Building a physics engine - part 5: various forces

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Table of contents

Gravity

Gravity

- The easiest :)
- $F_G = \frac{Gm_1M_2}{r^2}$ $G = 6.6738410^{-11} m^3 kg^{-1} s^{-2}$
- On the surface of a planet, $F = ma$, where $a = \frac{Gm_2}{r^2}$; for example, $a = g = 9.81$

Friction

Friction

- Friction is related to the *normal force*
- $F_N = mg\cos\theta$
- $F_F = \mu F_N$, where μ depends on the materials
- When not moving, static friction applies μ_S
- When moving, dynamic friction applies μ_K
- $\mu_K < \mu_S$

Springs

Springs

- Hooke's Law
- $F_S = -k\Delta l$

Centripetal force

Centripetal force

- During a circular movement
- Force towards the center of the circle
- $F_C = \frac{mv^2}{r}$

Projectiles

Projectiles

- A projectile is influenced by
  - Gravity
  - Aerodynamic drag
  - Laminar and turbulent flow
  - Wind effects
  - Spin effects
  - Projectile geometry and mass

Projectiles

Aerodynamic drag

- $F_D = \frac{1}{2}\rho v^2 A C_D$
  - ρ is the fluid density
  - A is the body area
  - C_D is the drag coefficient

Projectiles

C_D

- Drag is a force applied against motion $-\frac{v}{|v|}$
- The drag coefficient depends on the *Reynolds number*
- $C_D = f(Re)$ for some complex function f
- $Re = \frac{\rho v L}{\mu}$
  - L is the projectile length
  - μ is the drag coefficient

Projectiles

Air density

- Depends on altitude

Projectiles

Laminar vs turbulent flow

- Depending on the speed, the air travels over the surfaces of the projectile
- At low Reynolds numbers, flow is laminar
- At around $Re = 250000$ the switch occurs (for a golf ball and similar projectiles)
- At high Reynolds numbers, flow is turbulent
- We store at least two C_D coefficients per object

Projectiles

Wind

- Wind simply changes the *apparent velocity*
- All other computations simply use the apparent velocity
- $v_{\text{apparent}} = v - v_{\text{wind}}$

Projectiles

Spin effects

- When an object is spinning, the velocity difference between the top and bottom surfaces given by spinning causes acceleration
- This is known as the *Magnus Effect* or *Robin's Effect*

Projectiles

Spin effects

- $F_M = \frac{1}{2}\rho v^2 A C_L$
- $C_L = \frac{rw}{v}$ for a sphere
- $C_L = \frac{2\pi rw}{v}$ for a cylinder
- Direction of force is $\frac{v \times w}{|v \times w|}$

Projectiles

Bullets

- Rotation axis is horizontal
- Almost zeroes $\frac{v \times w}{|v \times w|}$
- Magnus Effect can be ignored
- $C_D = 0.3$ is a reasonable constant

Projectiles

Cannonballs

- Start with a velocity between $260 m/s$ and $344 m/s$
- Weight is between $2 kg$ and $10 kg$
- $C_D = 0.3$ is a reasonable constant

Assignment

Assignment

- Before the end of next week
- Group-work archive/video on Natschool or uploaded somewhere else and linked in your report
- Individual report by each of you on Natschool
- Add a personalized selection of forces to your simulator

That's it

Thank you!