Javelin throwing – the appliance of science

Preparation and technique are vital but on the day, you might need to know your physics

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Preparation and technique have been comprehensively covered on a number of occasions in articles by distinguished coaches such as Wilf Paish but as all throwers know, the javelin and discus are strongly affected by their flight characteristics on the day and an individual throwing series frequently varies by 15%. If you can't read the conditions and the effect they might have on your performance, all that preparation and technique will not be enough when 1cm in 90m is enough to win or lose. The javelin is particularly susceptible to this variation and so we will focus on that aspect here.

This article arose through a recent detailed academic study on the aerodynamics of javelin flight and this seemed an excellent opportunity to assess the accuracy of much of the folklore surrounding this spectacular event. At any javelin competition, you will see stiff, not so stiff, thin, thick, Headwind, Tailwind, blunter-nosed, pointed-nosed and 'house' javelins with distance ratings anywhere between 50 and100m. The relationship of these to physical characteristics such as drag, lift, the effects of cross-, head- and tail- winds, throwing 'through the point' and so on is opaque to say the least. In this article, we will discuss these factors with respect to basic physical principles and introduce a freely available piece of software which handles the complication for you.

Let's start with drag and lift. The two important points in a javelin are the centre of gravity where the mass acts, and the centre of pressure where the less tangible aerodynamic forces of drag and lift act. The centre of gravity is fixed but the centre of pressure moves a few cm. during the flight as it is dependent on the air-flow around the javelin. Until 1986, they were very close together most of the time meaning that there was very little downward pitching effect on the javelin and in the hands of athletes like Uwe Hohn, it went a dangerously long way, (> 104m). In 1986, the centre of gravity of the men's 800gm javelin was moved forward by a few cm to bring the nose down early rescuing the event from banishment outside the arena and making it much easier to measure the distance. In 1999, a similar modification was done for the women's 600gm javelin. To understand the old-fashioned flight characteristics, just watch a 700gm javelin as used both by male U17 and also M50-59 masters throwers, (the 700 has yet to be modified). This most frustrating implement leads to about half of all throws flat landing even as far out as 60m. Note that drag always acts on a javelin pulling it back but there is only lift if the javelin travels at an angle to the air-flow around it, (called the attack angle). Lift leads to greater drag but one may compensate the other and the dynamic relationship between them is very complicated.

The attack angle is quite subtle. Analysis of many video sequences suggest that throwers often throw with an attack angle. However, this may only be apparent. Even if you throw 'through the point', there will still be an apparent attack angle if there is a head or tail wind relative to a camera fixed to the ground, (an appropriate point to make in Einstein's centenary year for the physicists out there). The parallelogram of velocities implies that a javelin thrown through the point will appear to have a slight down-angle when thrown into a head wind and a slight up-angle when thrown into a tail wind relative to a fixed camera.

Another misconception concerns the so-called Headwind and Tailwind javelins. The belief has arisen that the former is better in a head-wind and the latter better in a tail-wind. Sophisticated aerodynamic modelling suggested however that the Tailwind is always superior and the mystery was finally cleared up recently in a personal communication to one of us (BP) from one of the pioneers of modern javelin design, Dick Held. Tailwind javelins are distinguished only by having a blunter point – the shafts are the same. When first introduced, nobody would throw them because 'they would increase the drag'. To counteract this, Dick Held simply said to use the Tailwind javelin for tail-winds and so the myth was born. In truth, he knew that *the Tailwind javelin out-performed the Headwind javelin in effectively all winds*. The thrower's intuition about drag is simply wrong and a little marketing was needed.

It is not even clear that throwing 'through the point' is always the best strategy even when there is no wind. Before the 800gm javelin was re-balanced in 1986, Dick Held commented that the longest throwers of the day, (Uwe Hohn and Tom Petranoff) would deliberately deliver the javelin relatively low at unusually high speed (> 30m/sec) with a very large attack angle (quoted as high as 30 degrees, which caused the javelin to soar). The advantages of throwing low are that the thrower can hang on to the javelin a little longer and accelerate it a little more. This is a crucial factor as the distance a thrown object flies is basically dependent on the square of the velocity. The trade-off of course is that the distance is also dependent on the angle but the correct balance between them also depends on the thrower's bio-mechanical properties. Since the re-balancing of the javelin, it is still far from clear that throwing through the point is universally optimal. Our experiments suggest otherwise.

Other factors intrude also. Top-class throwers can induce an axial spin of as high as 25 revolutions per second. When this is combined with the pitching down motion of the nose, the conservation of vertical angular momentum means the javelin precesses a little to the left for a right-handed thrower just as a gyroscope precesses. This precession induces a lateral lift and drag but resists the downward pitching motion. Whether this increases distance in all conditions is still a matter of conjecture although different grips will induce different axial rotation rates.

The interaction of attack and delivery angles, rotation and the prevailing wind speed and direction can all affect the distance the javelin flies very significantly, (see the figure for an example of getting the attack and delivery angle wrong in a head-wind) but to juggle these concepts during a competition is too much to ask of any competitor. To put all this on a more scientific basis, all of these factors are included in a recently developed and freely downloadable software package for Windows called the *Javelin Flight Analyser* available from (1). This solves the full three-dimensional equations of motion and a complete technical description containing the mathematics and physics behind this is available from (2) and should help throwers and coaches to understand and exploit some of the subtleties of javelin flight. The package has been calibrated on data acquired by eminent UK researchers Dick Best, Roger Bartlett and Calvin Morriss in major championships for throws in the range 55-87m and is within 1% with modest assumptions about the wind, (which was not recorded in their experiments unfortunately). We are continuing our researches into optimising javelin and also discus delivery as a function of both individual bio-mechanical properties and prevailing wind with an elite group of throwers in Sheffield to match their individual talents with insights that only a calibrated scientific approach can provide.

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(1) http://www.leshatton.org/javelin_2005.html

(2) http://www.leshatton.org/jav2005_paper.html

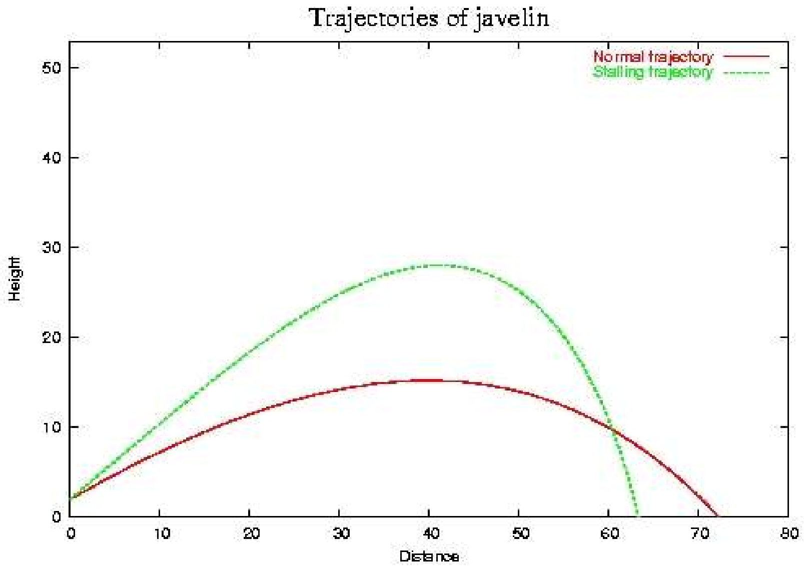

Figure 1: The flight of a javelin in a head wind with two different launch trajectories thrown at the same speed.