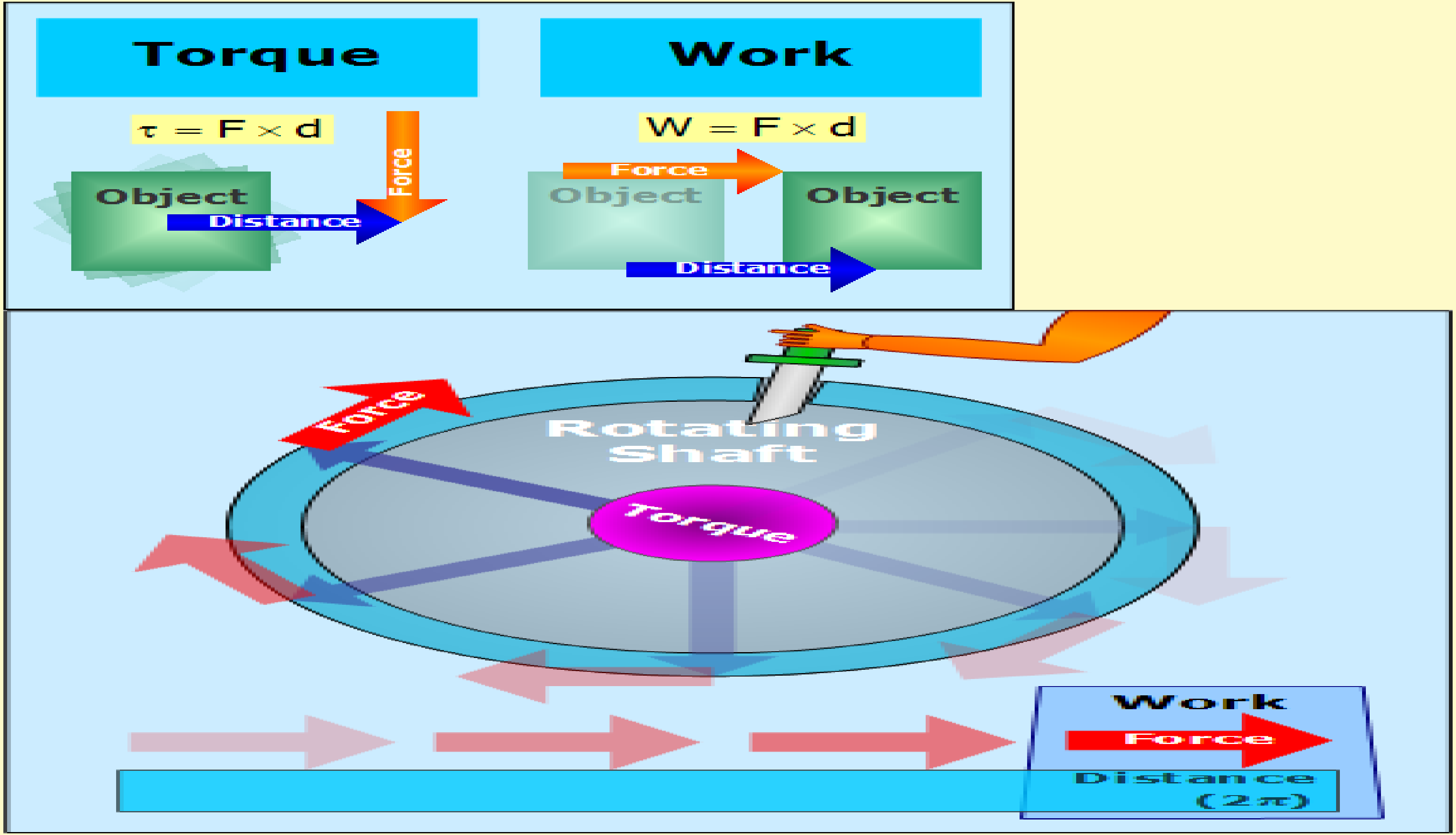
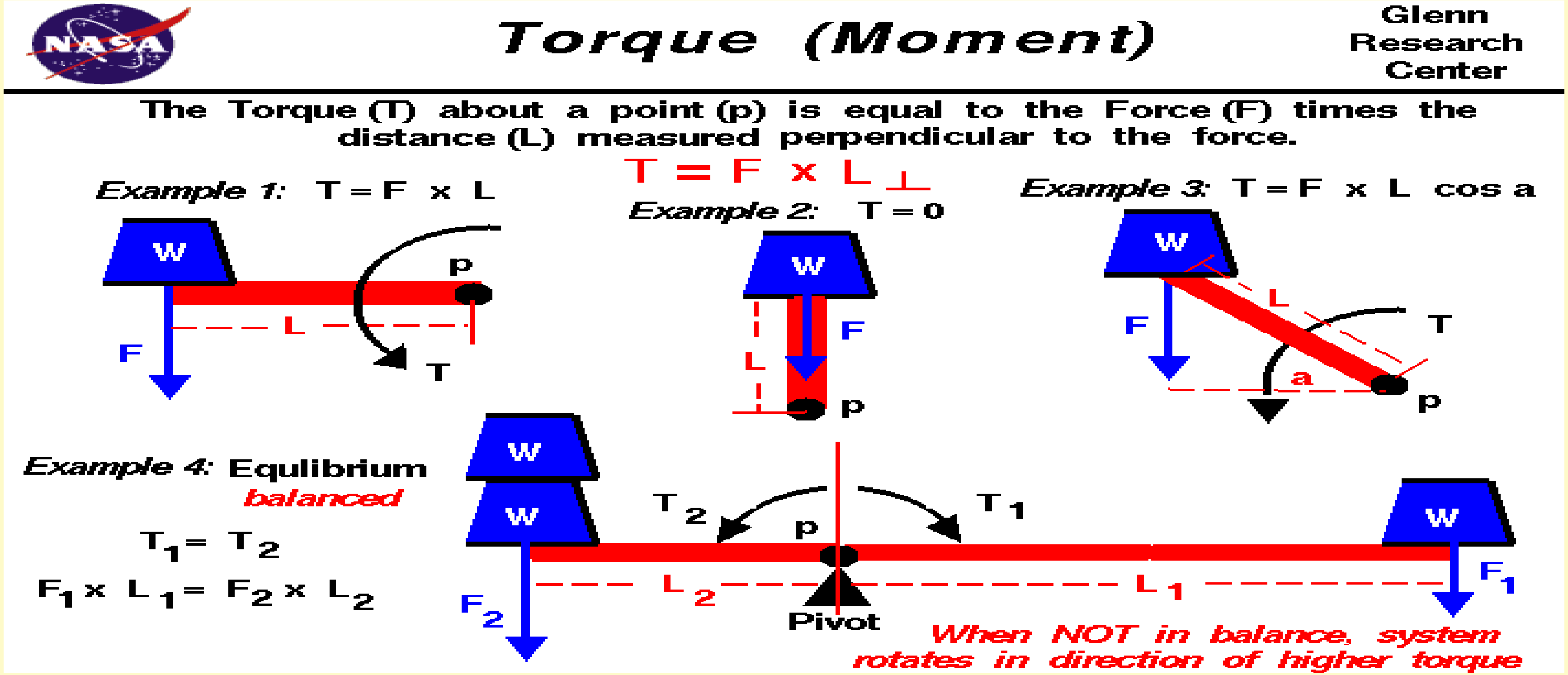
FIRST Robotics Community Center at Kettering University
FRC Mechanical Workshop

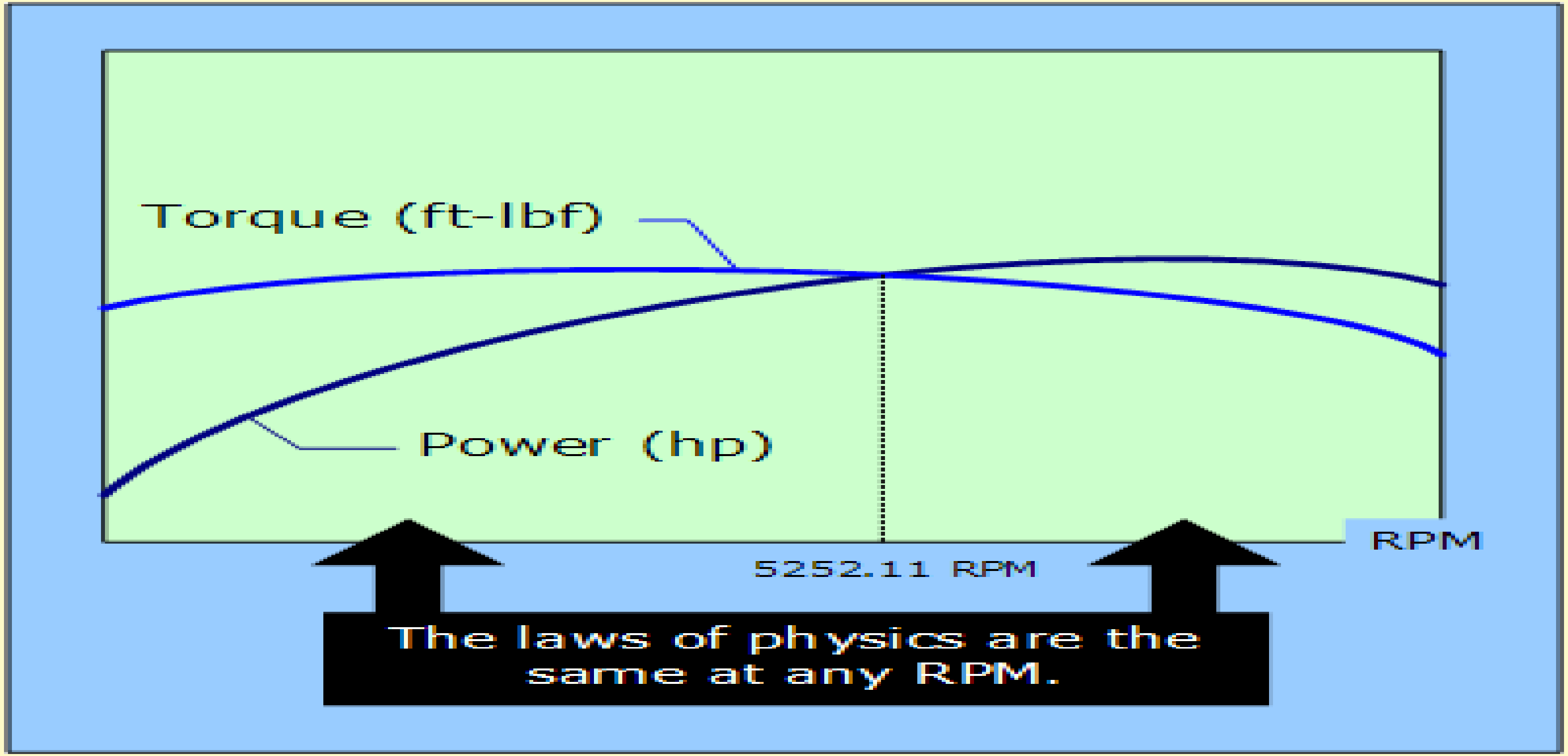


Torque
$\tau = F \times d$
Force
Object
Distance
Work
$W = F \times d$
Force
Object
Object
Distance
Force
Rotating Shaft
Torque
Work
Force
Distance
(2π)

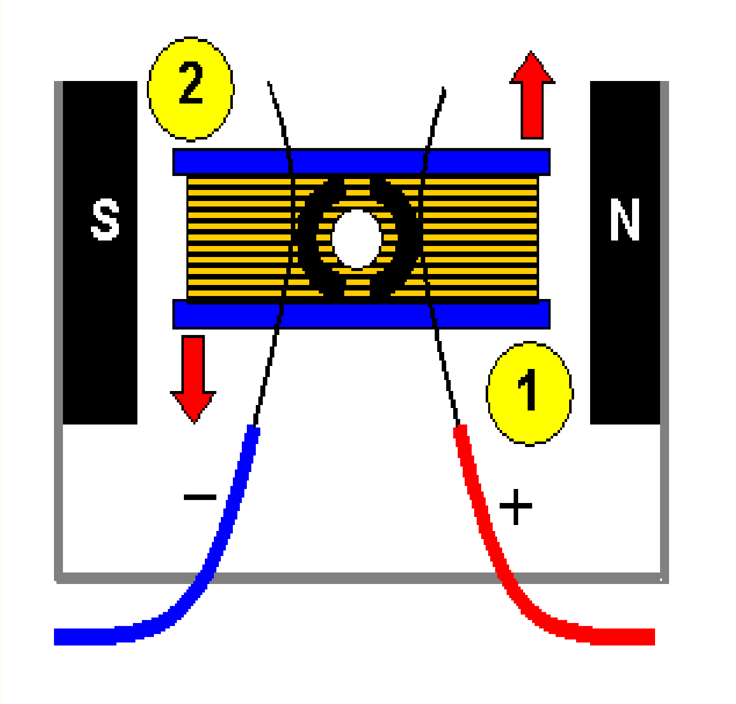
Torque=F x L sin a if the torque is clockwise. Torque = F x cos a if the torque is counterclockwise



Power is Force times velocity (speed) P=F x v . Power also equals work divided by time and energy divided by time. P=W/t = E/t. The units for power are Watts(W) which equals joules/seconds (J/s).



The electric motor works because if a wire carrying an electric current is in a magnetic field there is a force on the wire. This makes the wire move.



The diagram shows the view of a simple electric motor looking from the end of the axle. (The end of the axle is the small white circle in the middle of the diagram). When a current flows through the coil there is a force on the coil. The side marked 1 is forced upwards and the side marked 2 is forced downwards.

The coil turns in an **ANTICLOCKWISE DIRECTION**. The inertia of the coil keeps it turning between each contact with the input wires (+ and -).

If we have a split ring, we can change the poles from north to south. The inertia (object stay in motion) will keep the motor moving and spinning until the magnet is strong enough to attract it.

Gears, Sprockets and belts

- 25 chain - lighter then 35 chain but not as strong
- Belts can slip and stretch, but do not need a master link

Gear and Sprocket ratio

$$\text{Gear Ratio} = \frac{\text{Teeth}_{\text{Output Gear}}}{\text{Teeth}_{\text{Input Gear}}} = \frac{\text{Diameter}_{\text{Output Gear}}}{\text{Diameter}_{\text{Input Gear}}}$$

$$\text{If Gear Ratio} > 1 \rightarrow \text{Underdrive}$$

$$\text{If Gear Ratio} < 1 \rightarrow \text{Overdrive}$$

$$\text{RPM}_{\text{Out}} = \frac{\text{RPM}_{\text{IN}}}{\text{Gear Ratio}}$$

$$\text{Torque}_{\text{Out}} = \text{Torque}_{\text{IN}} \times \text{Gear Ratio}$$

$$\text{Power}_{\text{Out}} = \text{Power}_{\text{In}}$$

Assuming no losses due to friction.

Proof:

$$\text{Power}_{\text{Out}} = \text{RPM}_{\text{Out}} \times \text{Torque}_{\text{Out}}$$

$$\text{RPM}_{\text{Out}} = \frac{\text{RPM}_{\text{IN}}}{\text{Gear Ratio}}$$

$$\text{Torque}_{\text{Out}} = \text{Torque}_{\text{IN}} \times \text{Gear Ratio}$$

$$\text{Power}_{\text{Out}} = \left(\frac{\text{RPM}_{\text{IN}}}{\cancel{\text{Gear Ratio}}}\right) \times (\text{Torque}_{\text{IN}} \times \cancel{\text{Gear Ratio}})$$

$$\text{Power}_{\text{Out}} = \text{RPM}_{\text{In}} \times \text{Torque}_{\text{In}}$$

$$\text{Power}_{\text{Out}} = \text{Power}_{\text{In}}$$

Drivetrain

- 4 traction wheel kit chassis.
- 4 wheels - 2 traction, 2 omni
- 4 wheels mechanum drive
- 4 omni wheels
- 6 traction wheels (1/4 inch Lowered middle wheel)
- 8 wheels
- Swerve or Crab drive

Manipulators for FIRST FRC Robotics

Manipulate What ?

- Game pieces come in many sizes and shapes

Manipulate How ?

Game objectives change each year

Hang

Lift

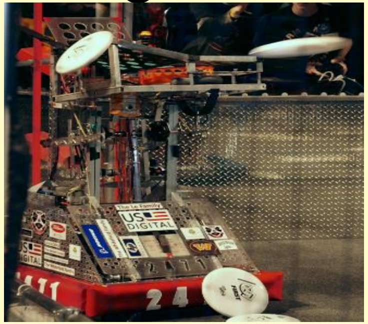
Dump

Kick

Gather

Throw

Fling



Where to Start ?

<u>Know the Objectives</u>

Test the game pieces

Read game & robot rules

Define your game strategy

<u>Learn from Others</u>

Look on line

Talk to mentors

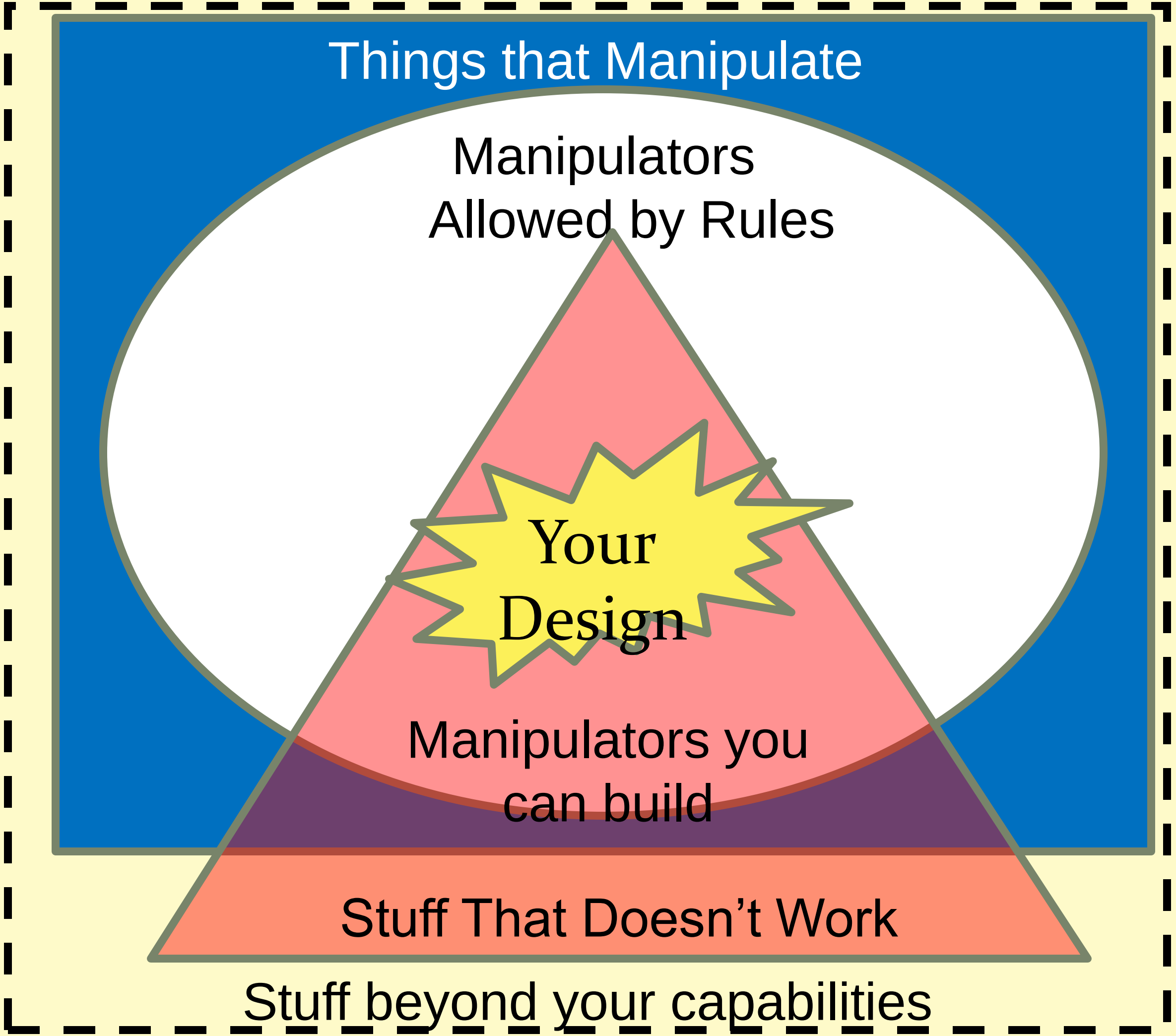
Visit other teams

<u>Consider you capabilities</u>

Team Tools & Skills,

Materials, Manpower

Budget, Time



FIRST Definition of a Manipulator

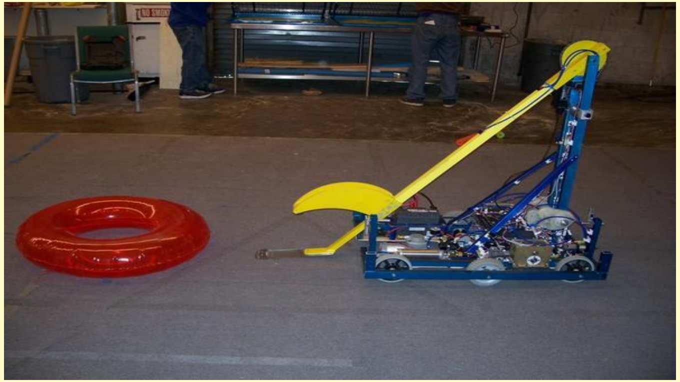
A device that moves the game piece from where it is to where it needs to be.

Reoccurring Themes

- Lifting High / Long reach
  - Articulating Arms, Parallel arms
  - Telescoping Lifts
- Grabbers & Grippers
  - Rollers, Clamps,Claws
- Collect and Deliver
  - Conveyers,Turrets, Shooters
  - Kickers, Buckets
- Power & Control
  - Winches, Brakes, Latches
  - Pneumatics, Springs / Bungee
  - Gears & Sprockets

Arms

Shoulder
Elbow
Wrist

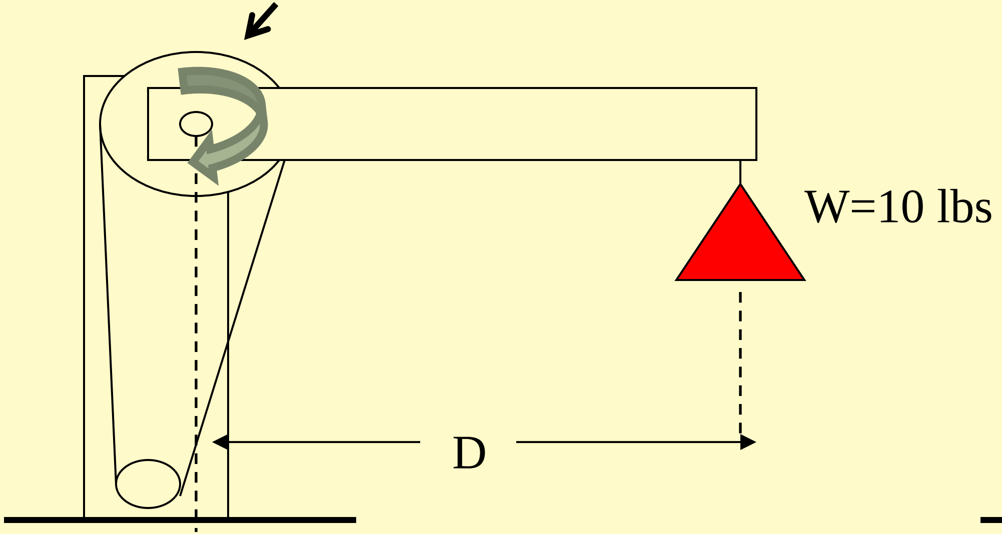


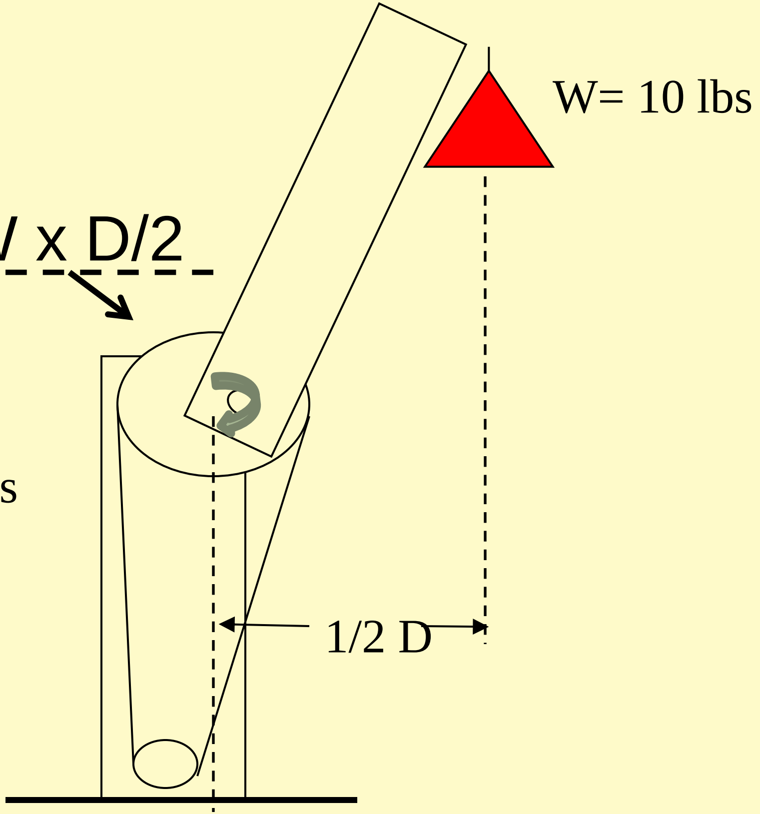
Torque & Weight limits arm length.

- Torque = Force x Distance
  - Measure from the pivot point
  - Different angle = different torque
  - Maximum at 90 degrees

Torque = W x D

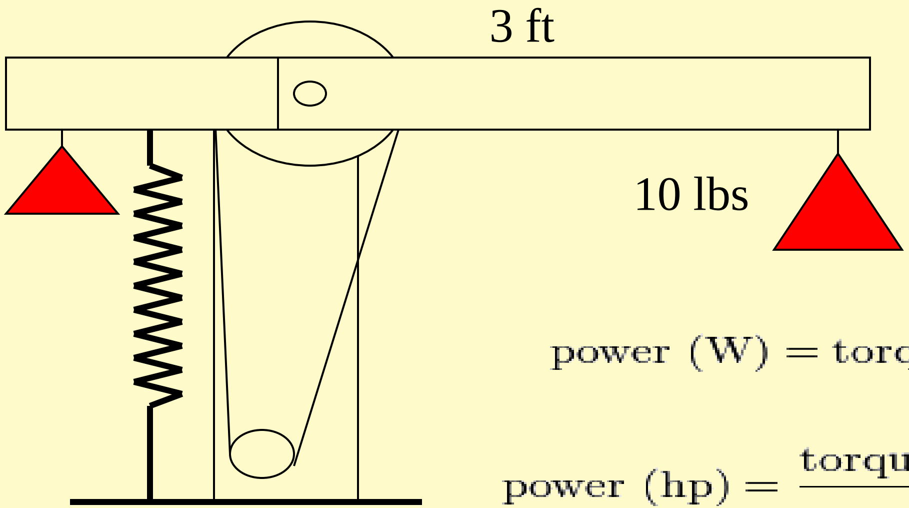
Torque = W x D/2





Power & Torque Limit Speed

- Power determines how fast you can move things
- Power = Torque / Time or Torque x Rotational Velocity
- Counter weight or springs can help



$$\text{power (W)} = \text{torque (N} \cdot \text{m)} \times 2\pi \times \text{rotational speed (rps)}$$

$$\text{power (hp)} = \frac{\text{torque(lbf} \cdot \text{ft)} \times 2\pi \times \text{rotational speed (rpm)}}{33000}.$$

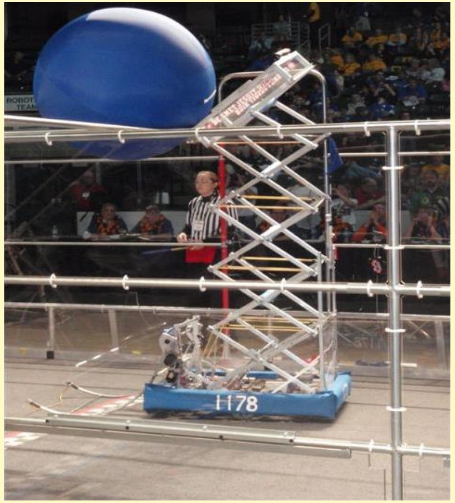
Arm Design Tips

- Lightweight Materials:
  - Thin wall tubes, lightening holes
- Use sensors for feedback & control
  - Limit switches
  - Potentiometers
  - Encoders
  - Banner light sensor
- Use Linkages to control long arms
- Use counterbalances
  - Spring, weight, pneumatic, bungee…
- Calculate the forces
  - Watch out for Center of gravity
  - Tipping force when arm extended
- Keep it as simple as possible
  - Less parts to build. Less parts to break

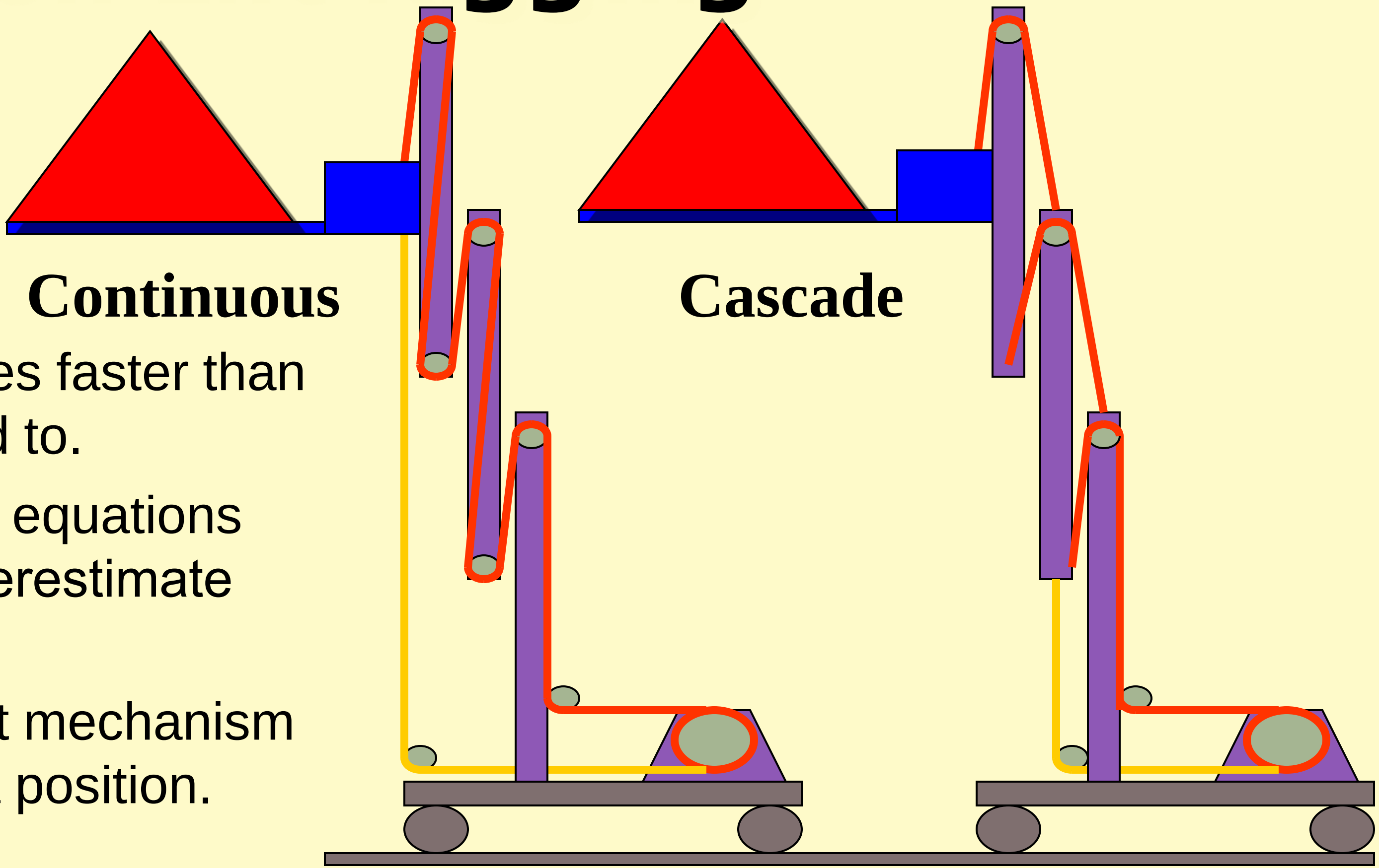
Dr. Claw in 2014

Telescoping Lifts

- Extension Lifts
  - Motion achieved by stacked members sliding on each other
- Scissor Lift
  - Motion achieved by “unfolding” crossed members
  - High stress loads at beginning of travel (spring assist can start movement)
  - Difficult to build well. Not recommended without prior experience



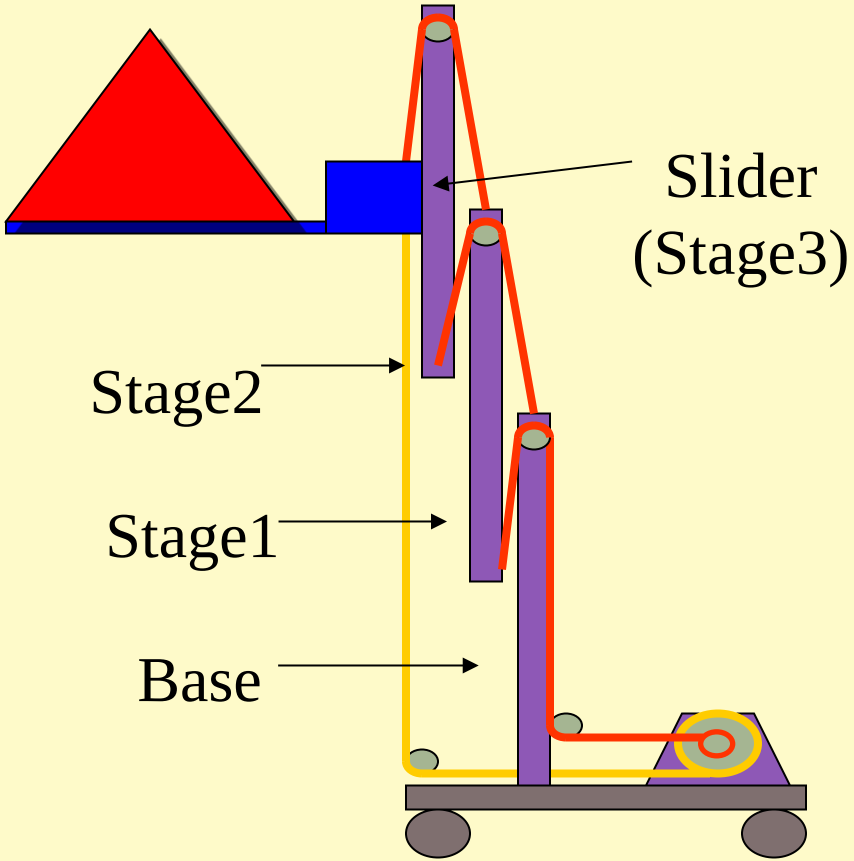
Extension Lift Rigging



- Each stage moves faster than one it is mounted to.
- Power vs. speed equations apply. Don’t underestimate power needed.
- Brakes or ratchet mechanism needed to hold a position.

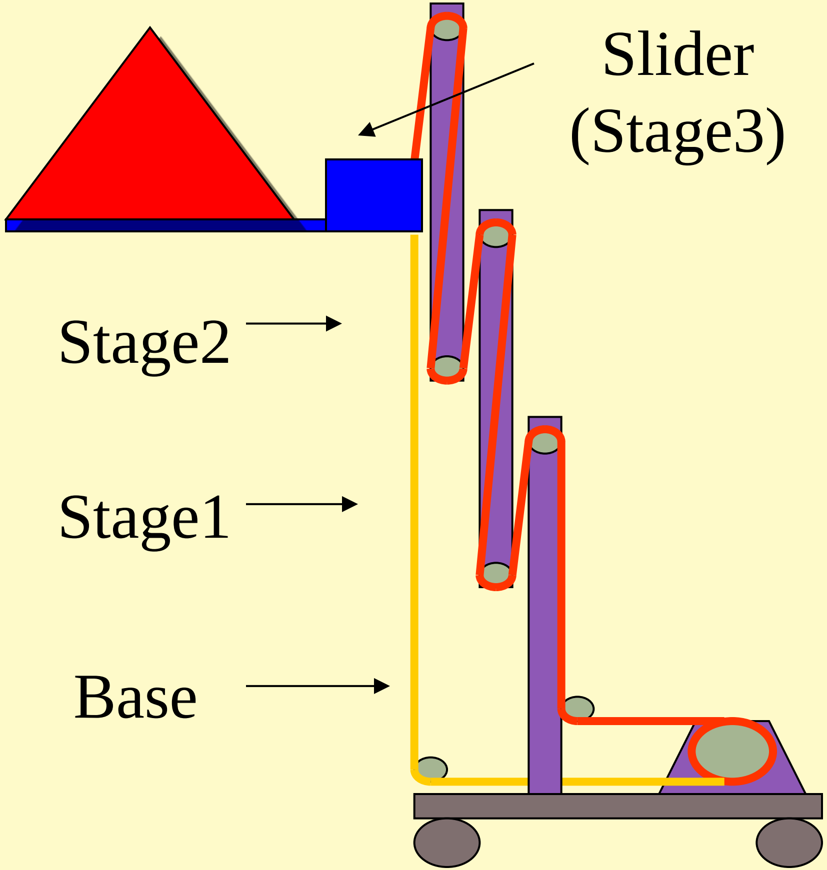
Cascade

- Pull-up and pull-down cables have different speeds
- Cable speeds can be handled by different drum diameters
- Intermediate sections don't jam – active return
- Higher tension on the lower stage cables



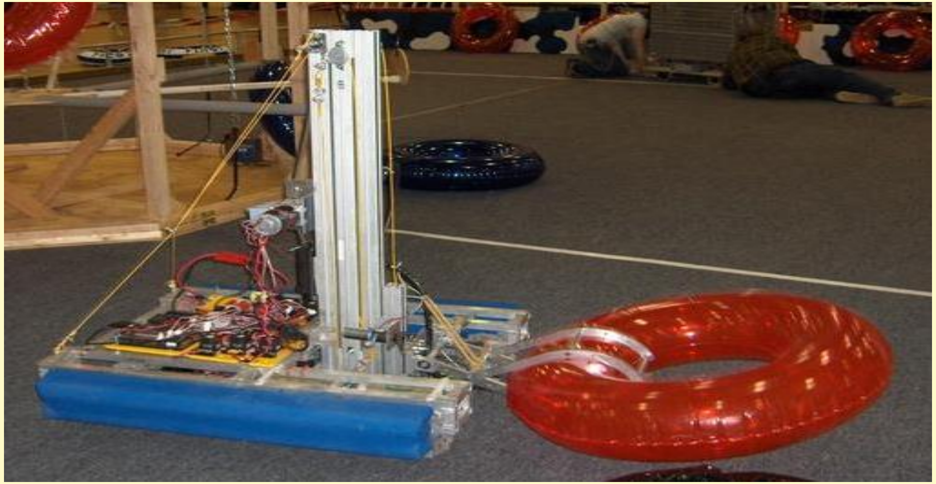
Continuous

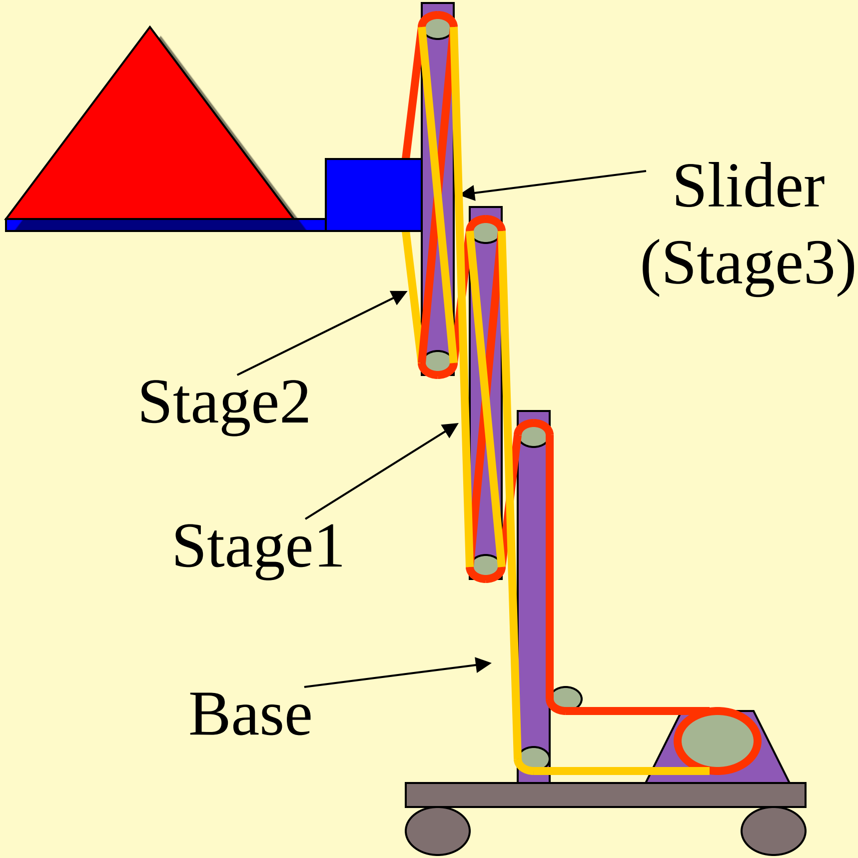
- Same speed for pull-up and pull-down cables
- More complex cable routing



Continuous Internal

- Pull-down cable routed on reverse route of pull-up cable
- Most complex cable routing
- All stages have active return
- Cleaner and protected cables



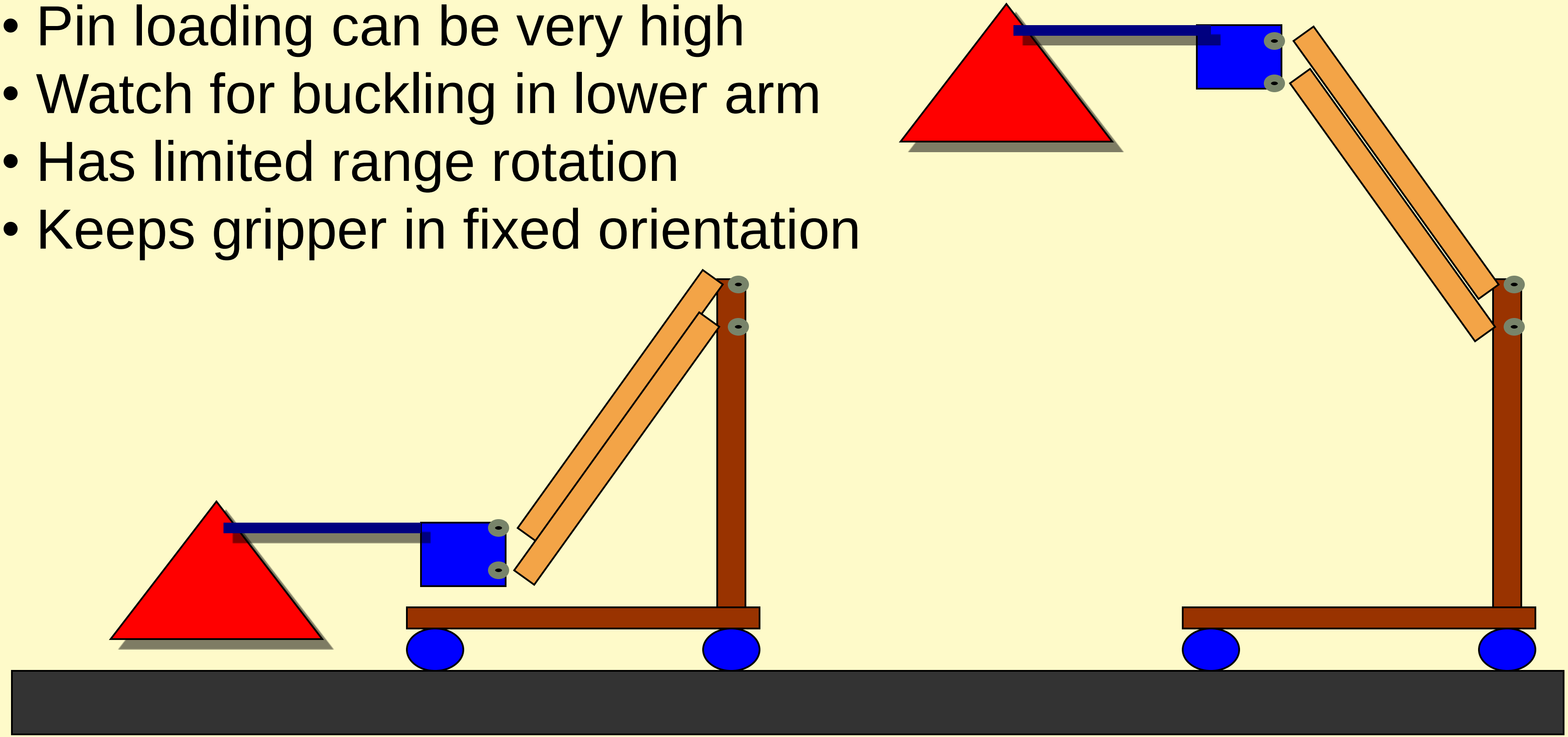


Extension Lift Design tips

- Use cables to drive up *and down*, or add a return spring.
- Segments must move freely
- Minimize slop and free-play
- Segment overlap for stability
  - 20% minimum
  - More for bottom, less for top
- Stiffness and strength needed
- Minimize weight, especially at top

Parallel Arms

- Pin loading can be very high
- Watch for buckling in lower arm
- Has limited range rotation
- Keeps gripper in fixed orientation



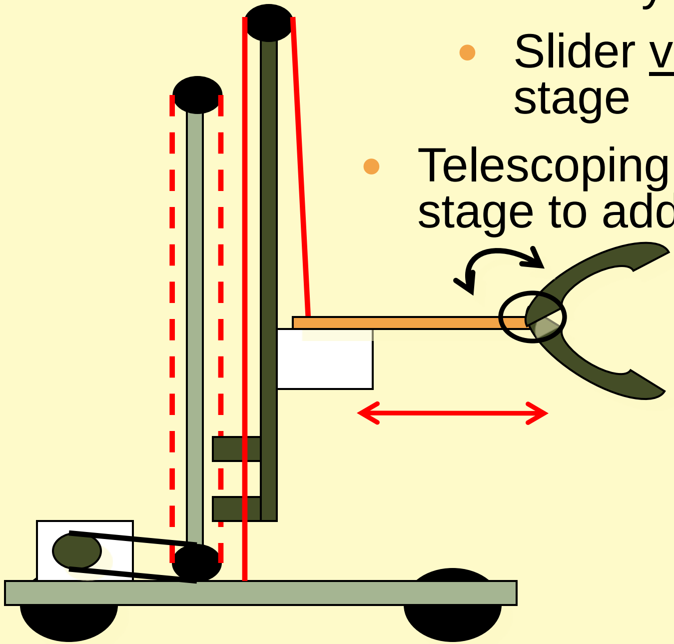
Arms vs. Lifts

Feature	Arm	Lift
Reach over object	Yes	No *
Get up after tipping	Perhaps, if strong	No
Complexity	Moderate	High
Weight capacity	Moderate	High
Go under barriers	Yes, folds down	Maybe, limits lift height
Center of gravity	Cantilevered	Central mass
Operating space	Large swing space	Compact
Adding reach	More articulations	More lift sections
Combinations	Arm with extender	Lift with arm on top

Combination Example:

Wallace in 2011

- Continuous direct drive chain runs stage 1 up and down
    - Drum differential not needed
- Cascade cable lifts slider stage
    - Gravity return
    - Slider <u>very</u> well balanced over first stage
- Telescoping arm with wrist on slider stage to add reach



Getting a Grip

FIRST definition of a gripper:

Device that grabs a game object

…and releases it when needed.

Design Concerns

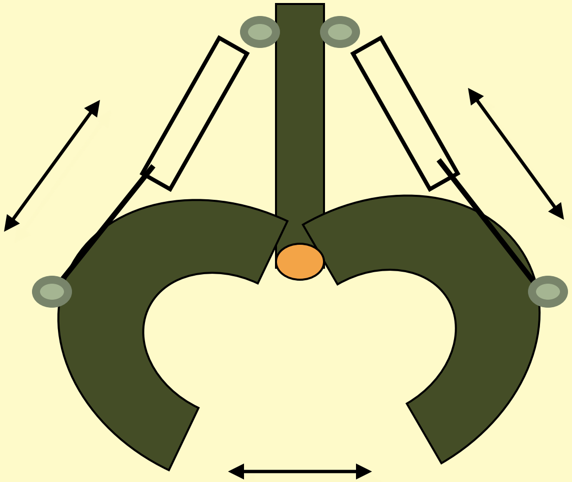
- Getting object into grip
- Hanging on
- Speed of grip and release
- Position control
- Weight and power source
  - If at end of arm

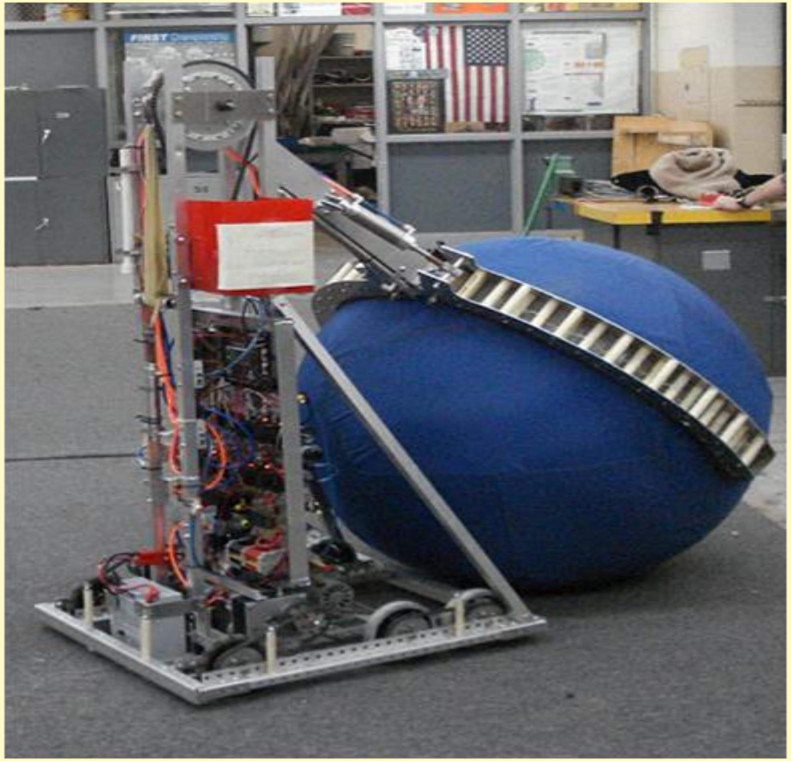
Lot of Methods

- Pneumatic claws /clamps
  - 1 axis
  - 2 axis
- Motorized claw or clamp
- Rollers
- Hoop grips
- Suction

Claw or clamp

- Pneumatic
- One fixed arm
- Hollow claw to reduce weight
- One or two moving sides





768 in 2008

Pneumatic: 2 and 3 point clamps

- Pneumatic Cylinder extends & retracts linkage to open and close gripper
- Combined arm and gripper
- Easy to make
- Easy to control
- Quick grab
- Limited grip force
- Use 3 fingers for 2-axis grip

968 in 2004

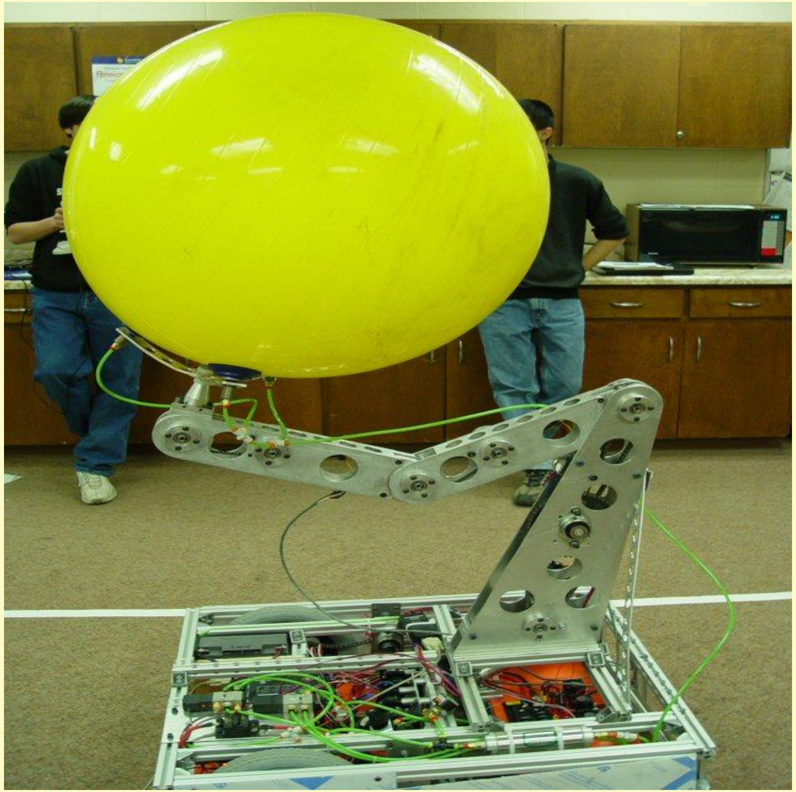

60 in 2004

Motorized clamp

- Generally slower
  - Not good for frequent grabs
  - Okay for a few grabs per game or heavy objects
- More complex and heavier
  - Due to gearing & motors
- Tunable force
- No pneumatics

49 in 2001

Suction Grips



- Needs vacuum generator
- Uses cups to grab
- Simple
- Can require precise placement
- Not force control: On or Off
- Subject to damage of suction cup or game pieces

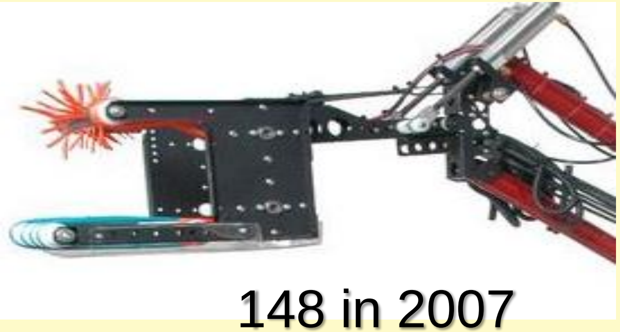
Not recommended for heavy game pieces

Used effectively to hold soccer balls for kickers

(Breakaway 2010)

Roller Grips

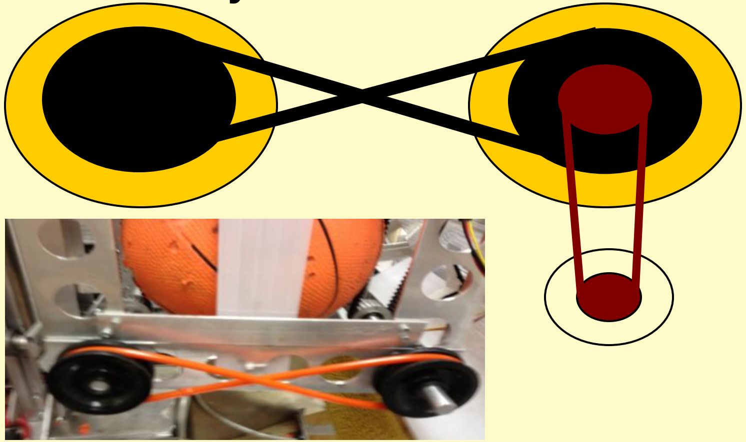
- Allows for misalignment when grabbing
- Won’t let go
- Extends object while releasing
- Simple mechanism
- Use sensors to detect position.
- Many variations
  - Mixed roller & conveyer
  - Reverse top and bottom roller direction to rotate object



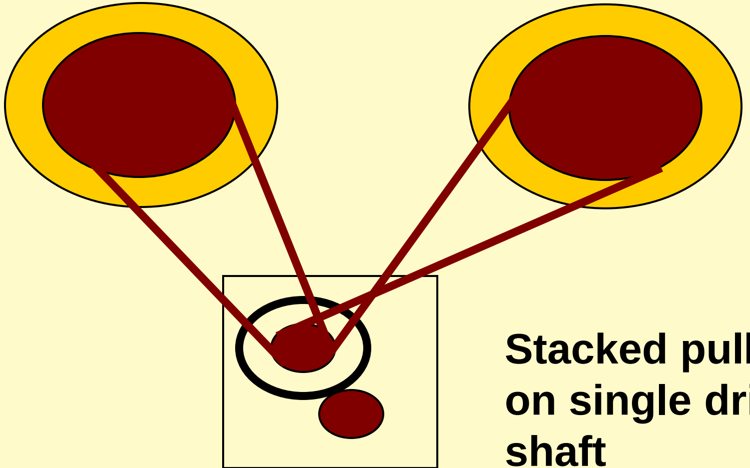
148 in 2007

Counter Rotating Methods

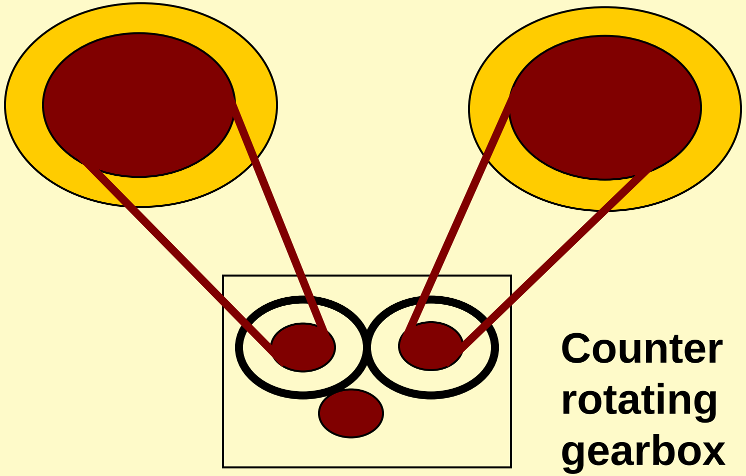
The Infinity Belt



- Many ways to achieve counter rotating shafts. Here are few configurations that can run off a single motor or gearbox.
- Can also drive each side with separate motors



Stacked pulleys on single drive shaft



Counter rotating gearbox

Gripper Design

Hang On!

- High friction surfaces
  - Rubber, neoprene, silicone, sandpaper … but don’t damage game pieces
- Force: Highest at grip point
  - 2 to 4 x object weight
- Extra axis of grip = More control buy more complexity

Need for speed

- Wide capture window
- Quickness counts
  - Quick to grab , Drop & re-grab
  - Fast : Pneumatic gripper.   Not so fast: Motor gripper
- Make it easy to control
  - Limit switches,   Auto-functions
  - Intuitive driver controls

Gathering: Accumulators & Conveyers

Accumulator: Collects multiple objects

- Horizontal rollers: gathers balls from floor or platforms
- Vertical rollers: pushes balls up or down
- Wheels: best for big objects
- Can also use to dispense objects out of robot

Conveyers: Moving multiple objects

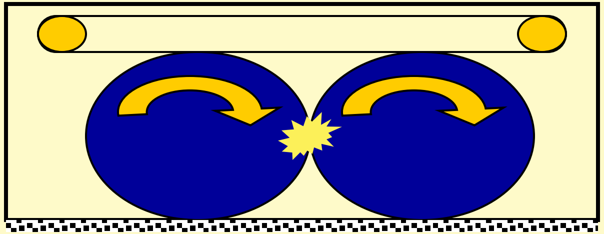
- Moving multiple objects point to point within your robot

Why do balls jam on belts?
- Stick and rub against each other as they try to rotate along the conveyor

Solution #1
- Use a slippery material for the non-moving surface (Teflon, pebble surface)

Solution #3
- Use individual rollers
- Adds weight and complexity

Solution #3
- Use pairs of belts
- Weight additional support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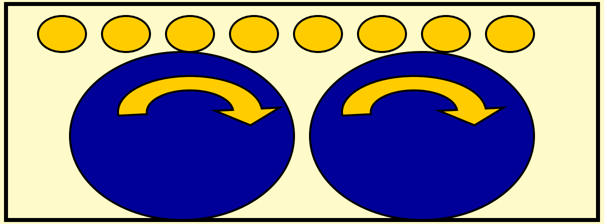
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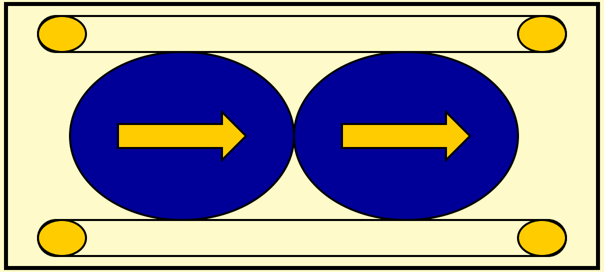
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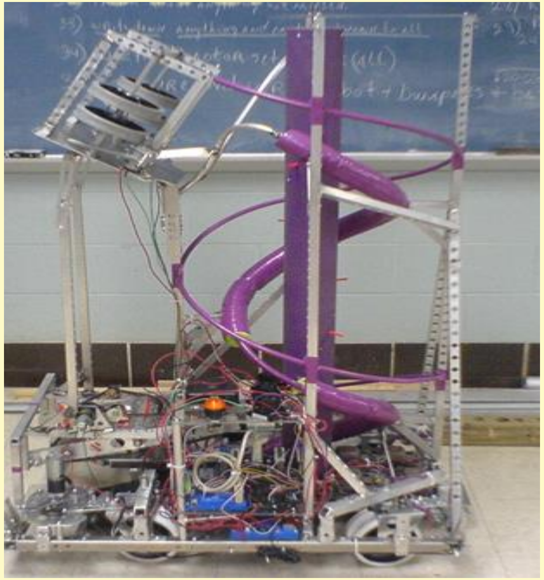
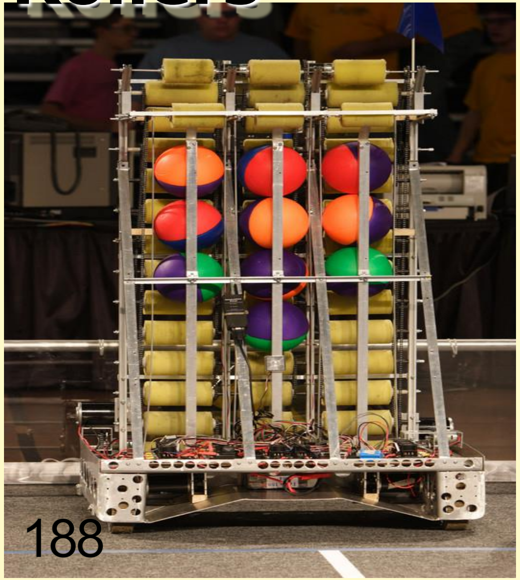
Conveyer Examples

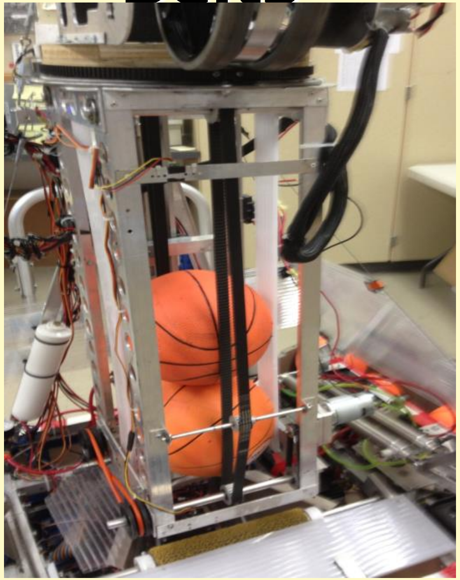
Tower



Rollers



Belts



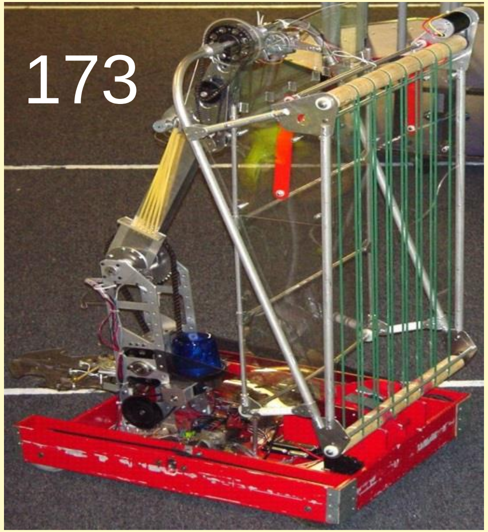
Solution 1

Solution 2

Solution 3

Accumulator & Conveyer Design

- Control the objects
  - Avoid gravity feeds – Slow and easily jam
  - Direct the flow. Reduce random movement
- Not all game objects are created equal
  - Variations in size, inflation, etc
  - Build adaptive or adjustable systems
  - Test with different sizes, inflation, etc.



Shooters

- Secure shooting structure = more accuracy
- Feed balls (or disks) individually, controlling flow
- Rotating tube or wheel
  - One wheel or two counter rotating
  - High speed & power: 2000-4000 rpm
  - Brace for vibration
  - Protect for safety
- Turret allows for aiming
- Sensors detect ball presence

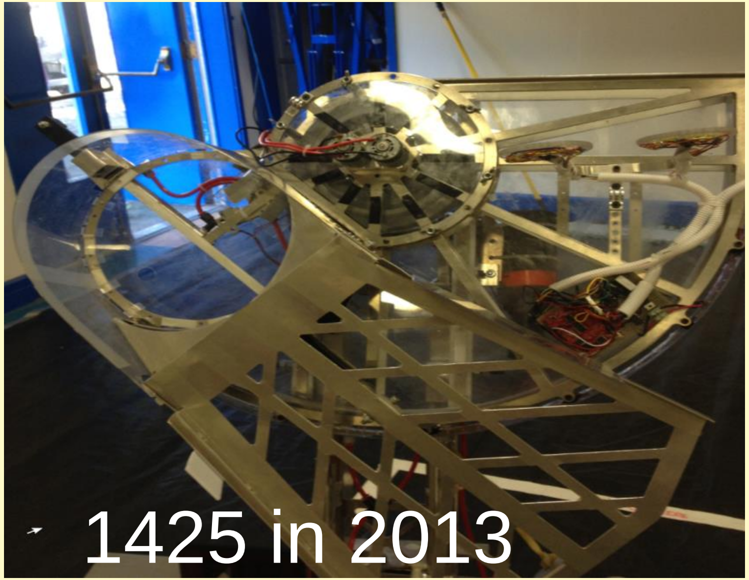
  & shot direction

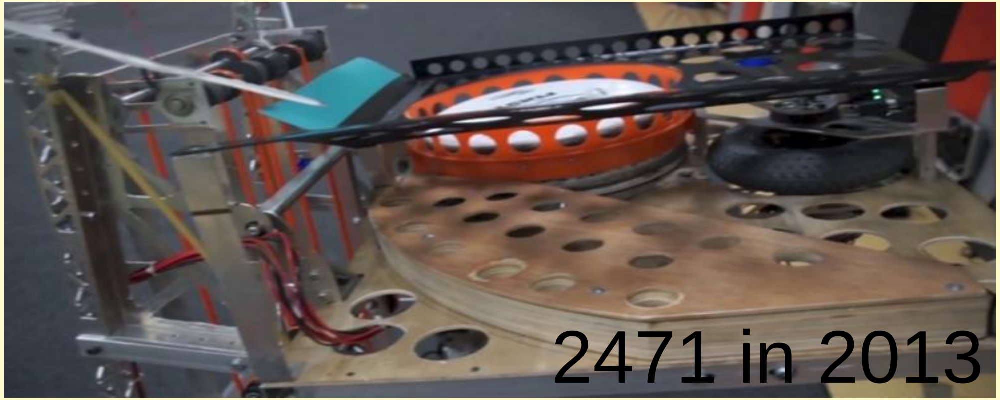
Circular Conveyer. One cylindrical roller inside. Rolling surface around outside

1771 in 2009

Frisbee Fling:

- Wheel rotates disc against a flat or curved surface.
- High speed ~5000 rpm
- Long surface & wheel contact time needed to get disc up to speed.
  - 2 wheel stages for linear shooters
  - 1 wheel for curved shooters



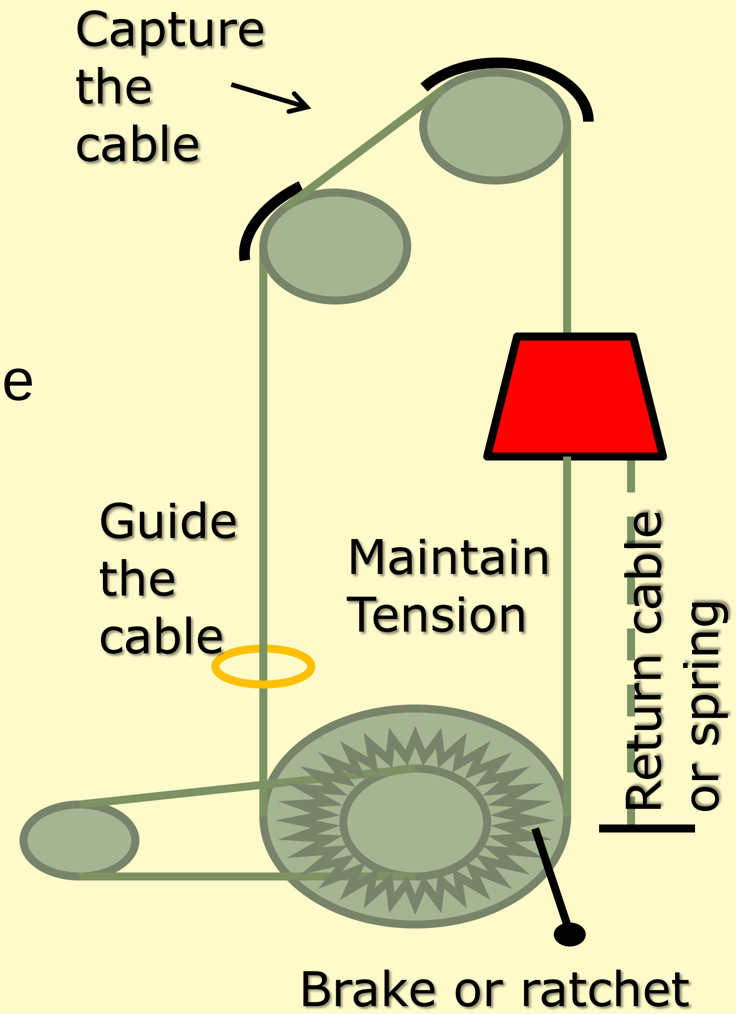


Winches

- Many uses
  - Hanging Robots: 2000, 2004, 2010
  - Climbing robots: 2013
  - Lifting Robots: 2007
  - Loading Kickers 2010, 2014
- High torque application
- Fits into limited space
- Good for Pull. Bad for Push

Winch Design

- Secure the cable routing
- Smooth winding & unwinding
- Leave room on drum for wound up cable
- Guide the cable
- Must have tension on cable to unwind
  - Can use cable in both directions
  - Spring or bungee return
  - Gravity return not recommended except after match ends
- Calculate the torque and speed
- Ratchet or brake to hold a position.

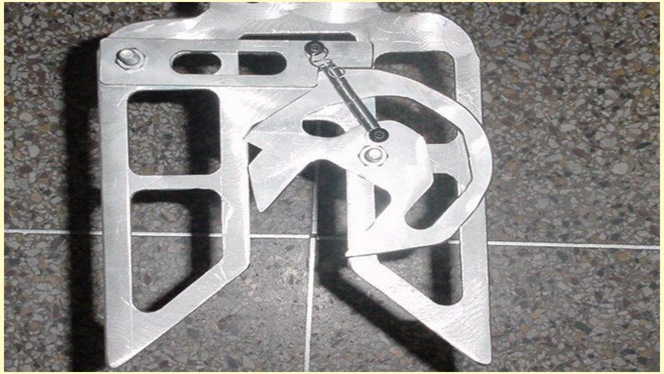


Kickers and Catapults

- Sudden release of power
- Use stored energy:
  - Springs Bungee, Pneumatic
- Design & test a good latch mechanism
  - Secure lock for safety
  - Fast release
- Once a game deployments
  - 2011 minibot release

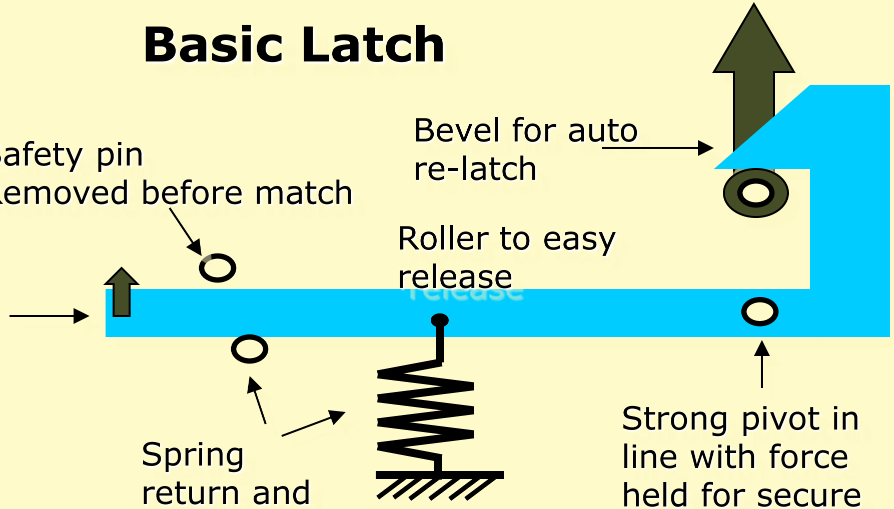
Latches

- Hook & hold to grab goals, bars, etc.
- Hold stored power until needed
  - Spring or bungee
- Several ways:
  - Hooks
  - Locking wheels
  - Pins
- Start latch design early.
  - Tend to be afterthoughts
- Don't forget the safety pin



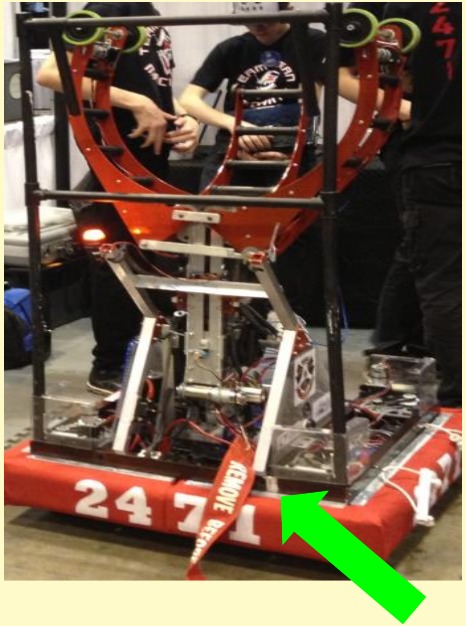
Self latching wheel lock

Basic Latch



Design in Safety

- Any manipulator strong enough to play the game is strong enough to hurt someone.
- Design in locking pins, safety signage and safe stop points



Summary

- Look around. See what works
- Know your design objectives and game strategy
- Stay within your capabilities
- Design before you build
  - Calculate the forces and speeds
  - Understand the dimensions using CAD or model
- Keep it simple and make it well
  - Poor craftsmanship can ruin the best design
- Test under many conditions
  - Refine the design and decide on spare parts
- Have fun

Acknowledgements

- **Bruce Whitefield 2014 Arm and Manipulator Presentation, Mentor, Team 2471, Washington**

Appendix

Motor Power:

- <u>Assuming 100% power transfer efficiency:</u>
- All motors can lift the same amount they just do it at different rates.
- No power transfer mechanisms are 100% efficient
  - Inefficiencies due to friction, binding, etc.
    - Spur gears ~ 90%
    - Chain sprockets ~ 80%
    - Worm gears ~ 70%
    - Planetary gears ~80%
  - Calculate the known inefficiencies and then design in a safety factor (2x to 4x)
- Stall current can trip the breakers

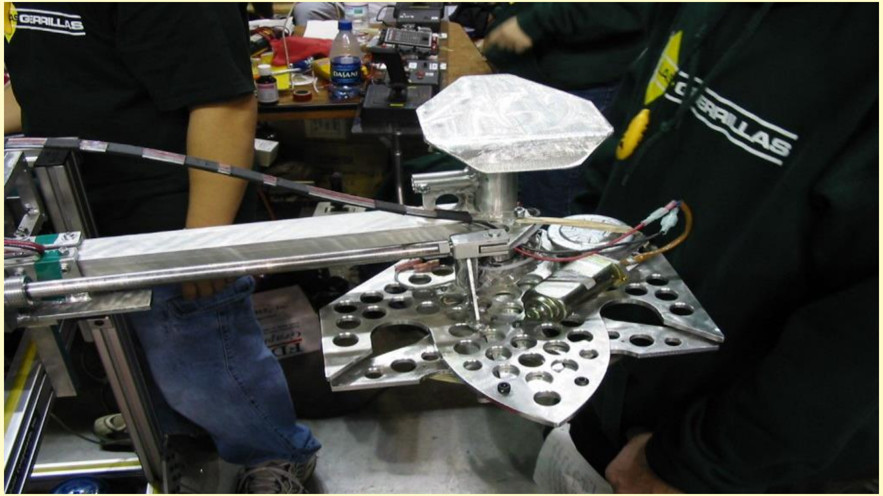
It adds up!
2 spur gears + sprocket =
.9 x.9 x.8 = .65
Losing 35% of power to the drive train

Scissor Lifts

- Advantages
  - Minimum retracted height - can go under field barriers
- Disadvantages
  - Tends to be heavy when made stable enough
  - Doesn’t deal well with side loads
  - Must be built very precisely
  - Stability decreases as height increases
  - Stress loads very high at beginning of travel
  - **Not recommend without prior experience**

Latch Examples

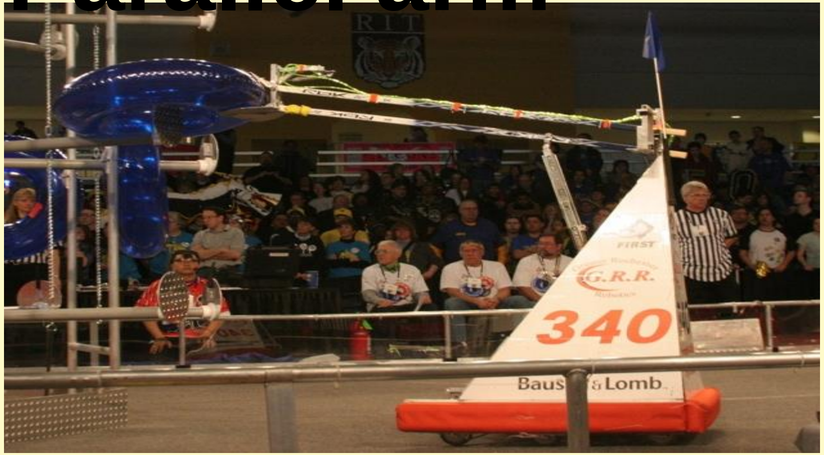
- Pneumatic latch, solidly grabs pipe
- Force and friction only
- No “smart mechanism”



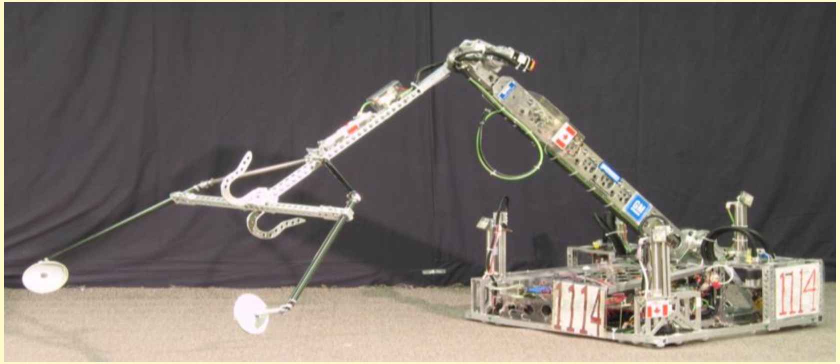
- Spring-loaded latch
- Motorized release
- Smart Mechanism

469 in 2003

Parallel arm



Fixed Arm



Jointed Arm

Brakes: Slowing and locking

- Ratchet - Complete lock in one direction in discrete increments
- Clutch Bearing - Completely lock in one direction any spot
- Brake pads - Squeezes on a rotating device to stop motion - can lock in both directions. Simple device
  - Disc brakes - Like those on your mountain bike
  - Gear brakes - Apply to lowest torque gear in gearbox
  - Belt Brake- Strap around a drum or pulley
- Dynamic Breaking by motors lets go when power is lost.
  - Use for control, but not for safety or end game
  - Gearbox that cannot be back-driven is usually an inefficient one.

Latch Design

- Start design early. Latches tend to be afterthoughts but are often a critical part of the operation
- Don’t depend on driver to latch, use a smart mechanism
  - Spring loaded (preferred)
  - Sensor met and automatic command given
  - Use operated mechanism to let go, not to latch
- Have a secure latch
  - Don’t want release when robots crash
- Be able to let go quickly
  - Pneumatic lever
  - Motorized winch, pulling a string
  - Cam on a gear motor
  - Servo (light release force only)
- Don’t forget a safety pin or latch for when you are working on the robot