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An experimental study of new rule javelins

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Abstract

This paper presents a comparative study of three new rule javelins (800g) used in elite competitions. Wind tunnel experiments were conducted on three commercially manufactured javelins (Hart Sports, Nordic Master 60 and Nordic Airglider) to investigate their aerodynamic characteristics. The aerodynamic drag, lift and pitching moment were measured over a range of wind speeds (25 to 33 m/s) for a range of angles of attack from 0 to 35 degree relative to the wind direction. The results suggest that the optimal release angles for each of the javelins are different due to their physical design. The angles of attack for highest lift-to-drag ratio for Hart Sports, Nordic Master 60 and Nordic Airglider javelins were found at 15°, 25° and 30° respectively. The findings of this study also indicate that Airglider javelin has better pitching moment stability than other two javelins.

Keywords: Javelin; aerodynamic; drag; lift; pitching moment; wind tunnel.

1. Introduction

The aerodynamic forces acting on the javelin play a major role in affecting the way the javelin moves through the air. The initial release conditions of the javelin are the most important factors that determine the maximum possible achievable range of the javelin. The difficulty however lies in the determination of what the optimal release conditions are and to be able to convey the optimal release conditions to the athletes and coaches. There has been fairly extensive research into the aerodynamics of the Javelin with a major focus being on the pre-1986 old rules javelin with less research undertaken on the post-1986 new rules javelin.

In addition, due to the change in rules and specifications for the javelin, the centre of gravity of the new

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rules javelin is now in the region of 60 mm forward of the centre of pressure which is the point where all the aerodynamic forces on the javelin act [1]. As a result, the pitching moment characteristics of the new rules javelin is affected with a negative pitching moment for all angles of attack thereby causing the javelin to pitch nose down for the duration of the flight unless the javelin is released with a negative angle of attack [2]. In simpler terms, the weight of the javelin causes it to rotate "nose-downward" during flight [2]. In reality, the location of the centre of pressure does change during the flight however this change is quite small for the new rules javelin and so a constant centre of pressure location can be used as a simplification [1].

Although the aerodynamic behaviour of javelin has been studied by computer simulations [3-4], there are little reliable experimental data available except some studies by Terauds [5], and Bartlett [6] on the new rules javelin used in elite competitions. Thus, the primary objective of this study is to investigate three new javelins for their aerodynamic behaviour.

Nomenclature

D	aerodynamic drag force (N)
L	aerodynamic lift force (N)
L/D	lift-to-drag ratio
PM	pitching moment (N.m)
α	angle of attack (degree)

2. Methods

2.1. Description of the javelins

Three javelins with different head geometry were selected for this study. The javelins are shown in Fig 1. Fig 2 shows the schematic of a javelin. The detailed geometric parameters of each javelin are given in Table 1.

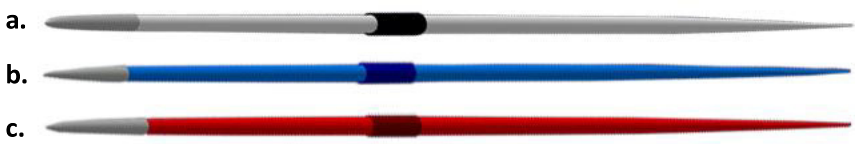


Fig. 1. Three javelins: (a) Hart Sports; (b) Nordic Master 60; (c) Nordic Airglider

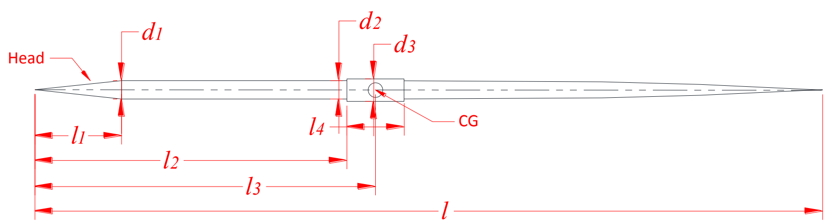


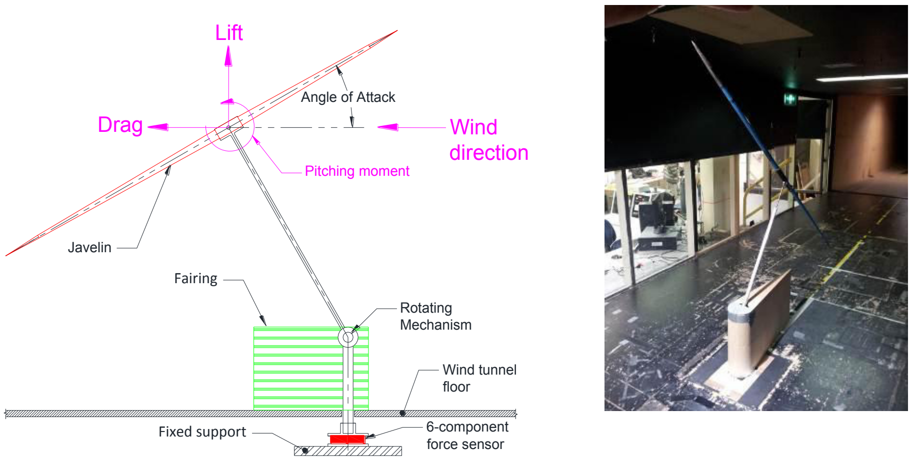
Fig. 2. Schematic of a typical javelin with different geometric parameters

Table 1. Detailed measurement of geometric parameters of three 800g javelins

Dimension (mm)	Hart Sports	Nordic Master 60	Nordic Airglider
Total length (l)	2606.00	2602.00	2607.00
Length of head (l_1)	282.00	265.00	324.00
Diameter of the head (d_1)	25.00	24.50	25.50
Length from the nose to the CG (l_3)	1053.00	1053.00	1060.00
Length from the nose to the grip (l_2)	1046.00	1027.00	1046.00
Length of grip (l_4)	150.00	158.00	154.00
Diameter at the grip (d_2)	28.50	29.50	30.00
Diameter of the grip (d_3)	36.00	36.00	36.00

2.2. Aerodynamic force and moment measurements

In order to measure the aerodynamic forces (drag and lift) and pitching moment acting on the javelin, a mounting system with a rotating mechanism was developed to hold the javelin on a force sensor in the wind tunnel. The rotating mechanism allowed setting up the javelin at different angles of attack relative to the wind direction. The distance between the top and bottom edge of the javelin and the tunnel floor was kept at 200 mm to minimise the boundary layer effect of the tunnel floor. The javelin was connected through a mounting system with a JR3 multi-axis load cell (made by JR3 Inc., USA). The experimental setup is shown in Fig 3. A purpose made computer software was used to digitise and record forces and pitch moment simultaneously. Each set of data was recorded for 30 seconds time average with a frequency of 20 Hz ensuring electrical interference and dynamic errors are minimal. Multiple data sets were collected at each speed tested and the results were averaged for minimising further possible errors.



(a) (b)

Fig. 3. Experimental setup: (a) schematic; (b) inside the wind tunnel test section

The aerodynamic drag and lift forces at zero yaw were measured over a range of wind speeds from 25 to 33 m/s using the RMIT Industrial Wind Tunnel. The maximum speed of the tunnel is approximately 40 m/s. The rectangular test section's dimension is 3 m (wide) × 2 m (height) × 9 m (long). Fig 4 shows the plan view of the wind tunnel. More details about the tunnel can be found in Chowdhury (2012) [7]. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than ±0.5 km/h.

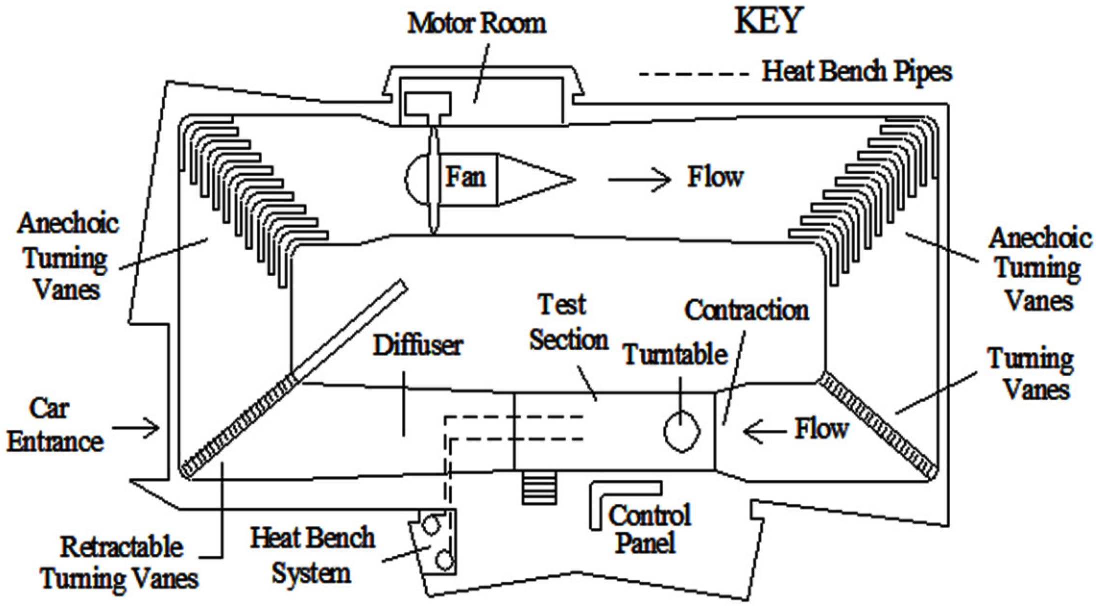


Fig. 4. Schematic of the wind tunnel

3. Results and discussion

The variation of average drag and lift forces with angles of attack (α) are shown in Fig 5. Each javelin shows the similar trends for both lift and drag variation with angles of attack. Maximum data fluctuations (about 20%) were found at $\alpha = 35°$. It was noted during the wind tunnel experimentation that at high angle of attack (above 30°) and high speeds (over 27 m/s) the javelin vibrated significantly. As a result, the data at these conditions are less reliable. The data obtained from this study agree well with the data from the previous studies by Bartlett [6].

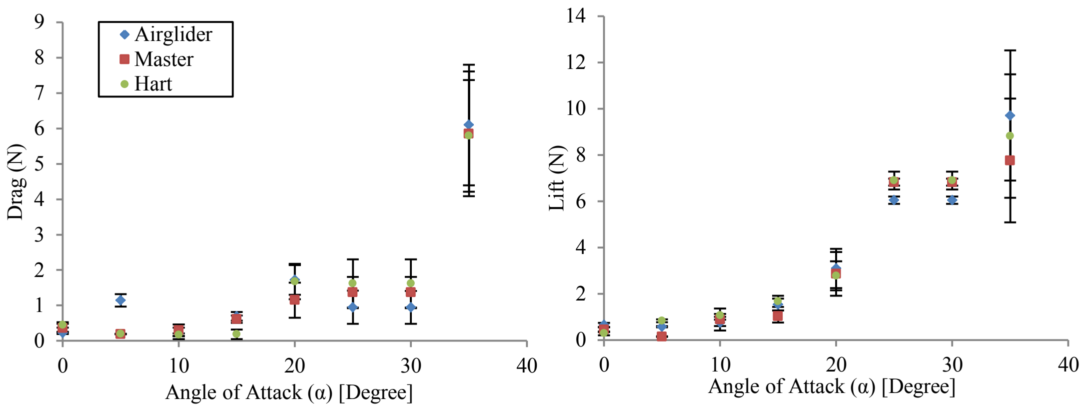


Fig. 5. (a) The variation of average drag force (N) with angles of attack (α); (b) The variation of lift force (N) with angles of attack (α);

The optimum release angles of each javelin can be identified by determining which angle of release would produce the largest lift-to-drag (*L/D*) ratio. Higher value indicates the longer horizontal distance travelled by the javelin. Hence it is most desirable that the javelin travel to a greater height as it is thrown in order for it to remain in the air for a longer period of time and therefore travel a greater range before it lands on the ground. The variation of lift-to-drag ratio with angles of attack is shown in Fig 6 for all three javelins tested in this study.

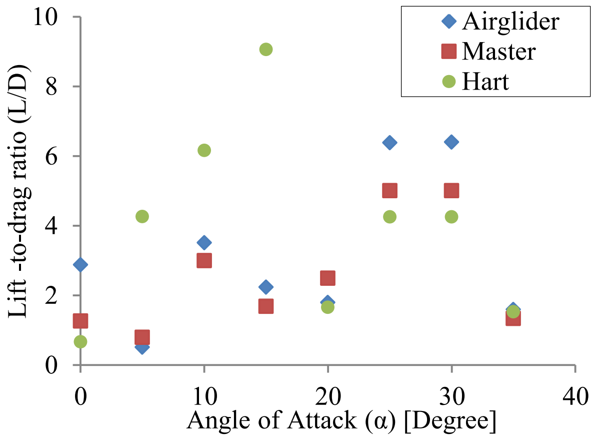


Fig. 6. The variation of lift-to-drag ratio (*L/D*) with angles of attack (*α*)

The pitching moment causes the javelin to pitch nose downward during its flight. The larger pitching moment pushes the javelin at a quicker rate towards the ground. As a result, the travel-distance becomes shorter. While the javelin is in flight, there is a constant nose downward pitching moment that is caused by the weight force of the javelin. The pitching moment as shown in Fig 5 is the moment produced by each javelin that causes the javelin to pitch nose upwards during its flight. Therefore, the significance of this moment is to counter the moment caused by gravity and hence reduce the overall nose downward pitching moment of the javelin.

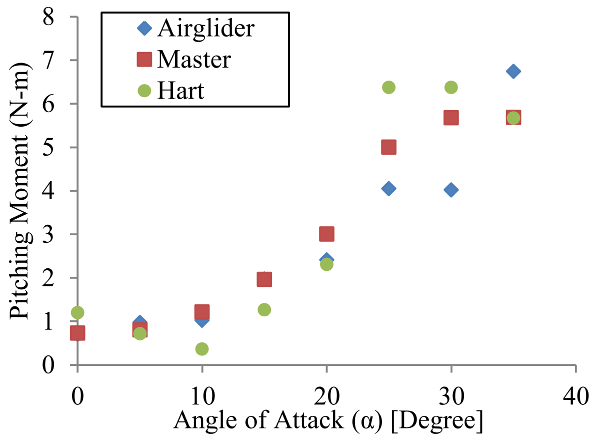


Fig. 7. The variation of pitching moment (N.m) with angles of attack (*α*)

Comparing the lift-to-drag (*L/D*) ratio of each javelin, it can be identified that Hart Sports javelin has higher value of *L/D* ratio at α = 15° (see Fig 6). Therefore, the optimum release angle for Hart Sports javelin was found to be at α = 15°. On the other hand, Master 60 and Airglider javelins have lower *L/D* values than Hart Sports javelin. These two javelins have close ratios of *L/D* and possess similar *L/D* characteristics. However, Master 60 has lower *L/D* values than Airglider javelin and the value is highest at α = 25°. The maximal value for Airglider javelin was observed at α = 30°. Besides, the pitching moment of Hart Sports javelin rise sharply than the other two javelins. Therefore, the flight of Hart Sports javelin can be unstable. On the other hand, the Airglider javelin has a steady rise of pitching moment that counter balances the moment produced by weight force of the javelin. Thus, it can have more stable flight than other two javelins.

In order to throw a javelin for attaining maximal horizontal distance, the athlete should release the javelin at an optimum angle where the *L/D* ratio is maximal. Additionally, the stability of the javelin is also important for the longest flight. Some javelins may have high *L/D* value, however, the fluctuation can cause an unstable flight and as a result, the aerodynamic performance can be detrimental to the stability. This study indicates that there is no one set of optimal release conditions found for all three javelin tested in this study. Different shapes of javelins structure especially the head and diameter at the grip may cause different optimal release conditions. As the aerodynamic behaviour may differ from one javelin to another, hence, it is important for the athletes and the coaches to determine the optimal release angle by field tests and practices under variable wind conditions.

4. Conclusions

- The optimal release angles for each of the javelins are different due to the variation of their physical design.
- The angles of attack for highest lift-to-drag ratios for Hart Sports, Nordic Master 60 and Nordic Airglider javelins were found at 15°, 25° and 30° respectively.
- Pitching moment plays an important role for the stability of the javelin during flight. The findings of this study indicate that Airglider javelin has better pitching moment stability than other two javelins.

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