

Banking of Tracks for the Thoroughbred Horse

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Background:

A good deal of speculation has occurred regarding the degree of banking for track design in thoroughbred racing. The degree of banking of a track not only impacts the loading on an athlete, but can also make higher track speeds possible without additional conditioning. To date however, no authoritative study of the proper banking of thoroughbred horse racing tracks has been performed. Many engineers have assumed that horses would respond in the same way to banking that an automobile or motorcycle would respond. However, in the case of an automobile or other vehicle, the ability to adaptively respond to the surface is limited. In any biological system that is unencumbered by a rigid vehicle, this adaptation to the banking of the road and curvature are expected to be a first order effect and cannot be neglected unless proven otherwise. An intermediate case would be in harness racing where a rigid vehicle is towed by a horse. In the case of harness racing the ability of the horse to adapt to the surface is influenced by the existence of a vehicle behind the horse which would be rigid like that of a vehicle. Thus, due to the partial adaptation of the harness racing horse, it would be expected to constitute an intermediate condition between that of a vehicle and a biologically adaptive system.

Previous literature.

Extensive literature exists on the proper degree of banking, also referred to as super elevation, in highway design. The banking of highways has been codified into standard design manuals which are the basis for safe roadway design¹. The principals upon which this design is based are straightforward from the perspective of an engineer and are derived in undergraduate engineering dynamic texts to illustrate the acceleration of a body moving around a curve at constant speed². However, as will be discussed below, for a biological system the ability of the system to adapt to the forces on the body change the response of the system. Thus the literature which is most relevant is that which relates directly to biological systems.

The literature on the turning of biological systems and the adaptation of the surface to the turns is more limited. The most relevant papers to the thoroughbred horse track design are those that discuss the banking of turns for standardbred horses. As previously noted, the dynamics of a standardbred are somewhat different than that of a thoroughbred because of the limitations on the adaptation of the gait as a result of the sulky. In this case the banking was in general assumed to be optimal when similar analysis was used as that which was used with vehicular traffic^{3, 4}. This may be true in a standardbred since the vehicle portion of the system will apply a lateral

¹ American Association of State Highway and Transportation Officials, 2004, *AASHTO Green Book: A Policy on Geometric Design of Highways and Streets*, 5th Edition, AASHTO, Washington DC.

² J.L. Meriam and L. G. Kraige, 2006, *Engineering Mechanics: Dynamics*, 6th Pkg edition, Wiley; Hoboken, NJ.

³ Fredricson I, Dalin G, Drevemo S & Hjertén G. A biotechnical approach to the geometric design of racetracks. *Equine vet J* 1975, 7, 91–96.

⁴ Fredricson I, Dalin G, Drevemo S & Hjertén G. Travhästens arbetsmiljö., *Svensk VetTidn* 1977, 2(29), 45–52.

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loading to the horse which is equivalent to that found in a vehicle system. Because the sulky has only two wheels, there is limited resistance to lateral loading on the horse, so that instead of sliding on the tire contact patch the sulky will apply a load to the inside flank of the horse which is proportional to the moment caused by the fore or aft weight imbalance on the sulky. This has the effect of magnifying the impact of the turning forces on the horse by a factor proportional to the weight of the sulky.

The fundamental change that a horse makes that a vehicle can not make is to lean into the turn by adapting the gait in an asymmetric fashion. This is true of a human runner as well. Thus, perhaps more relevant to the thoroughbred race horse than highway design manuals is the literature on human performance on running tracks. Surprisingly this literature is also limited. This is probably due to the relatively recent development of the technology required to obtain full three dimensional calibrated data for a runner on a track. One paper that appears to address some of these issues is from the German Democratic Republic⁵. However, given the mixed training of human athletes, it is likely that at least some of the training related injuries associated with banking, or the lack thereof, are mitigated. Thus while the literature is limited for thoroughbred horses, this may remain the priority area of study since the operation of a racetrack does not make it well suited to obvious solutions to training related problems such as reversal of training direction on a daily basis. Proper banking of a track can reduce the advantages associated with direction reversal.

Banking of Turns (Super elevation)

The simplest version of the banking argument is for a rigid horse on a hard flat surface. The horse is assumed in this case to be moving at a constant speed around a turn of constant radius. Gradual transitions in the radius, known as spiral turns, reduces the changes in lateral loading, but the effect once a finite radius of the track is reached is unchanged. In the front view (top left figure in figure 1) the weight of the horse is pushed over by a tipping force that is proportional to the velocity of the horse squared. This is shown in the lower right of figure 1 as a top view where the forces on the horse try to move the animal in a straight line. If the laterally directed force is not created the animal will move in a straight line tangent to the curve of the circle. Think of swinging a baseball tied to a string. If you let go of the string the baseball leaves its circular trajectory flying away from the circle in a straight line tangent to the circle at the instant of release. The lateral force to keep the ball swinging in an arc is provided by the string

The two forces due to the weight of the animal and the force resulting from the angular velocity of the horse through the turn can be summed in as vectors producing the resultant force as shown in figure 2. The resultant vector which is the sum of the other two force vectors is at an angle to the vertical as shown in the figure. The banking of the track is introduced (the left portion of figure 2) in order to keep the resultant normal (perpendicular) to the surface of the track. Thus, as shown in the right of figure 2, on a banked track there is no tendency of the horse to “tip over” since the resultant is normal to the track surface.

⁵ Rebner, H., *Kurvenueberhoehungen bei Leichtathletikrundbahnen in Hallen. / Turn banking for indoor athletic tracks*. Theorie und Praxis der Koerperkultur 32(1), 1983, 38-42.

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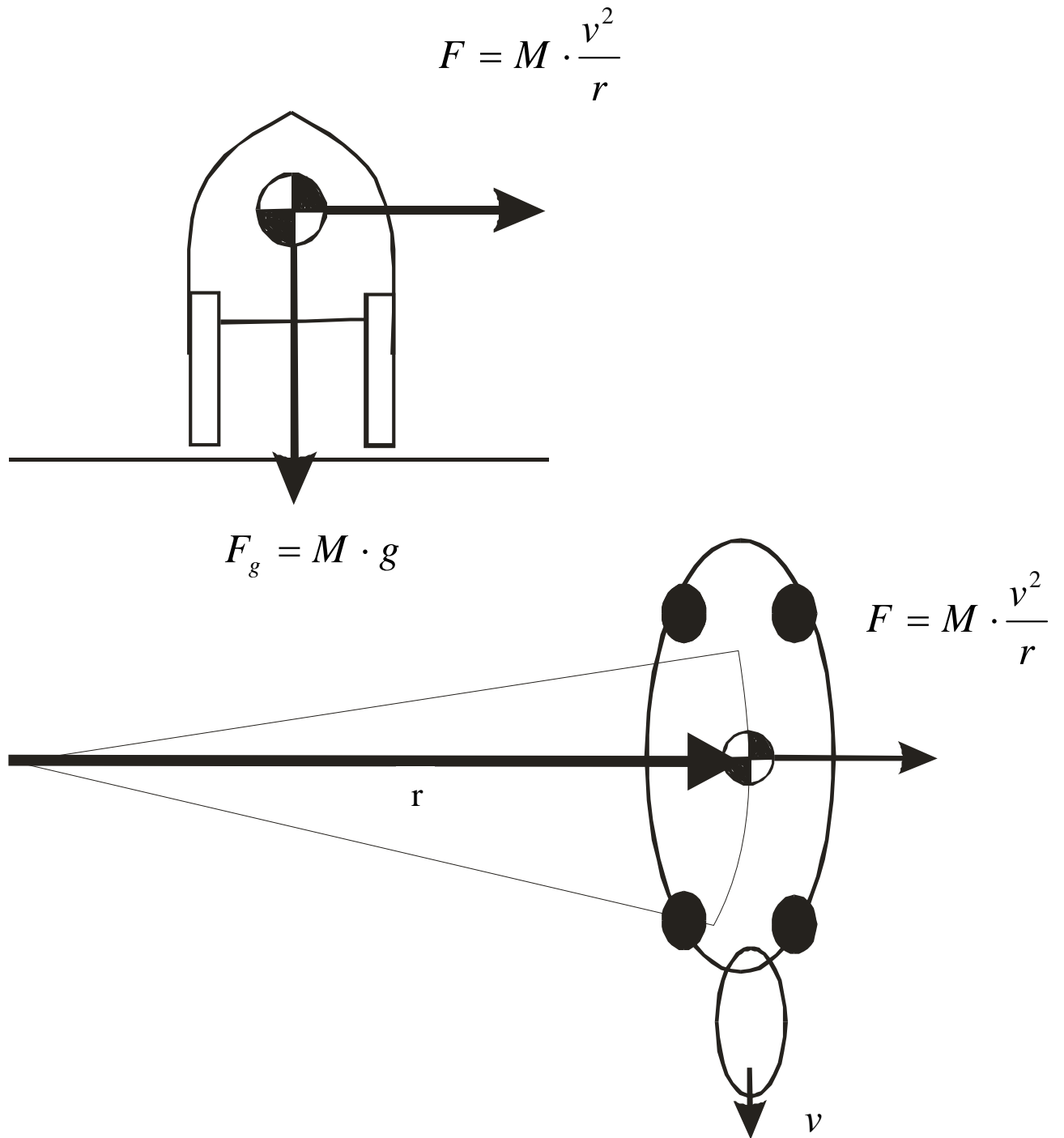


Figure 1: showing the front and top view of a horse of mass M traveling around a turn of radius r at a speed v .

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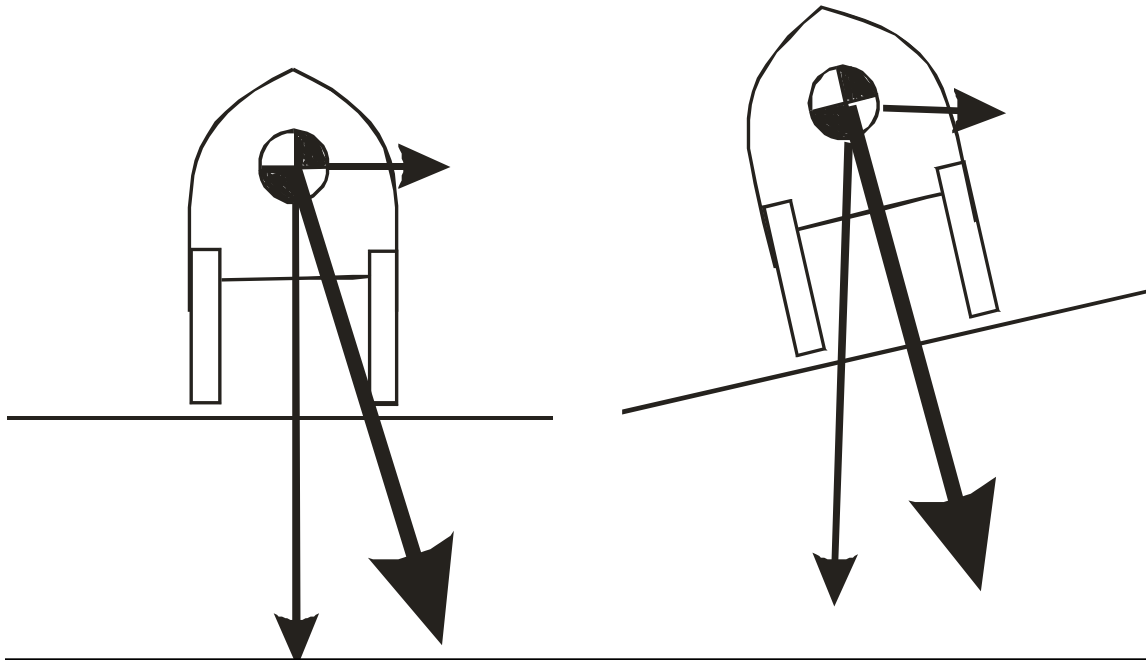


Figure 2: A horse that does not lean into the corner requires banking so that the sum of the lateral and vertical forces (the resultant) is perpendicular to the racing surface.

Response of the Horse to Turning

Another important feature of the banking is a reduced friction force lateral to the surface. With the surface tipped, the ground reaction force is directed normal to the surface and there is less chance for slipping. The analysis of many problems with biological systems is complicated by the ability to produce a response to a change on short and on long time scales. Longer term pressures on an animal produces evolutionary changes, shorter term pressures on an animal can produce local structural or even quick gait adaptations to reduce stress. Unlike a vehicle, an animal can make changes in order to reduce pressure due to loading, both for comfort and for efficiency. The animal can also make a decision to risk injury to increase performance at a particular point in time since survival may be entirely dependent on performance and thus taking the associated risk is desirable.

A horse, unlike a rigid vehicle, is able to lean into the turn. In fact, in four-wheel motor vehicles the rotation of the body due to spring action is to the outside of a turn (the wrong way). When the horse leans, the forces from each portion of the body are redirected along a new line of action which puts the resultant R_t vector (from the vector addition on the right side of figure 3) closer to the middle of the horse. This rotation of the body (and movement of the head and neck) reduced the tipping moment of the animal (R_t) and thus the need for banking. Conversely, leaning will also may place more force on the inside legs and possibly alter joint ranges of motion in a manner that might lead to both an increased risk for acute injuries as well as long-term overuse injuries. Thus a thorough study of the effects of banking should include some consideration of the epidemiology of injuries.

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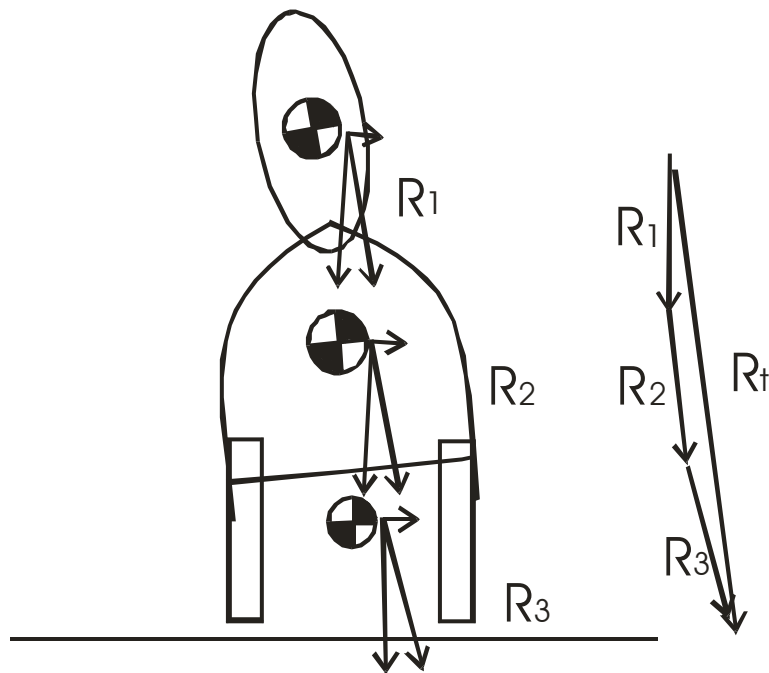


Figure 3: A horse is able move parts of the animal into a turn thus reducing the tipping moment of the animal and the need for banking.

Magnitude of the Effect due to Adaptive Response

While it is clear that a biological system will respond differently to turning than a motor vehicle, it is not clear the degree to which an animal can adapt. A complete understanding of the turning of an animal would require that the entire animal be oriented in three dimensional space while turning. Current technology may not make this possible, although some recent promising developments in instrumentation make it more realistic. However, even a simple model which traces the center of mass of a horse while cornering may give great insight. Additional insight into the turning of a thoroughbred horse could also be gained from carefully planned frontal plane 2-D analysis. This data would be used to assess how the thoroughbred gait is altered in the turns relative to a straight track. This technology exists and would provide important insight into the dynamics of the horse. This type of data, however, does not exist at this time for a thoroughbred racehorse. While this type of investigation can be undertaken at reasonable expense, any information which would be useful for design of a racing surface is at least a year away.

If, in the future data does become available which helps in understanding the optimal superelevation for a thoroughbred racetrack, the rebuilding of the base will be necessary. This is because it is not possible to increase the depth of the synthetic or dirt on the base without introducing significant bilateral differences in the surface. It is expected that this would be more dangerous to the horse than banking that was slightly too low.