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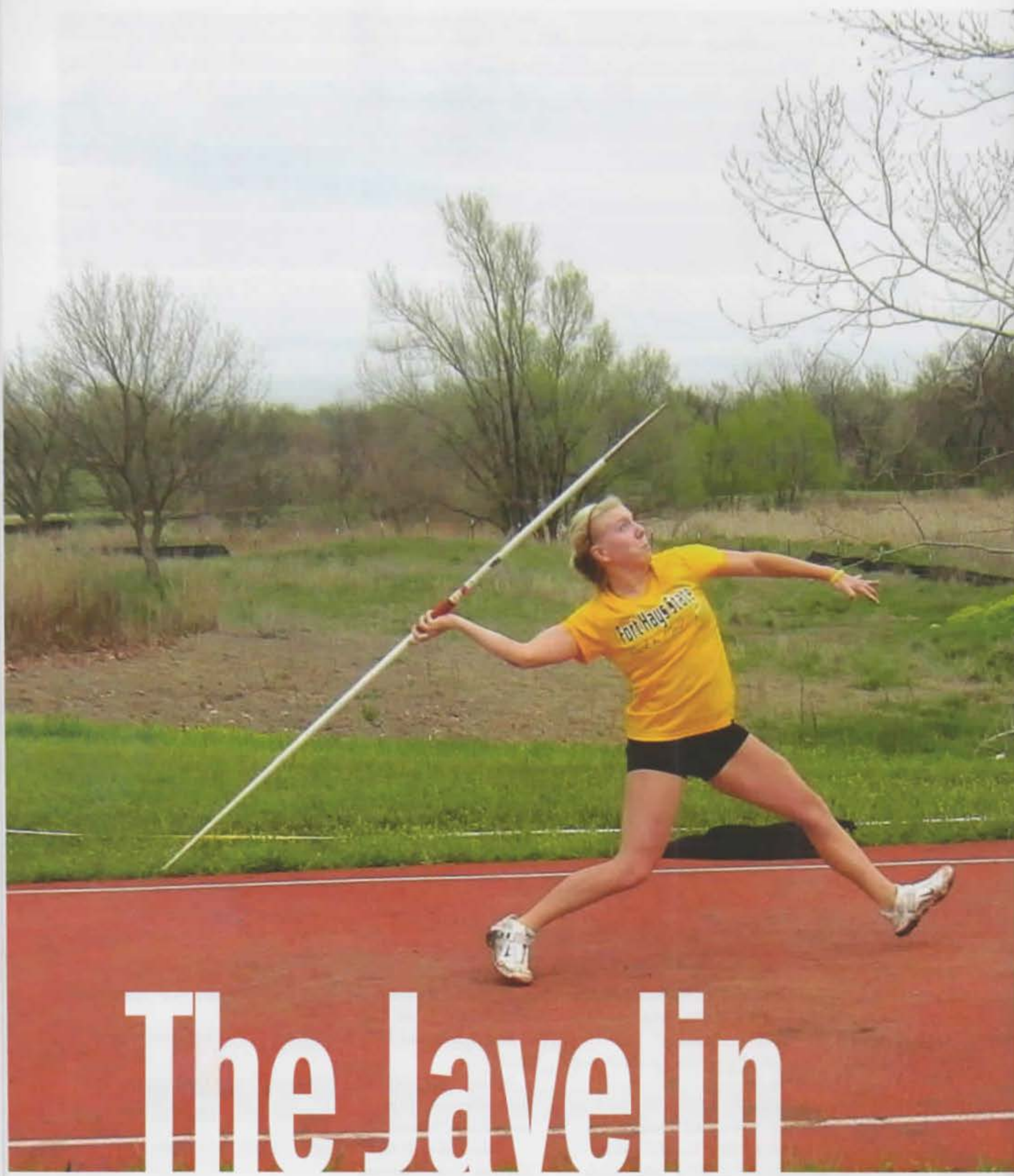

The Javelin

BASIC JAVELIN AERODYNAMICS AND FLIGHT CHARACTERISTICS (PART 2)

BY ANDREAS V. MAHERAS, PH.D.

Editor's note: This is the second and final part of the article regarding javelin aerodynamics. The first part appeared in the previous issue of Techniques.

The javelin during its flight can rotate three different ways. It can rotate about its long axis, about its short horizontal axis and its short vertical axis. When the javelin is released, there is always a rotation about its long axis at a rate that fluctuates between 15 to 32 revolutions per second for the majority of good throwers. Those rotations may be beneficial for the current javelins given the fact that, as mentioned earlier, they are perpetually stable and thus, tend to return to a zero degree angle of attack as they also tend to quickly "nose down." When the javelin rotates around its long axis in the high end of the range given above, there is a stabilizing effect, which tends to delay a rotation about the short horizontal axis, ie., delay the nose down effect. This delay generates a small attack angle and a beneficial lift. Indeed, for shorter throws (release velocity ~ 24 meters/second), high rotation about the long axis will increase the distance by approximately 50 centimeters. when compared to a non-rotating implement. Although Terauds (1985), Hay (1993), and Bartlett (1989), wrote about the stabilizing effect of the "spinning" of the javelin, Bartlett (1989) also mentioned that the moment of inertia about the long axis is less than 0.1 percent of that about the short axis an observation that suggests that the spinning effect on the javelin's pitching moment may be minimal. Similarly, Soodak (2004), applying a geometric theory, postulated that the trajectory of a javelin throw is affected little by any initial axial spin because the "gyroscopic action" is quite weak. Bartonietz (2000) mentioned that the positive effect of the rotations on the distance thrown is very small and he quantified it in the order of 0.5 meters for an approximately 55-meter throw assuming a 25 revolutions/second rate of rotation.

Another aerodynamic issue with a high rotation about the long axis has to do with the Magnus effect. As the air moves past the rotating javelin, it creates a low-pressure area on the side of the javelin that moves with the direction of the air (right), and a high-pressure area on the side of the javelin that moves toward the air (left). This difference in pressure will tend to move the javelin towards the side with the low pressure. This way, in the later phase of the javelin's flight, the Magnus effect moves the center of pressure behind and to the right of the center of mass. The net resulting effect is a javelin that "yawes" right (rotates to the right about the short vertical axis). Most practitioners would blame such an effect on the wind, but to avoid that yaw toward the right, the angle of attack should not be too large, this being one more factor to consider regarding the initial magnitude of the attack angle. Genxing et al., (1986) found that at angles of attack higher than 30 degrees, vortices around slender cylindrical bodies become asymmetrical and generate sideways forces that would cause such a body to "yaw" (turn to the right).

The rotation of the javelin about its short horizontal axis can be quite influential in the result of a throw. It may be desirable to release the javelin without any rotation about the short horizontal axis but it is unlikely that the javelin will not

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have even a small measure of that rotation. Indeed, small values of such rotation will not affect the flight of the javelin greatly. On the other hand, high values of it (>50 degrees/second), can be disastrous. They could reduce the distance thrown by several meters. An interesting phenomenon here that practitioners need to be aware of is the existence of a relationship of sorts between the angle of attack and the rotation about the short horizontal axis. If a thrower is to impart a large angle of attack at release (>10 degrees), she, at the same time, needs to impart positive rotation about the javelin's short horizontal axis. In other words, in the case in which a thrower releases the javelin in a way that a rotation is initiated so that the javelin is actually rotating downwards, if there is not an initial positive angle of attack, the javelin will eventually develop a negative angle of attack which will lead to a quick nose dive and a short distance. To avoid this predicament, a larger than normal angle of attack would counter the error of a high rotation downwards, resulting in a satisfactory flight.

Rotation of the javelin around its short vertical axis is occurring as throwers bring the javelin back and have it pointing to the right side of the sector just before release. Following, the thrower often "sidearms" the javelin and if it were not for the rotation imparted around the short vertical axis (here the point rotates from right to left), the javelin could have landed way to the right of the sector. The Magnus effect described earlier will also cause such javelin rotation and of course the sheer force of the wind can impart rotation about the short vertical axis.

JAVELIN VIBRATIONS

The tremendous energy transfer to the javelin initiates vibration of the javelin at the moment of release, via a dramatic pulling down. The acceleration of the javelin during delivery has a mean value 40 times gravitational acceleration and the large forces involved make javelin vibrations inevitable. Their amplitude depends on the stiffness, mass and geometry of the shaft (Bartlett, 1989). The vibrations can be primary and secondary. The former occur while the javelin is in flight, whereas the later occur while the javelin is being held at its center of mass. Primary vibrations range from 19 per second to 28 per second for stiff and soft javelins respectively. A primary vibration is defined as a periodic motion that occurs between two limits. When a javelin shaft vibrates in flight, it appears to quiver. Secondary vibrations range from 13 to 19 per second. Because a vibrating motion occurs perpendicular to the forward path of the javelin, vibrations represent energy delivered by the athlete at the beginning of the throw that is wasted. Ganslen (1967) speculated that vibrations could increase drag and thus result in a decrease in the distance thrown. Terauds (1985) stated that the greater the oscillations in the javelin shaft in flight, the less efficient the throw and the shorter the distance the javelin will fly. This is because a great amount of oscillations will increase drag and decrease lift, thus shortening the flight. Similarly, the stiffer the javelin the further it flies. On the other hand, Hubbard and Bergman (1989) found that the effects of vibrations on the javelin aerodynamics at small angles of attack are enormous. They found that with both drag and lift increase, that increase is larger at larger release velocities. The implication was that elite javelin throwers may be benefited the most, or pay the price for, from thrower-induced vibrations and, is therefore more important for those throwers to control the vibrations as compared to less capable throwers. In that study the authors could not answer the question whether the benefit from the increased lift can outweigh the disadvantage from the increased drag. A few years later Hubbard and Laporte (1997) implied that, in the best case, the increase in distance thrown due to an increase in lift could slightly outweigh the decrease in distance due to an increase in drag. However, the significance of the effect of those vibrations does not have a first order effect on the distance but is in fact a second order perturbation of magnitude of approximately 1 meter. Of interest is also the relationship between the number of primary oscillations and elbow or shoulder injury. One may surmise that a stiffer javelin will exert greater forces on those joints, exactly because the former yields less to those forces, which eventually may damage the joint.

The stiffness of the javelin can also be linked to a quick damping quality particularly on longer flights where there is adequate time for damping to occur. However, the damping of the oscillations is less important than the actual reduction of them. These days there have been dramatic improvements in the construction of stiff javelins with the use of either aluminum alloy or carbon fibers.

Some have proposed that to counter the oscillation of the shaft in flight, the thrower should impart spin to the shaft by rotating the shaft on release. The rotation of the shaft counters any perpendicular vibration and it makes the javelin more stable in the air. Oscillation in the javelin shaft can also be minimized by delivering the javelin into the air on the identical vertical plane as the intended flight path of the javelin. Although those are some rational suggestions to remedy the oscillation problem, oscillations of some magnitude are bound to occur during javelin release, because no javelin thrower, no matter how proficient she may be, is able to direct all the force straight along the long axis of the javelin. Therefore some initial vibrations occur at all times.

MOMENT OF INERTIA

The javelin's moment of inertia is about its short horizontal axis. The purpose of any change in the javelin's moment of inertia is to force the javelin to fly at the most desirable angle of attack throughout the flight (Terauds, 1985). The moment of inertia increases as the mass is located further away from the javelin's center of mass and similarly, as the javelin's mass is brought closer to its center of mass, the javelin's moment of inertia decreases. From this, one can assume that a javelin with low moment of inertia is more prone to influences from external forces that attempt to act on it. Javelins with high moment of inertia tend to resist those external forces and also any kind of rotation. The importance of a javelin's moment of inertia is essential because that inertia forces the javelin to fly at the most appropriate angle of attack during its flight. It should be clear by now that, in the end, it is the angle of attack that matters because it generates lift for an optimum flight.

Any change in the moment of inertia of the javelin will also affect the oscillation patterns of that specific javelin. If the mass of the javelin is placed towards the ends to increase its moment of inertia, the javelin will oscillate with greater amplitude, which may result in the javelin bending more with each oscillation cycle.

Additionally, with an increased moment of inertia there is a decrease in the tendency of the javelin to rotate about its short horizontal axis. For short throws, where "adjustment" of the attack angle in flight by the javelin itself may not be of utmost importance, the javelin's long axis, due to the increased moment of inertia, cannot catch up with the gravity as it influences the javelin along its path. Therefore, for short throws, a high moment of inertia may be more preferable because it will tend to delay its going "nose down" tendency.

During long throws, the javelin should assume the proper angle of attack as quickly as possible and then maintain it for the duration of the flight. However, any resistance to the pitching moment as it tries to adjust the javelin's angle of attack is not necessary and the moment of inertia presents such resistance. For that reason, high caliber throwers may prefer a javelin with a small moment of inertia.

SHARP VS. BLUNT TIP

The tip of the javelin can basically have a wider "blunt" shape or a more narrow "sharp" shape. It is interesting to note that the blunt tip javelins are also sold as "tail wind" javelins, i.e., most appropriate to throw in conditions where tail winds are prevalent. Given this background, in the absence of a significant wind or the presence of a headwind, most athletes would gravitate towards the use of a javelin with a sharp tip considering that this type of a tip will "cut" through the air and consequently fly further. In the presence of a tail wind, a javelin thrower would then use the blunt tip javelin designed for that kind of wind.

The situation, however, may not be as clear. Schneeberger (2009) has reported that an increase of the area of the front end of the javelin, by widening the tip, may bring the CP forward resulting in a decreased rate of change in the angle of attack and a decreased tendency of the javelin to turn over fast. Hatton (2012) also has reported that he would expect the centre of pressure to be a little closer to the centre of gravity for blunt javelins because of the earlier onset of the turbulent boundary layer than for the pointed javelins, an effect that reduces the downward tipping moment and giving a small competitive advantage. He also mentioned that in essence, the modest increase in drag due to the tip's increased surface, is more than compensated by the movement forward of the centre of pressure and the subsequent reduction in downward pitching moment. He also noted that in talking to a couple of former British world competitors over the years (Mick Hill, Steve Backley), they both had the distinct impression that the advantage was of the order of 2 to 3 meters in 80 meters. Although we do not know of any study that has examined that position, Walchner (1947) tested missiles of different head shape and reported that at a zero angle of attack and a given speed, the air force on the blunt shapes is applied farther forward than on the more slender ones thus, lending some validity to Hatton's postulates. The speeds in those tests where approaching 1 Mach or more, and it is unknown whether the findings are applicable to javelin throwing.

In addition, a known pioneer in javelin design who also crafted the concept of a tail wind blunt tip javelin, has reportedly mentioned that although he knew that the blunt tip javelins would fly further under any circumstances, including head or no wind, he came up with the blunt nose tail wind javelin concept in an effort to make those javelins more acceptable to javelin throwers. Therefore, it seems that there may be a general advantage of the blunt tip over the sharp tip javelin. By the same token, individual preferences should always be taken into account as they can influence the "psyche" of the thrower. Furthermore, differences in the construction of the javelin, may influence the rate of change in the angle of attack.

MEN AND WOMEN JAVELINS COMPARED

Comparatively, the women javelin throwers may not throw the javelin as far as men. That is, after one accounts for the differences in implement weight or strength, and also given the relative world records in men's and women's implements in the other →

throwing events, one would expect the women to throw their javelin further than they currently do. Some aerodynamic differences that exist between the javelin implements, women's vs. men's, may help explain that paradox.

The most salient difference is that women's javelins are lighter, shorter and have a smaller diameter compared to men's. The overall cross sectional surface area (the planform) is decreased by approximately one third. Since lift increases as a function of the planform, if the release parameters are the same, the two javelins will not behave the same during flight. The men's javelin has greater planform area, and it will experience greater lift than the women's relative to the gravitational force. According to Schneeberger (2009), for an 800-gram javelin thrown at its take-off speed, the gravitational force is minus 7.84 Newtons (mass x acceleration). The lift force would be equal to 7.84 Newtons. For the 600-gram javelin, those values are minus 5.88 and 5.56 Newtons respectively. In comparing the two javelins, while the gravitational force is 25 percent smaller for the 600-gram javelin, the lift force is 29 percent smaller. Therefore, the ratio of the drag force on the women's to that of the men's javelins is greater than the corresponding lift and pitching moment ratios. That is, the lift to drag ratio is smaller for the women's javelin (Bartlett, 1989) and it, at least partially, explains why the distances thrown are below their ballistic range.

Another possible difference has to do with the distance between the CM and the CP. The longer the distance, the greater the leverage, and the higher the potential for the aerodynamic force to turn the javelin over. According to Schneeberger (2009), the women's javelin has a very small advantage in leverage. Moreover, because the distribution of the weight is spread across a relatively larger area, i.e., 25 percent less weight is spread across only 15 percent less length, it gives the women's javelin a relatively larger moment of inertia. Assuming that all other factors are equal, the net result is that it would take a relatively larger force to achieve the same rate of turning over for a women's javelin and therefore, they may have a greater tendency to land flat.

Regarding potential flat landings, similarly to what LeBlanc and Mooney (2005) found, Schneeberger (2009) also noted that women tend to employ higher attitude angles at release as compared to men. Although the former authors accepted that fact as an error and suggested ways to remedy that, the latter argued that the differences between the men's and women's javelins mentioned above, may need to be taken into account for practice purposes. He addressed the fact that women may have instinctively been throwing at higher attitude angles to make sure that the javelin lands point first. He also argued that it might be relatively more difficult to get the women's javelin to land point first. To resolve that, he proposed an increase in the initial angle of attack via an increase in the attitude angle while maintaining the release angle closer to normal. The increased attack angle would also increase the lift force, resulting in additional angular momentum, which will aid the javelin to turn over and land nose first.

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