The identified problem was that there are three different long jump techniques, each of which has a unique aerodynamic that can have an impact on performance. During the approach and aerial phases, the effect of wind and altitude on the aerodynamic drag has been assisted (Smith, 1985).The air dynamics vary from player to player and even within the same technique. Throughout their whole journey, there are always modifications to the surface area. Height of the body and method affect the change in body surface area (frontal plane) (movement of the body segments). Based on the player, the same technique may have different aerodynamics. Throughout their whole flight, the surface area is a variable. The height of the body and the technique has an impact on changes in body surface area (frontal plane) (moving the body segments). Previous study on changes of mass during the long jump flight phase, Jasminan and Chandana (2021) explained that Hitch and Sail technique is suitable to maintain the path of CG in a projectile path compare to other techniques; there is a possibility that external factors like wind velocity, air pressure, air density, humidity, temperature, ground reaction force to affect the path of CG.Based on these findings, it is possible for external factors to affect the path of the CG. As a result, it was difficult to determine the study's factual evidence or to verify the statement's accuracy.



(a)

(b)

(c)

Figure 1: Long jump style a) Hand b) Sail/Stride c) Hitch kick
Source: Kamnardsiria, et al. (2015)

II. Material And Methods

This study enrolled national senior male long jumpers at the national trial (n=6). According to their technique of flying, they were grouped into three categories (hitch-kick group, n = 2, hitch-sail group, n = 2, and hang group, n = 2). All athletes had their height and weight measured before to the test. Data was gathered at the Asian Trial in Sri Lanka in 2022. For the data analysis, the best leap out of six tries was selected. In order to capture the performances of each player, there were two (02) video cameras employed.

As shown in Figure 2, two cameras were positioned on the sagittal and frontal planes. Both cameras had a 1.2m height. The calibration was performed using a 1.5m solid rod. To synchronize the cameras, two (02) Godox TT650 speed lights and a Godox X1R-N TTL wireless flash trigger were employed (Thotawaththa&Arangala, 2021).

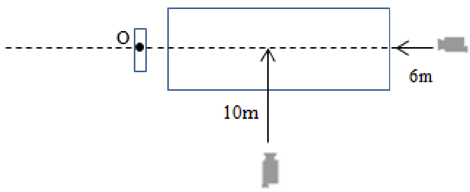


***Figure 2**: Experiment setup on around the long jump landing pit*
(O is the origin of the coordinate system) (Jayaneththi&Chandana, 2022)

Space Calibration

Step 1: The square frame (S_{Sqaure}= 2025 cm^2) was moved on the sagittal plane and it was captured by two cameras.

Step 2: Fixed distance on the sagittal plane was captured (Laksara&Chandana, 2019).

Calibration of Surface Area and drag force on Frontal Plane

Step 1: Retrieved the horizontal displacement, vertical displacement, and speed (sagittal plane) of the CG in each time frame for every 6 players using Kinovea (0.9.3 version). Determine the corresponding position of the square frame (frontal frame) which traveled through the pit (on the sagittal frame).

Step 2: Calculated body surface (on frontal frame) using the ratio between the number of pixels in the athlete and the square frame (Photoshop 2020).

Step 3: find the corresponding drag coefficient to the relevant Reynolds number. The Reynolds number (Re) quantifies the ratio between inertial forces and viscous forces in a fluid flow. It provides a significant role in the examination of the boundary layer.

$Re = \frac{\rho u L}{\mu}$(1)(Guo&Ghalambor, 2005)
Where; L = reference length, V = reference airspeed, ρ = air density, μ = air viscosity

Step 4: calculate the aero drag force using the equation of aero drag force.
$D = \frac{1}{2}\rho(V - w)^2 SCd$ (2) (Smith, 1984)
Where; ρ- Airdensity, V-Body speed, W- wind velocity, S-frontal body surface area, Cd-drag coefficient

III. Result

The following plotted graphs show aero dynamics drag force against the time in every three techniques.

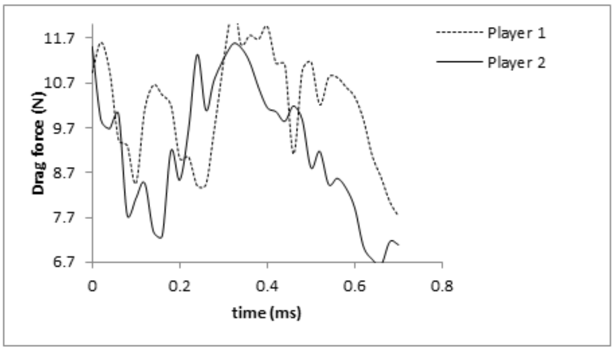


***Figure 3:** Dashed line shows graph for Player 1 with technique (Hitch and Sail), m=81kg, h=1.78 m, flight time 0.75s, Performance-6.3 m and wind velocity -1.2 $m.s^{-1}$. Solid line shows graph for player 2 with Technique (Hitch and Sail), m=73kg, h=1.81 m, flight time 0.8s, Performance- 5.87 m and wind velocity -1.5 $m.s^{-1}$*

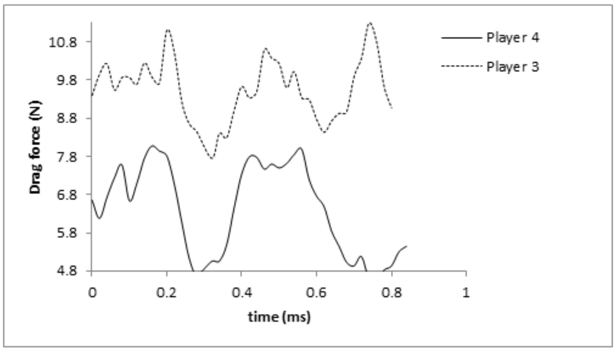


***Figure 4:** Dashed line shows the graph for Player 3 with Technique (Hitch Kick), m=83kg, h=1.84 m, flight time 0.84s, Performance- 6.68 m, and wind velocity -0.9 $m.s^{-1}$. The solid line shows the graph for player 4 with Technique (Hitch Kick), m=69kg, h=1.78 m, flight time 0.85s, Performance- 6.62 m, and wind velocity -1.2 $m.s^{-1}$*

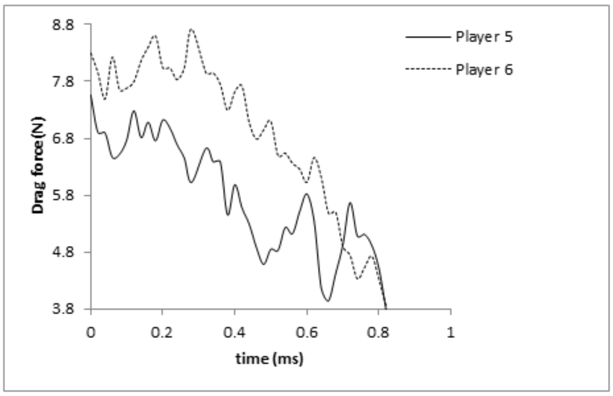


***Figure 5**: Solid line shows the graph for Player 5 with Technique (Hang), m=80kg, h=1.82 m, flight time 0.8s, Performance- 6.93 m, and wind velocity -1.1 $m.s^{-1}$. The dashed line shows the graph for player 6 with Technique (Hang), m=72kg, h=1.79 m, flight time 0.82s, Performance 6.87 m, and wind velocity -1.2 $m.s^{-1}$*

IV. Discussion

The flying phase of the long jump is examined in the current research. For specific starting circumstances, relationships are provided for how changes in air resistance (air drag) in each time frame and the horizontal displacement of the jumper's COM affect to the aerial performance. The performance of a long jumper is majorly influenced by surface area changes, vertical and horizontal components of velocity during take-off, and velocity during flight. Finding the aero drag force depends on the frontal body surface area and the subtraction of the horizontal velocity of the player's CG to wind velocity at that period of the flying movement.

In the hitch and sail technique, the aero drag force maximizes when the player is at their maximum height in the flight. Because of this position, the player's frontal surface area was maximized. Once the player started for the landing, the surface area decreased. Then the drag force can be decreased as a consequence.

For the players who perform hitch kicks, the upper body extends in his 2nd paddling in the air but minimizes the body surface area by moving the lower extremities. However, the drag force is greater when the position of the upper body extension. The most tremendous drag force (equation: 2) achieved by the player in hitch kick is 11.28N. The last drag force value can be seen as 4.47N when the player is at his jerk position.

In the hang technique, the drag force gradually decreases with time. The greatest drag force acted on the body just after the take-off or traveled after a few milliseconds. According to the graph, it shows 8.72N. The least aerodynamic drag force indicates 3.84 N. Mostly; the players who perform the Hang technique are lumpish toward the body.

The average aero drag force for Hitch and Sail, Hitch kick and Hang techniques are 9.7 N, 7.9 N, and 6.3 N respectively. According to the results of this investigation, the minimized drag can be seen from the Hang technique.

Certain segmental body motions influence the performance of a long jump. To maximize an athlete's performance, the athlete's surfaces during the aerial phase must be minimized in 21 out of 50 frames (frontal frames) (Jayaneththi&Chandana, 2022). Those are emphasized for all three techniques in their exact position in the air. The 1st position, 2nd position, 3rd position, 4th position, and 5th position is chosen from 0.17T, 0.51T, 0.71T, 0.8T, and 0.94T respectively in traveling through the air just after the take-off.

Table no 2: *Surface area changes for each technique (5 positions from 21) (Jayaneththi&Chandana, 2022)*

Technique	Position				
	0.17T	0.51T	0.71T	0.8T	0.94T
Hitch and Sail					
Hitch Kick					
Hang					

According to the records in Table 2, the surface area at the maximum height of Hitch Sail and Hitch Kick techniques is greater than in other positions. If the player splits his legs as far as possible, he will reduce his body surface and gain greater distance. The body surface area is greatest in the Hang technique just after takeoff. It takes a minimum value in the jerk position. The illustrations above show that hip flexion, knee extension, and hip angle vary for each posture and technique. A player may decrease body surface and enhance distance by separating the legs as much as possible. The body surface area is at its greatest during the takeoff phase of the hang technique. It is at its lowest value while executing the jerk posture. As seen in the images above, hip flexion, knee extension, and hip angle change depending on techniques.

The study revealed that varied surface areas were adequate for hip flexion even while in the same position in the air. The surface area is determined by movements of body segments such as hip flexion, knee extension, and hand and leg motions. The maximum surface area was measured just after takeoff, while the minimum surface area was measured in the jerk position. Compared to the other two techniques, the later phases, which began with a jerk, required the least proportion of surface area before landing. Extending the knee and minimizing hip flexion means a greater distance in the air

V. Conclusion

The performance is also impacted by the various air dynamics of the three long jump techniques. The current study determined the relationship between performance and the drag force produced by air and arm motions while altering the body's surface area at each time frame of the long jump's flight phase. A long jump's performance is influenced by particular body motions. For each of the three techniques' in time frames, the drag force varies between 7N and 11N. Hence there is an obvious influence on aero drag force for the long jump flight. The athlete'saverage body surface area (on the frontal plane) should be kept to a minimum during the aerial phase to maximize performance. Considering the aerodrag force, the Hang technique takes the minimum value.

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