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BICYCLE HANDLING EXPERIMENTS YOU CAN DO

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The contents of this short note are largely based on work described in the draft report *Bicycle Steering Dynamics and Self-Stability.* However, while that report was concerned with understanding bicycle dynamics and with designing for intrinsic bicycle stability, this focusses on what you as a rider might be able to perceive in the behaviour of your own bicycle. One reason for doing this is to explore the notion that some of the dynamic characteristics may actually correspond to recognisable handling 'qualities'; another is as an introduction to some of the concepts in the longer document. The contents are somewhat speculative in the sense that I have checked (roughly) only *some* of the conclusions, for only one or two bicycles.

By the way, the predictions made here apply to conventional bicycles only. It is possible to design weird vehicles with negative trail or head angle, or no gyroscopic effects, etc., which ought to be quite rideable, but in some ways will behave differently than suggested here.

Experimental considerations: The idea here is that you can actually perform informative experiments while you are riding, as long as you try to be sensitive to the bicycle's response. Several things are useful: An appropriately clear and safe parking lot, or running track, or road (level or slightly downhill). A speedometer. Relatively windless conditions. A sound bicycle with good steering bearings. Some method of marking uniform curves and slaloms on the road surface. Safe judgement!

Your bicycle may have to be slightly modified: In a number of tests, you will have to feel sensitively which direction the handlebars are trying to turn, and this is not too easy if you are supporting much weight on your hands. However, when riding no-hands in racing position on a bicycle with a slippery seat, it is very difficult not to slide forward off the seat. Probably this can be solved by tilting the seat up, and/or wrapping it with rubber, rags, velcro etc. for friction. More radically, perhaps a chest support would be useful. At any rate, you should make arrangements to hold the handlebars sensitively with just a thumb and finger of one hand.

Another problem is that we more or less unconsciously lean our bodies to one side or other of the frame* to help control the bicycle, and this can disturb what we are trying to measure. It is important to hold your body *rigid.* (Would a chest support or back-rest help here?) It may help your rigidity to clamp your knees against the bicycle frame.

To emphasise the motions of the handlebars, perhaps some kind of *pointer* along the top tube might be useful.

Trimming the Bicycle: If you ride your bicycle no-hands, you may find that some body-lean is needed to go straight. (This means that when riding *with* hands but *without* body lean, a small torque must be applied to the handlebars.) For convenience and sensitivity, the bicycle should be trimmed so as to travel straight.

Two simple trimming operations are: loosening the front wheel, and pulling its bottom to the right or the left; or loosening the rear wheel, and pulling its front to the right or the left. (Many others are possible, but less convenient.) Starting with a balanced bicycle, pulling the bottom of the front wheel to the right should make it travel in a curve to the right when ridden no-hands (or when ridden straight with hands, the handlebars should try to turn to the left). Aiming the rear wheel to the left should produce the same effects. Either of these trim methods may be used to cancel out an unbalanced condition so the bicycle rides straight.

Steady-Turn Torque: Travel through a given curve at various speeds, and get an idea of the steering torque required, being careful not to tilt your body relative to the bicycle! (This experiment might be especially convenient on a running track with its marked lanes.) At the lower speeds, for a leftwards curve, the handlebars *try to turn left,* and must be restrained. Somewhere between 12 mph and 20 mph, the handlebar torque should decrease to zero, and above this speed, the handlebars increasingly *try to turn right.*

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* It is actually my impression that we also shift our hips sideways, perhaps even more than leaning our upper body.

Near the torque inversion speed, it may be easiest to sense tiny torques by holding the handlebars (or the handlebar stem itself) closer to the steering axis.

As far as I know, the only reason that the steering torque changes as velocity increases is because of the increasingly large gyroscopic effects of the spinning wheels.

Effects of Leaning your Body: While riding straight, if you hold your body inclined to the right side of the bicycle, so that the frame is leaned to the left of vertical, the handlebars will try to turn left. This effect is independent of speed.

The tendency of the handlebars to turn will be decreased if you reduce the weight on the front wheel by sitting upright.

If you ride no-hands with your body leaned to the right side of the frame, the bicycle's response depends on its speed. If this is below the above–mentioned 'torque-inversion speed', you will end up travelling a curve to the right. On the other hand, if you are travelling faster than the inversion speed, the bicycle should curve to the left. At the inversion speed, it appears that the bicycle simply cannot be ridden steadily without hands unless your body is in the plane of the bicycle.

[At any speed, to leave a no-hands rightwards turn, is it always appropriate to lean your body leftwards briefly, so as to cause a temporary sharpening of the turn?]

Instability Speeds: Many bicycles are intrinsically stable for a range of speeds (often somewhere between 10 mph and 20 mph). What this means is that if the no-hands rider is replaced by a sack of cement, the bicycle will travel straight and upright — and if it is disturbed by a push or a wind gust, it will automatically return to the upright condition, though perhaps its direction will have been somewhat altered. (Note that this 'no-hands intrinsic stability' is not necessarily what people are referring to when they say a bicycle is stable — it's just a well-defined concept we have chosen to work with.) To say that a bicycle is 'very stable', in the sense that it very quickly recovers to straight–ahead riding after a disturbance, doesn't imply that it is at all hard to steer.

The property of self-stability derives from the bicycle+rider's geometry and mass distribution, but it can be disrupted by faulty steering bearings, and perhaps other factors.

If your bicycle is intrinsically stable at a certain speed, then you could hold your body rigid, close your eyes, and confidently ride no-hands (until the bicycle slows down too much). Practically, it is probably best to keep your eyes open and one hand close to the handlebars, in case you are not stable at that speed!

The range of stable speeds has upper and lower limits. At the lower limit, instability is oscillatory in nature, that is the bicycle will turn to the left, then over-correct and turn to the right, then over-correct, etc. Just below the lower unstable speed, the bicycle weaves increasingly back and forth. Just above that speed, any weaving oscillations arising from a disturbance will die away. Exactly at that speed (according to linear systems theory), the oscillations should go on and on.

At the upper limit of the stable speed range, instability is non-oscillatory. The bicycle leans a little to one side or other, and 'under-corrects' — it steers a little but not quite enough to reduce (or even to balance) the lean. The lean and the steer thus keep increasing, and the bicycle follows an inward spiraling path until it crashes. In contrast to 'weaving', this behaviour is called 'capsizing' (though perhaps 'spiralling' would be a better term). At a speed just below the speed of capsize instability, a leaned turning bicycle slowly straightens up. Exactly at the capsize speed, it remains in any steady turn. Just above the speed, it increasingly accentuates any turn.

The question is, what are those two instability speeds? How do they differ for different bicycles and riders? Do they in any way relate to the 'feel' of a bicycle? My personal bicycle seems to be self-stable only in the range of 13 mph – 14 mph, and I'm never really comfortable riding no-hands. When I first rode it, I felt it was 'twitchy'. On the other hand, a Schwinn Continental I tried seemed to be stable between 8 mph and 16 mph, and I felt extremely safe on it. No aspect of the handling drew my attention.

It turns out that the capsize instability speed is exactly the same as the 'torque-inversion' speed at which the steady-turn handlebar torque vanishes. This makes some sense: if no torque is required to hold a bicycle in a turn, then when you remove your hands from the handlebars the bicycle remains in the turn, i.e. doesn't straighten up. When it is stable, the handlebars are trying to *accentuate* the turn, so when released they steer the front contact back under the rider, thus bringing the bicycle upright. When the handlebars are instead trying to *straighten out,* if released they will do just that, and the bicycle will fall over.

An experiment: for a range of different speeds, ride your bicycle in a steady gentle turn (try to feel the handlebar torque), then simply remove your hands from the handlebars while holding your upper-body rigid, and see whether the bicycle straightens up (and how quickly). At low speed it should over-correct and begin to weave increasingly. At a stable speed it should come upright very nicely. And at high speed, it should start curving and leaning even more.

Alternately you can ride the bicycle straight and simply remove your hands from the bars, and see whether weaving or spiralling develop. In particular, if you have a lot of space, on the level or down a hill, you can let the speed change while you coast, and try to decide when stability is lost.

You can prevent 'capsize' instability with almost un-noticeable small body movements, so for accurate results it's essential to try to suppress such motions.

Inducing Instability: Restraining the steering with a spring should affect the bicycle's stability, reducing the capsize speed and possibly also reducing the weave speed. (If you have a flexible pointer attached to the stem, simply tying down the free end will let it serve as a spring.) Adding sufficient frictional or viscous damping to the steering will also affect stability.

Slalom: Even though the bicycle's weaving behaviour is stabilised (damped) by increased speed, it may still be easiest to make the bicycle 'slalom' at a rate close to the weave rate (in this case, your hands are performing work to keep the oscillation going*). The really interesting thing is that at the higher speeds, the weaving frequency should be proportional to speed, so that each cycle of weaving takes place over a fixed distance, and a single set of slalom markings might be good for all speeds.

The experimental question is: if you decide on an 'easy–weaving' frequency at 15 mph, and lay out corresponding slalom markers, is this still the easiest slalom to negotiate at 5, 10, 20, 25, and 30 mph?

Slaloming is made much easier by lifting your weight off the seat and allowing the bicycle to move under you. However, to demonstrate the effects discussed here you should sit firmly on the seat, and perhaps even squeeze your knees against the bicycle.

Artifical Shimmy: (This section is based mainly on observations — I have not yet studied shimmy theoretically. However other researchers seem to agree that elastic flexibility is an essential part of it.)

If a riderless bicycle's seat is pressed against a wall or door-jamb to represent the rider's nearly immovable mass, it is possible to shake the head tube sideways at a natural vibrating frequency of five to ten cycles per second. (Sometimes this is even possible with a rider on the seat.) This vibration seems to be due to the mass of the handlebars and the front part of the frame; and to the elasticity of the wheel (not tire), the frame, and perhaps the fork. Adding mass or stiffness in various places could help confirm this.

This 'laboratory' oscillation is not affected by locking the steering bearings.

Coasting no-hands at various speeds (10, 15, 20, 25 mph), you may demonstrate a similar oscillation by shaking the front of the frame or the handlebar stem with your hand, or by striking it with your fist — the frequency is about the same as for the bicycle at rest. On both of my bicycles, as speed is increased, the oscillation takes longer to die away, and at a certain speed it becomes self-sustaining. At the few higher speeds I have checked, the oscillation doesn't grow continuously, but stabilises itself as a constant-amplitude vibration. The amplitude is larger at higher speeds. (This behaviour appears consistent with a result from nonlinear systems theory.)

This oscillation feels like the dangerous shimmy that some bicycles can develop spontaneously even when the rider is holding the handlebars. (I don't know if the velocity at which an oscillation becomes self-sustaining is determined by either the slalom frequency or the wheel rotation frequency; or whether a more virulent shimmy could be induced at some particular velocity by adding a flexible bicycle attachment, e.g. a loaded luggage rack, whose natural frequency matched the wheel frequency or the slalom frequency near that velocity.) You can easily stop this artificial shimmy by lifting your weight off the seat, by pressing your knees to the frame, or by grasping the handlebars.

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* The work supplied by your hands is presumably helping to propel the bicycle! Could this be demonstrated in a coast-down test?

Announcement of Scott's 1987 demonstration.

BICYCLE STABILITY DEMONSTRATION

On Saturday November 15th at 11:00am Scott Hand will demonstrate some results of his bicycle stability research in the west end of the veterinarian parking lot. Unfortunately this demonstration is restricted to the weekends due to the availability of the parking lot. The demo will show:

1) A riderless bicycle can be stable. We will push and release best technique — run alongside a riderless Schwinn Varsity with bent forks, and show that it stays upright and goes straight for speeds greater than 7 mph. Even after its motion is perturbed the bicycle will return to an upright position or steady curve. Good steering-bearings essential

2) Bicycle alignment is critical to the straightness or curvature of stable motion. We will misalign a wheel and show that the bicycle takes a curved path. The direction of this curved path is predictable. Tilt front wheel towards right brake pad — bike will steer to left.

3) Increasing the inertia of the front wheel of a bicycle increases its stability. We will substitute a much heavier wheel and show that it remains stable at slower speeds, and that its ability to recover from perturbations is improved. At fast-walking speed, knock bicycle sideways ~30°, and it recovers in ≈ 1sec.

4) A bicycle with negative trail can be stabilized by adding a negative spring. We will extend the fork to get a negative trail and show this configuration is unstable. We will then add a negative spring to the steering (rubber bands trying to de-center handlebars) and show this configuration is stable. Scott improved no-hands ride of his bicycle with a negative spring.

5) For bicycles which are stable in a straight path, nonlinear effects can sometimes stabilize other paths of finite curvature. Our bicycle can be stable in a steady turn, but as it slows down the stability is lost, and it returns to the upright condition.

6) A bicycle can be towed by a string (time permitting). We will show how to tow a bicycle, similar to flying a kite. In doing so we will show that the place of attachment of the string is critical to stability. Best — on handlebar assembly behind steering axis.

This demonstration will take between 30-40 minutes. Those attending are welcome to try any of the experiments after the demo. For further information please call Scott Hand at 255-3518 or Jim Papadopoulos at 255-5035.

Rain date Sunday November 16th at 1:00pm.

Please see map to the parking lot on reverse side.