OPTIMIZATION OF FLIGHT DISTANCE FOR THREE TYPES OF JAVELIN TIP

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Optimization of javelin flight distance was carried out using a genetic algorithm. Javelin tips with three different shapes were designed within the confines of the regulations. The first design was that of a typical commercially available tip, whereas the second design was thinner and the third design thicker than the commercially available tip. The aerodynamic forces acting on the three types of javelin tip with respect to the angle of attack were calculated using a commercial solver. In the optimization study, the design variables were the initial conditions at release, and the objective function was the flight distance. It was found that the flight distance for the thinner design was shorter than that for the other two types. The key to a longer flight distance is that in the first half of the flight the drag should be small and in the second half of the flight the lift should be large.

KEYWORDS: Javelin tip, Flight distance, optimization.

INTRODUCTION: The javelin throw is a field event in athletics, with the winner being the athlete who throws the longest distance. Since 1986, the regulations severely restrict the flight-enhancing effects of the javelin, and the possible variations in javelin construction are very limited. However, improvements might be possible by optimizing the design of the javelin tip.

Best et al. (Best, 1995) found that the optimal initial conditions depend on the type of javelin used, i.e., each javelin has its own optimal release conditions. Chiu (Chiu, 2009) simulated the flight distances for two kinds of javelin and found that obtaining the longest possible flight distance depends on javelin type. They also found that the initial angle of attack should be negative to obtain the longest possible flight distance.

In the present work, the aerodynamic forces acting on a javelin were measured in a wind tunnel that used a magnetic suspension and balance system. The validity of a computational fluid dynamics (CFD) model was confirmed by comparing the CFD results to experimental data from the wind tunnel. Javelin tips with three different shapes were designed. The first design was that of a typical commercially available tip, whereas the second design was thinner and the third design thicker than the commercially available tip. The aerodynamic forces acting on the three types of javelin with respect to the angle of attack were calculated using a commercial CFD solver. Finally, the longest possible flight distance for each tip was estimated using a genetic algorithm.

METHODS: The aerodynamic forces acting on a javelin were measured in a wind tunnel. The facility at Tohoku University is the world's largest magnetic suspension and balance system and can accommodate a full-size javelin. The main advantage of a magnetic suspension and balance system is that interference from strings, struts, and wires is eliminated (Kobayashi et al., 2020). For this study, cylindrical neodymium magnets were inserted at 495 mm along the longitudinal axis of a women's javelin. A commercially available CFD solver (Ansys 19.2) was used to calculate the three aerodynamic coefficients (drag, lift, and pitching moment) of the javelin. A design modeler was used to design the javelin (Figure 1); Ansys Meshing was used to mesh the flow region and Ansys Fluent was used to numerically solve the Navier–Stokes equations.

Javelin tips with three different shapes were designed within the regulations using the design modeller (Figure 2). One design was that of a typical commercially available tip. A second design was thinner and a third design thicker than the commercially available tip. The aerodynamic coefficients for each tip were calculated using the CFD model.

A block diagram of the genetic algorithm used is shown in Figure 3. The rectangular boxes denote genetic operators. The index of performance (fitness) is flight distance. In order to determine flight distance, the force and moment equations must be integrated. In order to perform such integration, the aerodynamic coefficients as well as the initial conditions, must be known. It is possible to determine the aerodynamic coefficients for each tip on the basis of CFD results.

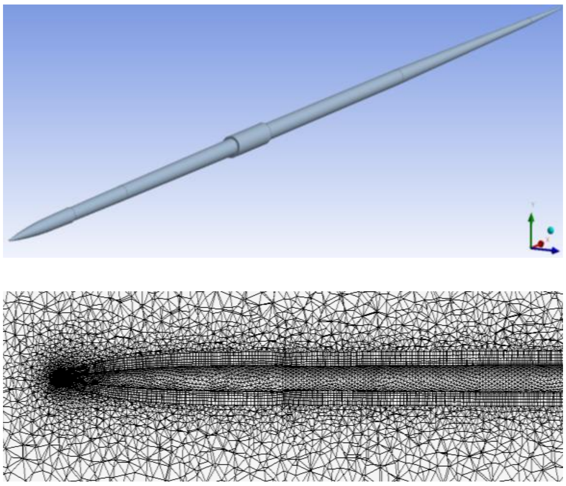
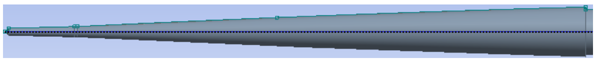
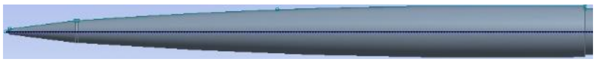


Figure 1: Javelin designed by Design Modeler and Meshing the flow region around the javelin.



Thinner tip



Typical commercially available tip

Thicker tip

Figure 2: Javelin tips with three different shapes.

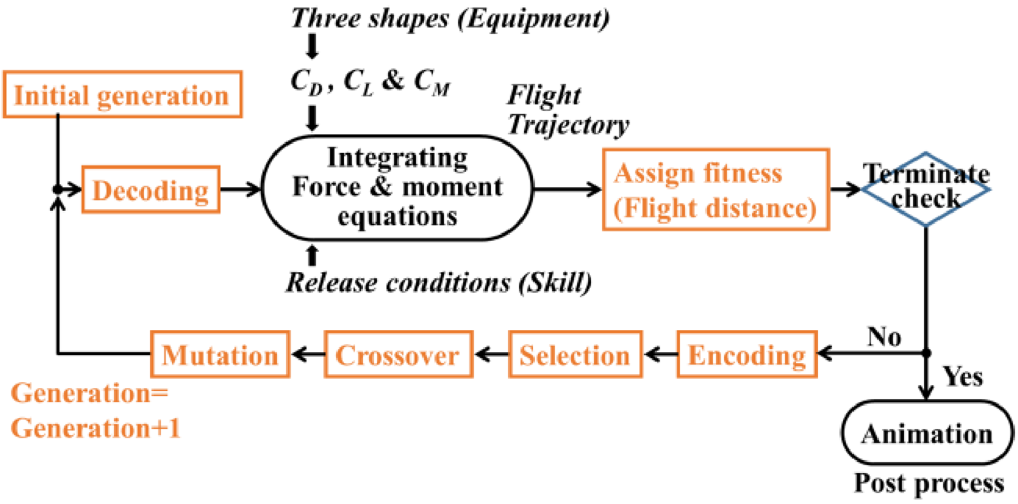
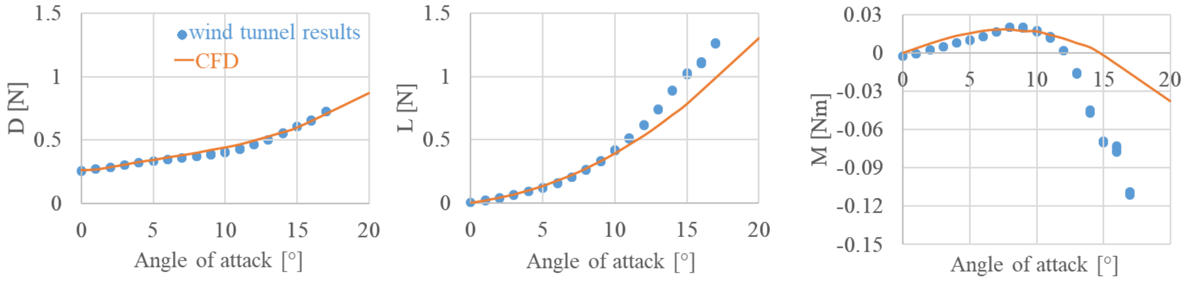


Figure 3: A block diagram of the genetic algorithm.

RESULTS: The CFD results qualitatively agree with the experimental results from the wind tunnel (Figure 4). The drag force calculated by CFD is in very good quantitative agreement with the wind tunnel results, but the agreement of the lift force and pitching moment is not so good at high angles of attack. The aerodynamic coefficients estimated by CFD were used in the simulations of the flight trajectory of a javelin.

Comparisons between the aerodynamic coefficients (lift, drag, and pitching moment) for the three javelin tips are shown in Figure. 5.

The calculated longest flight distance for each javelin tip is shown in Figure 6. The longest flight distance (92.3 m) was achieved with the thicker tip (Figure 7). This distance was only slightly longer than that for the typical tip, but was substantially longer (0.9 m) than that for the thinner tip.

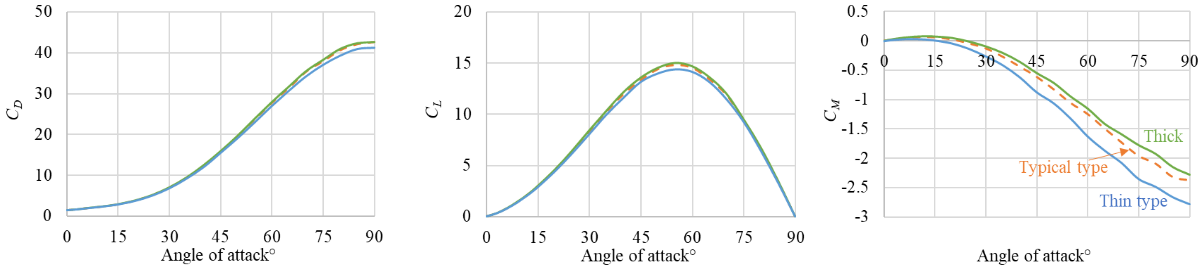


Drag

Lift

Pitching moment

Figure 4: Comparison of the CFD results with wind tunnel results.



Drag coefficient, C_D, as a function of the *angle of attack*.

Lift coefficient, C_L, as a function of the *angle of attack*.

Pitching moment coefficient, C_M, as a function of the *angle of attack*.

Figure 5: Comparison of the CFD aerodynamic coefficients for the three javelin tips. Calculations for a men's javelin at 25 m/s.

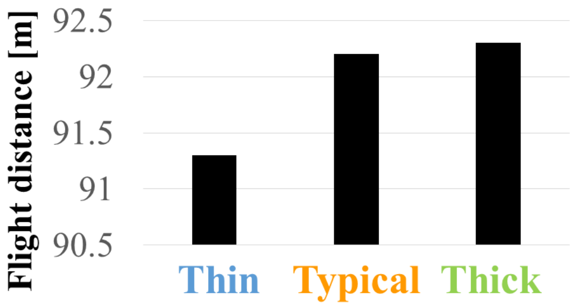


Figure 6: Calculated longest flight distance for the three javelin tips. Calculations for a men's javelin at the initial speed of 30 m/s.

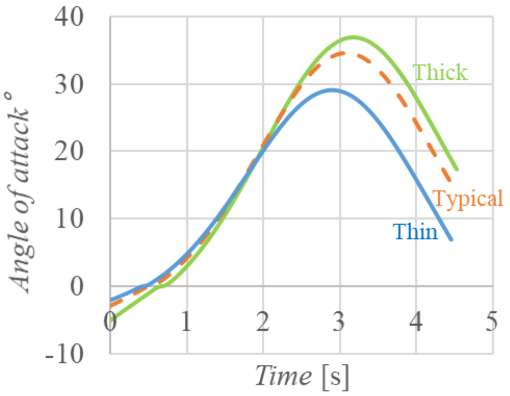


Figure 7: Time trace of the angle of attack for the optimal flight with each javelin tip.

DISCUSSION: The design of the javelin tip type does not markedly affect the drag coefficient or lift coefficient (Figure 5). In contrast, the tip design has a substantial effect on the pitching moment coefficient at high angles of attack. For all three tips the drag coefficient increases with increasing angle of attack, whereas the lift coefficient increases with increasing angle of attack until 55° and then decreases. The pitching moment coefficient is positive (nose-up rotation) at less than 10° and becomes negative (nose-down rotation) at greater than 25°. The reason for the negative pitching moment is that the center of mass of the javelin is closer to the front end of the javelin than to the rear end. (The total length of the javelin was 2200 mm, but the distance between the tip and the center of mass was 920 mm.) Therefore, a nose-down rotation acts on the javelin. In the case of the thinner tip, the javelin does not significantly catch the wind. As a result, a large nose-down rotation acts on the javelin. In the case of the thicker tip, the javelin can catch the wind to a greater extent. As a result, a nose-down rotation still acts on the javelin but the absolute value becomes small.

The time variations in the angle of attack for optimal flights of the three designed tips are shown in Figure 7. The flight time is about 4.5 seconds. At the very beginning of the flight, the angle of attack is negative in all cases. This means that air inflow to the javelin arrives at the upper side; from the point of view of lift, this is not ideal. However, this contributes to the maintenance of lower drag during the first half of the flight. The angle of attack for the three cases becomes large in the second half of the flight; this contributes to increasing the lift.

The difference in the angle of attack becomes large in the second half of the flight. The maximum angle of attack for the thicker tip is largest and that for the thinner tip is smallest. The larger angle of attack provides more lift; therefore, the lift for the thicker type is greater than that for the thinner type. Because of this, the flight distance for the thicker type is longest.

CONCLUSION: The optimum flight distance is longest for the thicker tip and shortest for the thinner tip. In order to enhance flight distance, it is important to keep drag small in the first half of flight and make lift large in the second half of flight. In order to keep the drag small in the first half of flight the angle of attack should be negative at the very beginning of the flight. Because the absolute value of the nose-down pitching moment for the thicker tip is small, the angle of attack becomes large in the second half of the flight.

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