Bicycles 1

Bicycles

Bicycles 2

Question:

How would raising the height of a sport utility vehicle affect its turning stability?

1. Make it less likely to tip over.
2. Make it more likely to tip over.
3. Have no overall effect on its stability.

Bicycles 3

Observations About Bicycles

- Hard to keep upright while stationary
- Easy to keep upright while moving forward
- Require leaning during turns
- Can be ridden without hands
- Are easier to pedal when they have gears

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Static Stability, Part 1

- Static stability is determined by
  - base of support:
    polygon formed by ground contact points
  - center of gravity (COG):
    effective point at which gravity acts
- Static stability occurs when
  - center of gravity is above base of support

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Static Stability, Part 2

- When COG is above base of support,
  - is in a stable equilibrium
  - gravitational potential rises when tipped
  - accelerates opposite direction of tip
  - tends to return to this equilibrium

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Static Stability, Part 3

- When COG is not above base of support,
  - has no equilibrium
  - gravitational potential drops when tipped
  - accelerates in direction of tip
  - tends to fall over

Static Stability, Part 4

- When COG is above edge of base,
  - is in an unstable equilibrium
  - gravitational potential drops when tipped
  - accelerates in direction of any tip
  - never returns to this equilibrium

Stationary Vehicles

- Base of support requires ≥3 contact points
- Tricycle
  - has 3 contact points
  - is statically stable and hard to tip over
- Bicycle
  - has only 2 contact points
  - is statically unstable and tips over easily

Dynamic Stability, Part 1

- Dynamic stability is determined by
  - statics: base of support, center of gravity
  - dynamics: inertia, accelerations, horiz. forces

Dynamic Stability, Part 2

- Dynamic effects can fix stability
  - place base of support under center of gravity
  - dynamically stabilize an equilibrium
  - make system dynamically stable

Dynamic Stability, Part 3

- Dynamic effects can ruin stability
  - displace base of support from center of gravity
  - dynamically destabilize an equilibrium
  - make system dynamically unstable

Moving Vehicles

- Tricycle
  - can’t lean during turns
  - dynamically unstable and easy to flip
- Bicycle
  - can lean during turns to maintain stability
  - naturally steers center of gravity under base
  - dynamically stable and hard to flip

Bicycle's Automatic Steering

- A bicycle steers automatically
  - places base of support under center of gravity
  - due to gyroscopic precession of front wheel (ground's torque on spinning wheel steers it)
  - due to design of its rotating front fork (fork steers to reduce gravitational potential)

Torques and Tipping Over

- Torques act about bicycle's center of mass
  - Support force acts at wheels, causes torque
  - Friction acts at wheels, causes torque
  - Weight acts at center of mass, no torque
- If torques don't cancel
  - net torque on bicycle
  - bicycle undergoes angular acceleration
  - bicycle tips over

Leaning During Turns, Part 1

- When not turning and not leaning,
  - zero support torque (force points toward pivot)
  - zero frictional torque (no frictional force)
  - bicycle remains upright

Leaning During Turns, Part 2

- When turning and not leaning,
  - zero support torque (force points toward pivot)
  - nonzero frictional torque (frictional force)
  - bicycle flips over

Leaning During Turns, Part 3

- When turning and leaning correctly,
  - nonzero support torque (force not at pivot)
  - nonzero frictional torque (frictional force)
  - two torques cancel (if you're leaning properly)
  - bicycle remains at steady angle
- Bicycles can lean and thus avoid flipping
- Tricycles can't lean so flip during turns

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Gear Selection

- From rider’s perspective, ground is moving
- With each crank, ground moves a distance
  - Ground distance covered increases with gear
  - Work done per crank increases with gear
  - Pedal forces must increase with gear
- High gear yields high speed (level road)
- Low gear yields easy pedaling (steep hills)

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Mechanical Advantage

- Gears allow you to exchange force for distance or distance for force.
- On hills, low gear lets your feet move large distances to exert large force on wheel.
- On descents, high gear lets your feet push hard to move rear wheel long distances.

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Rolling and Energy

- Wheel rim moves *and* spins.
- A kilogram in the wheel rim has twice the kinetic energy of a kilogram in the frame.
- To start the bicycle moving, you must provide its energy.
- Massive bicycles, particularly with massive wheels, are hard to start or stop.

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Rolling Resistance

- As a wheel rolls, its surface dents inward
- Denting a surface requires work
- An underinflated tire
  - has a low coefficient of restitution
  - doesn’t return work done on it well
  - wastes energy as it rolls

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Braking

- Sliding friction wastes bicycle’s and rider’s kinetic energies as thermal energy.
- Braking power is proportional to:
  - sliding frictional force between pads and rim
  - support force on brake pads
  - tension of brake cable
  - force on brake levers

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Braking problems

- Brake too hard,
  - wheels stop rotating and start skidding
  - energy is wasted and steering fails
- Slowing force exerts a torque on bicycle
  - Rear wheel loses traction and may “fishtail”
  - Front wheel has improved traction
  - Rider and bicycle can flip head first

Summary About Bicycles

- Are statically unstable
- Are dynamically stable
- Naturally steer under your center of gravity
- Use gears for mechanical advantage
- Use work from you to get started
- Convert work into thermal energy to stop