Pneumatic Power

Presented by:

Raul Olivera, WildStang - 111

Outline

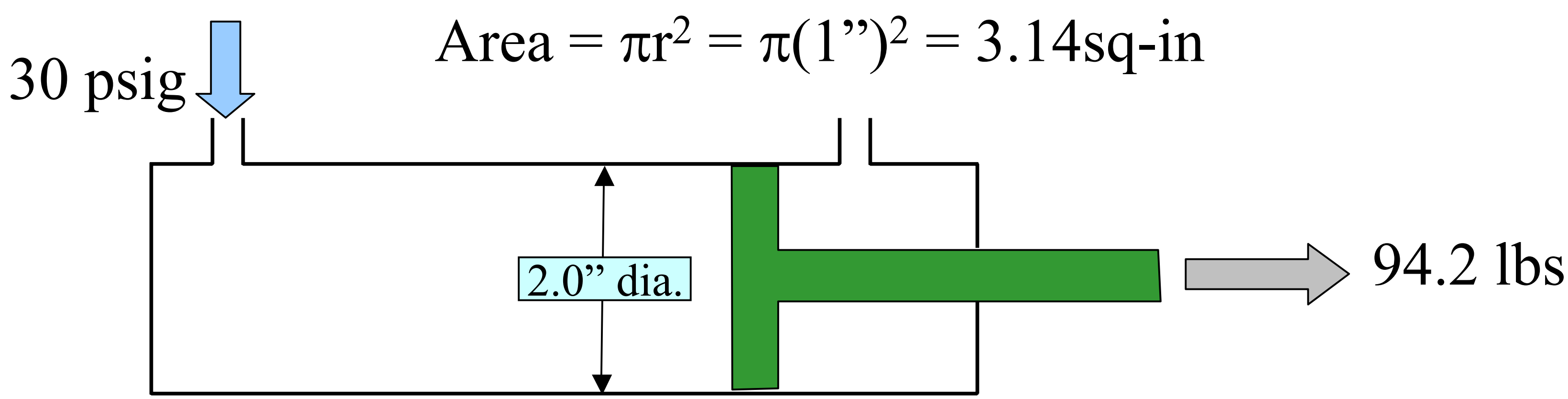
- Some Basics of Pneumatics and Associated Physics
  - Pressure - Absolute & Gage
  - Force, Pressure & Area
  - Air Properties
  - Flow Rates
  - Electrical Analogy
  - Mechanical Power & Work
  - Pneumatic Energy & Power
- Managing Pneumatic Energy Capacity
- Power Experiment
- Pneumatics vs. Motors

Pressure - Absolute & Gage

- Pressure = matter pushing against matter
  - Object pushing against another object
- Absolute (psia) => True matter based pressure
  - 0 psia => no matter present to press against objects
  - Not too important in our designs
- Gage (psig) => Relative to Atmosphere
  - 0 psig => pressure in equilibrium with atmosphere
  - All regulators and gauges based on this

Force, Pressure & Area

- Pressure = Force / Area
- Force = Pressure X Area
- Example: 30 psig in 2” diameter cylinder

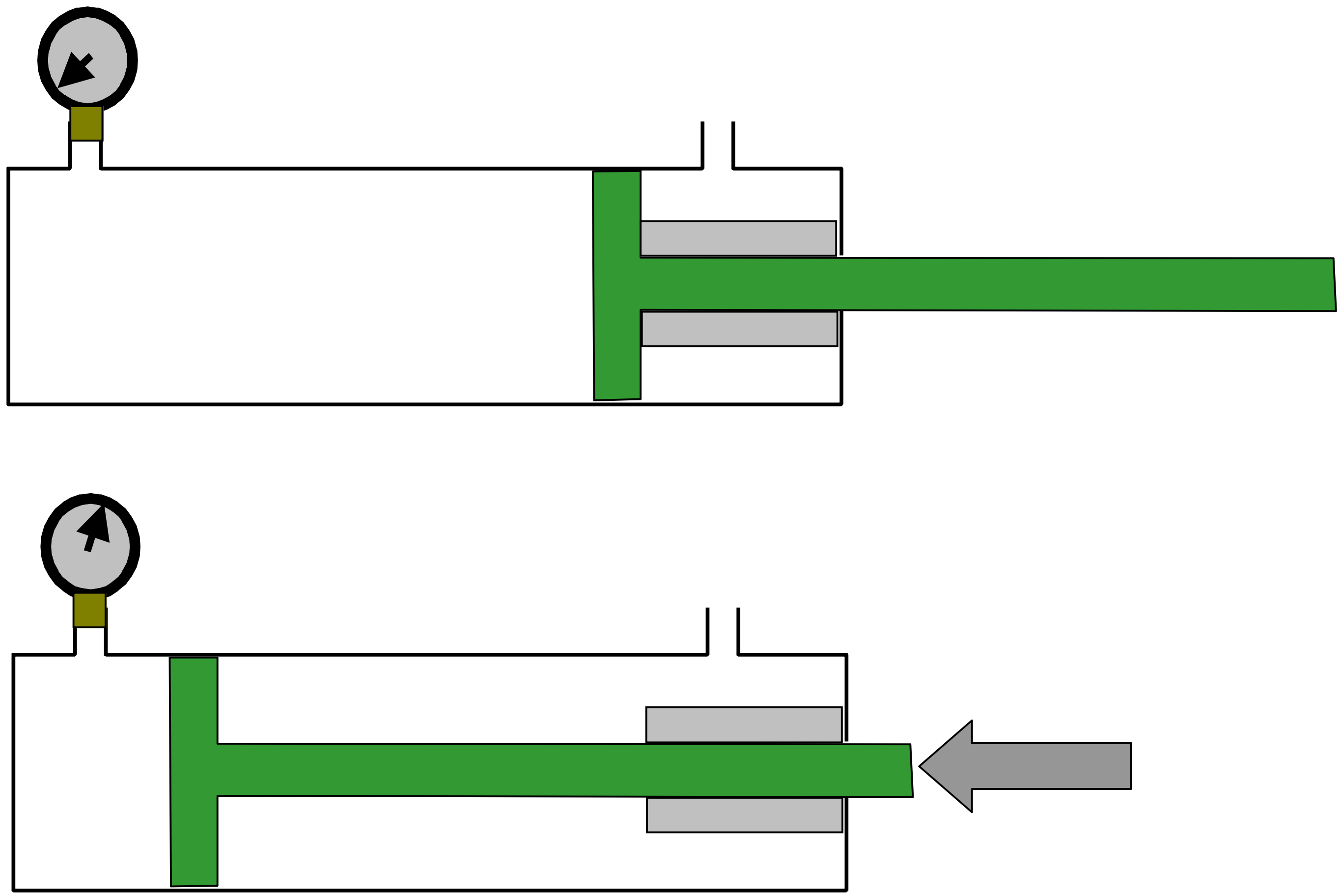


Force = 30 psi X 3.14 sq-in = 94.2 lbs

Some Basic Properties of Air

- Compressible
- Higher Pressure = Higher Friction
- Ideal Gas Law:
  - $PV = nRT$
  - Pressure is proportional to Temperature
  - Pressure is inversely proportional to Volume

Pressure & Volume



Flow Rates

- Flow rate = Volume / time
  - i.e. CFM (L/min, cu-in/sec)
- Flow Controls - Valves
  - Solenoid Value
  - Check Valve
  - Relief Valve
  - Flow Control Valve
- Unintended Flow Restrictions:
  - Narrow Passages
  - Flow Friction
  - Pressure drops while it is flowing due to restrictions

Electrical Analogy

- Pressure = Voltage
- Volume = Capacitance
- Flow rate = Current
- Flow Restrictions = Resistance

- HOWEVER: Air is compressible
  => more non-linearities than those in electrical systems

Mechanical Power & Work

- Work = Force x Distance
  - Also Work = Torque x Revolutions
  - Mechanical Energy is always involved in doing work
    - It is transferred or converted
- Power = Work / Time
  - or Energy / Time
- Power Concept
  - How far an object can be moved in a given time
  - The power rating of motors is what allows us to determine which ones can be used for a given job
- Power rating for pneumatic actuators?
  - **Depends greatly on the rest of the pneumatic system**

Pneumatic Energy & Power

- Energy = Force x Distance
  - Force = Pressure x Area
  - Distance = Volume / Area

  $\Rightarrow$ **Energy = Pressure x Volume**
  (psig x cu-in => in-lbs)

- Power = Energy / Time

  $\Rightarrow$ Power = Pressure x Volume / Time
  (Units = in-lbs)
  - Flow rate = Volume / Time

  $\Rightarrow$ **Power = Pressure x Flow rate**
  (Psig x cu-in/sec => in-lbs/sec)

PEU =
Pneumatic
Energy
Units

Managing Pneumatic Capacity

- Pneumatic Energy Capacity = Pressurized Air
  - Managing the loss and addition of pressurized air is very important

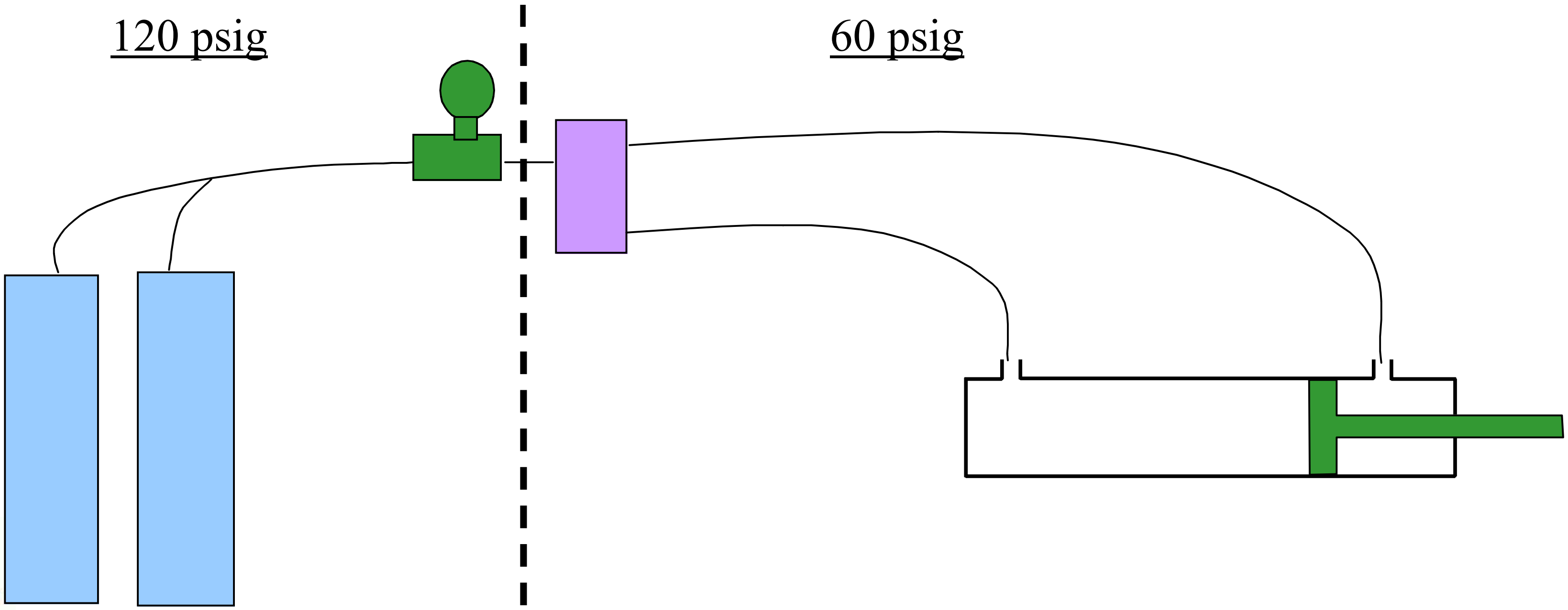
  WHY - the volume of air used in large cylinders could deplete your supply very quickly if not managed

Managing Pneumatic Energy Capacity

- Store Pneumatic Energy
  - Storage Tanks
  - Tubing, Fittings & Valves
  - Compressor
- Consume Pneumatic Energy
  - Exhaust of actuators
  - Leakage
- Add Pneumatic Energy
  - Activate compressor

Energy Capacity Example

120 PSI Side			60 PSI Side			
PEU	P	V	P	V	PEU	Tot PEU
2400.0	120.0	20.0	60.0	10.0	600.0	3000.0
1800.0	90.0	20.0	60.0	10.0	600.0	2400.0
1200.0	60.0	20.0	60.0	10.0	600.0	1800.0
800.0	40.0	20.0	40.0	10.0	400.0	1200.0
533.3	26.7	20.0	26.7	10.0	266.7	800.0
355.6	17.8	20.0	17.8	10.0	177.8	533.3



Managing Pneumatic Energy Capacity

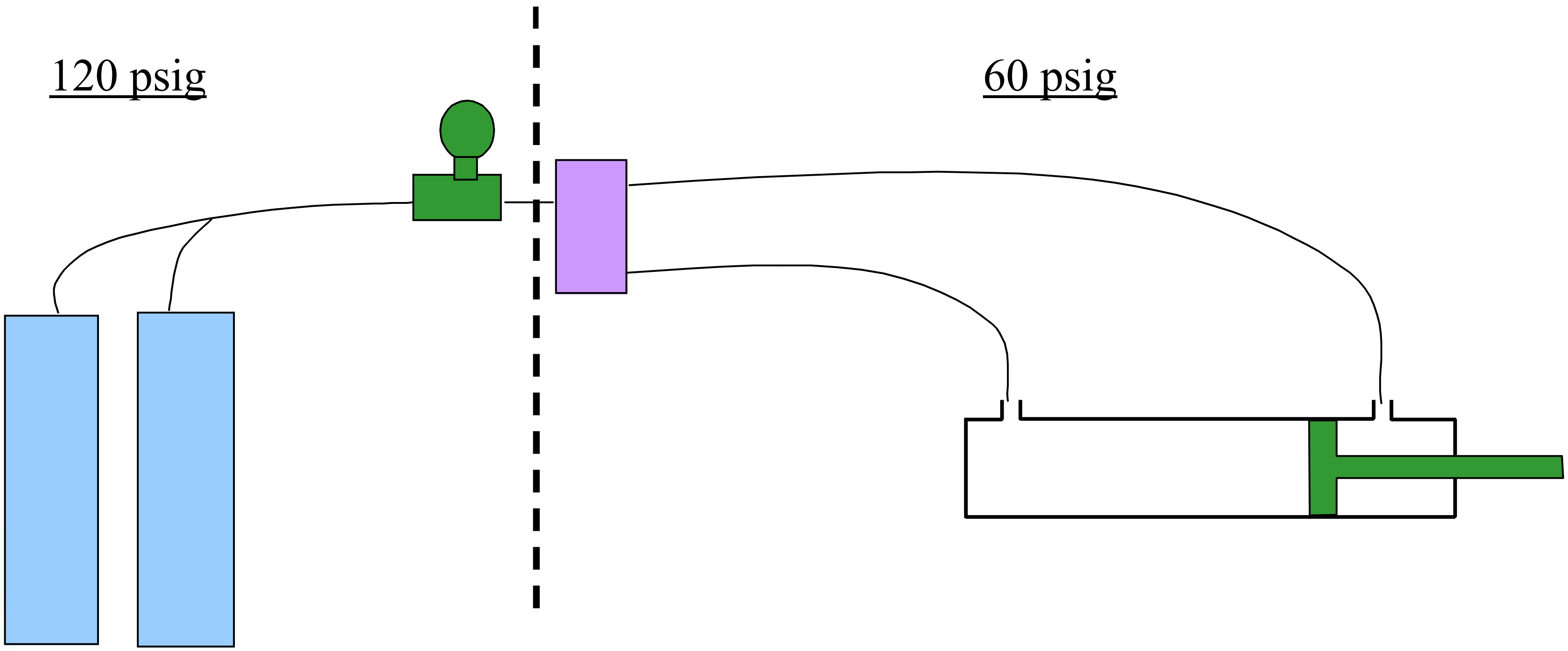
- Energy Capacity Example:
  - Storage Tanks
    - Volume = 18.85 cu-in (37.7 cu-in for 2 tanks)
    - Pressure = 120 psig

    => Energy Capacity = 4524 (2 tanks)
  - Cylinder - 2” dia x 24” stroke
    - Volume = 75.4 cu-in
    - Pressure = 60 psig

    => Energy Capacity used = 4524
- Conclusion: After 2 extensions and one contraction, the pressure in the tanks drops to less than 20 psig

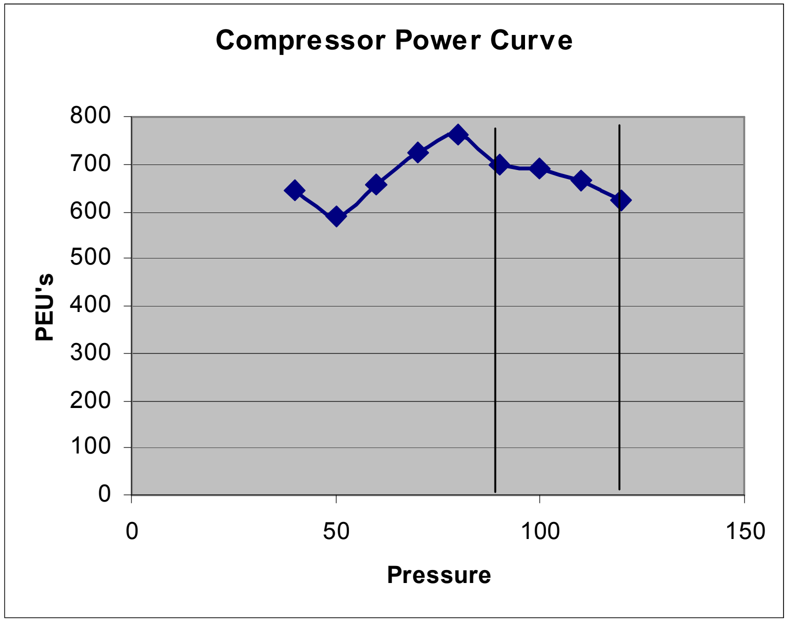
Energy Capacity Example

120 PSI Side			60 PSI Side			
PEU	P	V	P	V	PEU	Tot PEU
4524.0	120.0	37.7	60.0	75.4	4524.0	9048.0
2262.0	60.0	37.7	60.0	75.4	2262.0	4524.0
1131.0	30.0	37.7	60.0	75.4	1131.0	2262.0
565.5	15.0	37.7	7.5	75.4	565.5	1131.0
282.8	7.5	37.7	3.8	75.4	282.8	565.5
141.4	3.8	37.7	1.9	75.4	141.4	282.8



The Compressor

Pressure (PSI)	Flow Rate (CFM)	cu-in / sec	PEU/s
40.00	0.56	16.13	645.12
50.00	0.41	11.81	590.40
60.00	0.38	10.94	656.64
70.00	0.36	10.37	725.76
80.00	0.33	9.50	760.32
90.00	0.27	7.78	699.84
100.00	0.24	6.91	691.20
110.00	0.21	6.05	665.28
120.00	0.18	5.18	622.08



- Averages about 660 PEU/s in the cut out range (90 to 120 psig)

Managing Pneumatic Energy Capacity

- Energy Capacity Example - AGAIN:
  - Storage Tanks
    - => Energy Capacity = 4524 (2 tanks)
  - Cylinder - 2” dia x 24” stroke
    - $\Rightarrow$Energy Capacity used = 4524
  - Compressor can replace 660 per second
- Conclusion: It will take 6.85 seconds to replace the energy used by one activation

Managing Pneumatic Energy Capacity

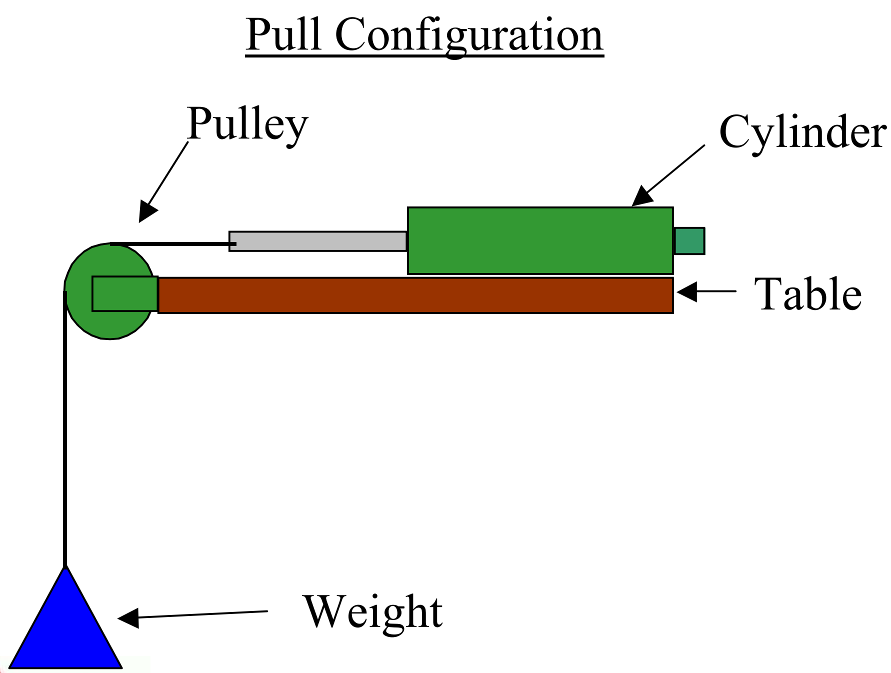
- Managing the Loss of Energy
  - Use only the amount of energy required, not too much more - WHY?
  - Minimize Volume:
    - tubing length - valve to cylinder
    - cylinder stroke
    - cylinder diameter
  - Minimize regulated pressure
    - But, keep above valve pilot pressure requirement

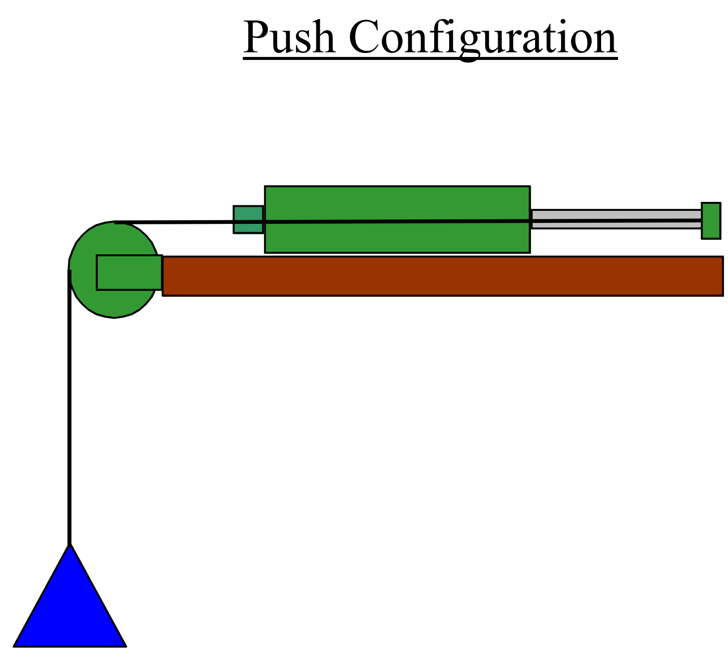
Optimize Cylinder Stroke, Diameter and Pressure

- Stroke
  - Shorter stroke => less leverage for angled movement
  - Shorter stroke => less weight for cylinder
- Diameter
  - Smaller diameter => more pressure required for same force
  - Smaller diameter => less weight for cylinder
- Pressure
  - Less pressure => need a bigger, heavier cylinder
  - Less pressure => less likely to leak

Power Experiment

- Purpose: Determine Force and Power curves for a pneumatic cylinder
- Set-up:
  - 8” stroke by 1.5” diameter cylinder
  - All data taken at 60 psig
  - Time recorded to fully extend or contract (8.0”)
    - Electronic sensor used at both ends of stroke for timing accuracy





Force Values

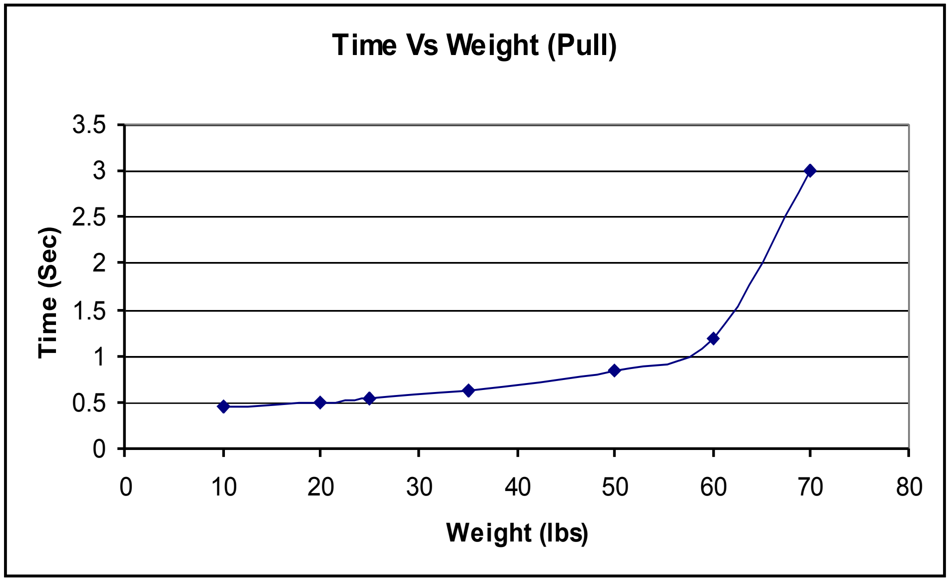
Pressure (pounds/sq. inch)	3/4" Bore Force Extended (pounds)	3/4" Bore Force Retracted (pounds)
20	9	8
25	11	10
30	13	12
35	15	14
40	18	16
45	20	18
50	22	20
55	24	22
60	26	24

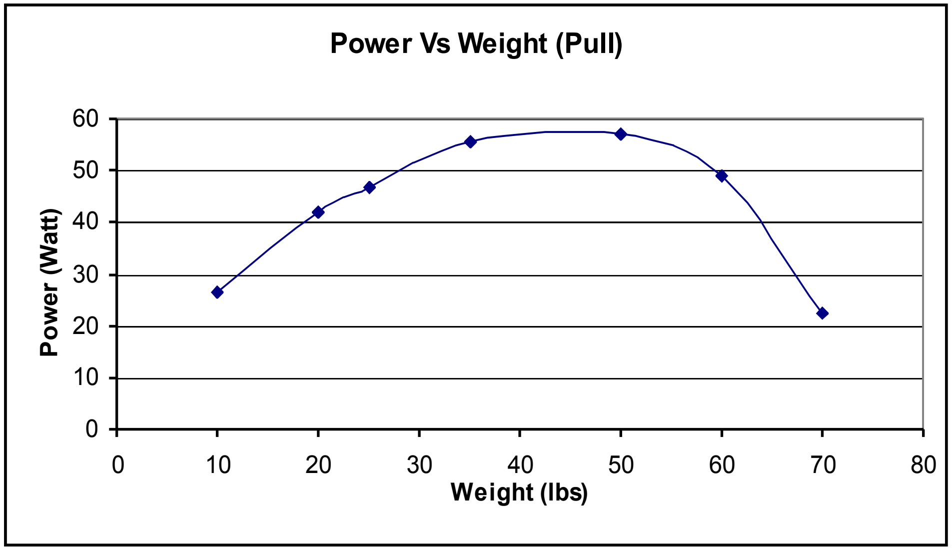
Pressure pounds/sq. inch	1-1/2" Bore Force Extended (pounds)	1-1/2" Bore Force Retracted (pounds)
20	35	32
25	44	40
30	53	48
35	62	57
40	71	65
45	79	73
50	88	81
55	97	89
60	106	97

Pressure pounds/sq. inch	2" Bore Force Extended (pounds)	2" Bore Force Retracted (pounds)
20	63	57
25	79	71
30	94	85
35	110	99
40	126	113
45	141	128
50	157	142
55	173	156
60	188	170

Pneumatic Power

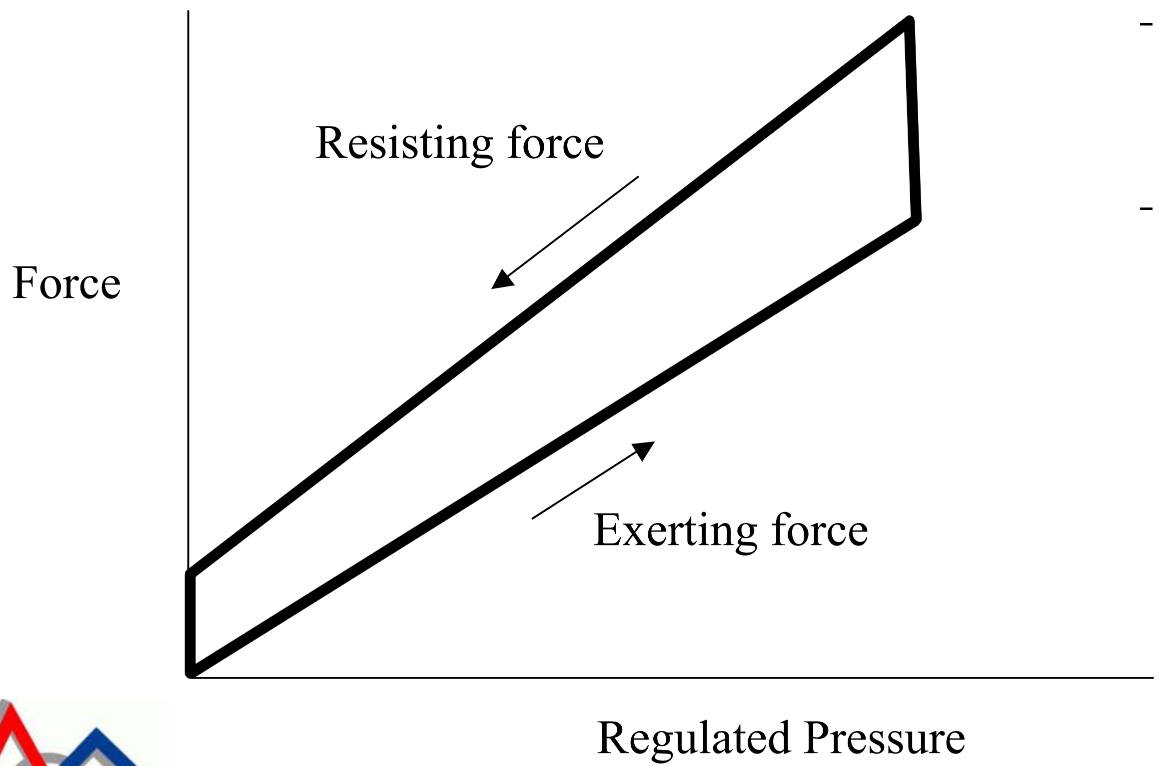
- Force versus time curve was non-linear as expected
- Experimental setup was not perfect, some variation in data expected
  - Some friction in cable system
  - Ran several times for each weight and took average
- Max force that could move was typically less than 85% of theoretical max force





Cylinder / System Hysteresis

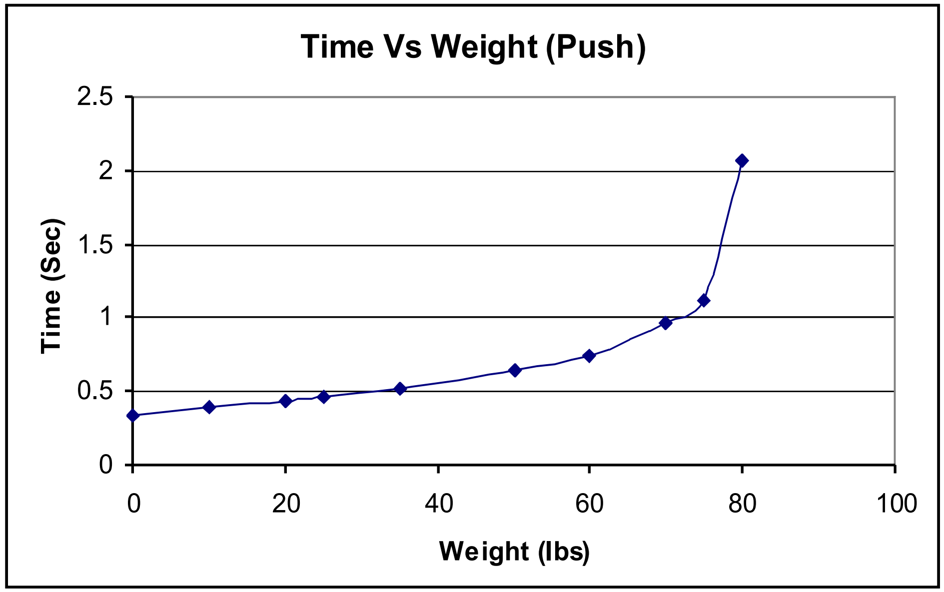
- Actuation hysteresis is very pronounced due to:
  - Internal cylinder friction
  - Non-linear behavior of flow through delivery system

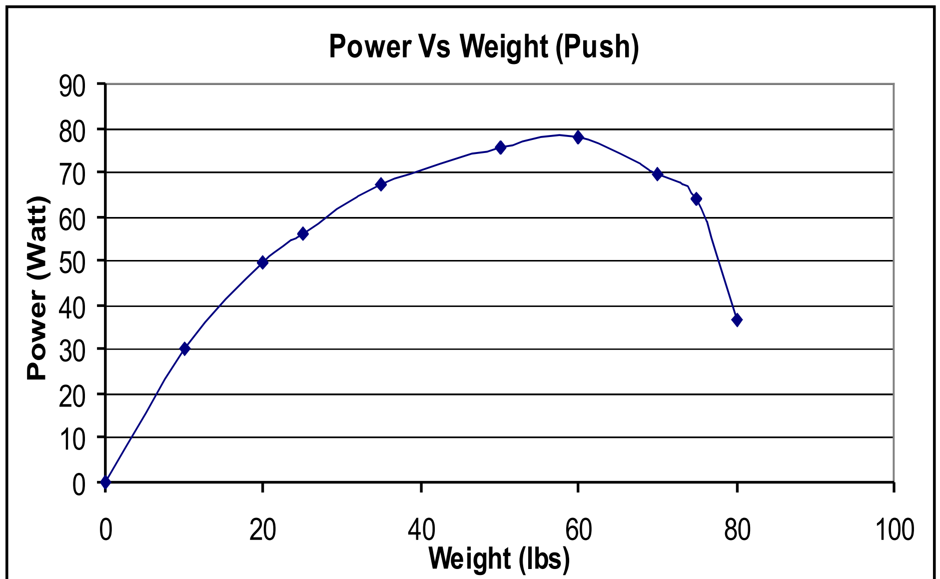


- This can be bad, cannot move objects at rated force - design for this
- This could be good, if leakage occurs and pressure drops slightly, the cylinder will still hold

Pneumatic Power

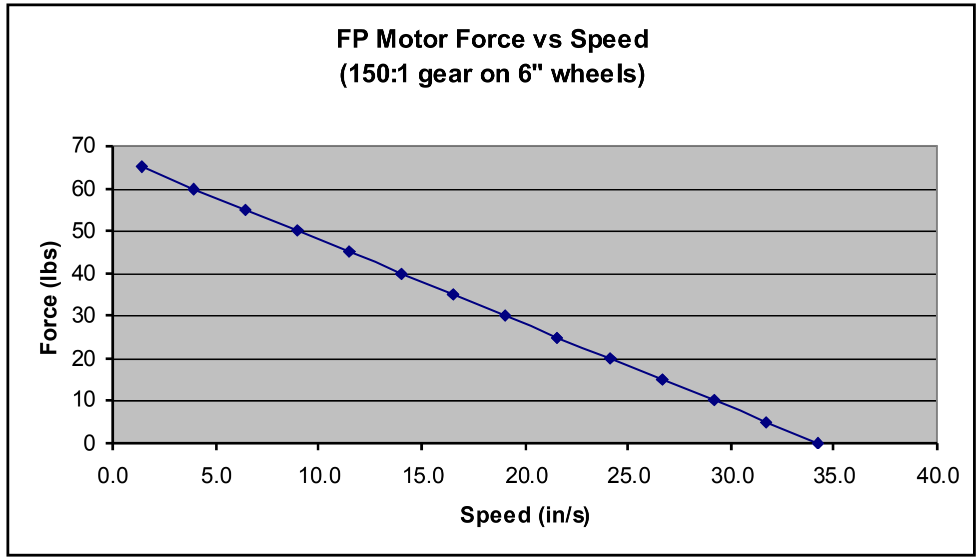
- This pneumatic cylinder systems is not as powerful as better motors in our KOP
  - 1.5” cylinder ~= 80 watts
  - FP motor ~= 171 watts
  - CIM motor (small) ~= 337 watts
- How do we deal with non-linear behavior?
  - Design for the max force to occur before the “knee” in the curve

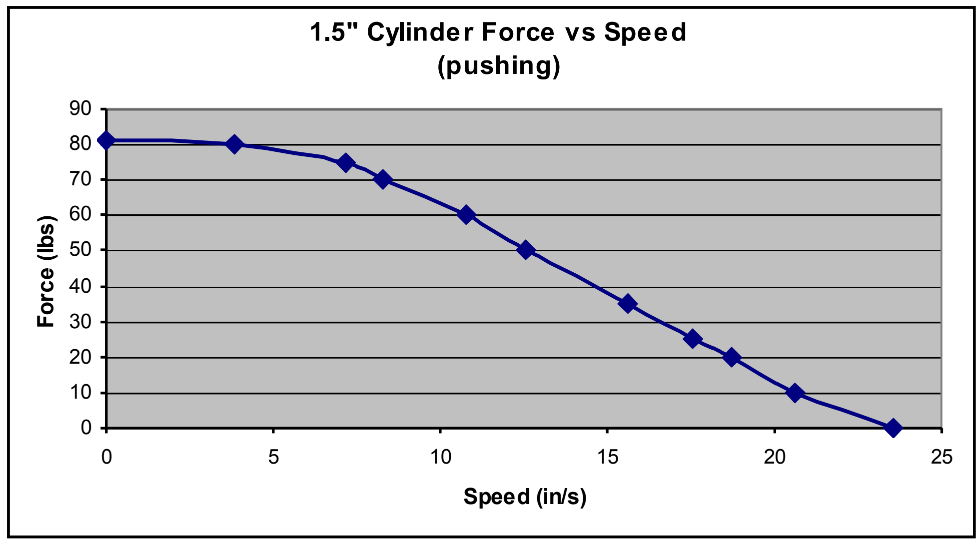




Cylinders vs. Motors

- Force versus speed curve is linear for DC Motor system; non-linear for the Pneumatic system





Pneumatics vs. DC Motors

Some, but not all important differences

- You are allowed to use as many cylinders as you like
  - However, you are limited in the types and sizes of cylinders allowed
  - You are limited to the KOP Motors
- Most of what you need for the pneumatic system is provided in the KOP or easily ordered

- Motors have to be geared to produce the desired forces
  - Cylinder size can just be picked for the forces you need
- Pneumatics are best suited for linear motion
  - Motors are best suited for angular motion

Pneumatics vs. DC Motors

Some, but not all important differences

- Our ability to control the position of mechanisms actuated by cylinders is very limited
  - We are not given integrated, dynamic airflow or pressure controls
  - We are given much more versatile electronic controls for motors
- Cylinders can be stalled without damage to the pneumatic system
  - Motors will draw large current and let out the magic smoke
- Cylinders absorb shock loads rather well and bounce back
  - However, be careful of over pressure conditions caused by flow control valves
- Motors have to be actively held with feedback controls or locked

Pneumatics vs. DC Motors

Some, but not all important differences

- Cylinders use up their power source rather quickly
  - The 4 air tanks we are allowed do not hold much work capacity
  - Motors use up very little of the total capacity of the battery
- The decision to use Pneumatics
  - The initial investment in weight is great - mostly due to compressor
  - Otherwise, very limited air capacity if leave compressor off robot
  - Once invested use for as many applications as feasible
    - Easy to add more functionality
- Cylinders used with single solenoid valves are great for Armageddon devices - stuff happens when power is shut off
  - This could be good or bad - use wisely