MATH
PHYSICS
ENGINEERING

HOBBYIST

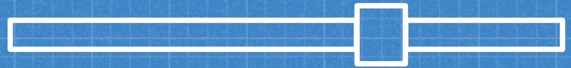
Air cannon fundamentals
&
Optimized barrel length

OBJECTIVE

To create a hypothetical homemade cannon out of appropriately rated PVC pipes and components.

- Projectiles will be potato like in terms of mass, size and shape.
- Achieve a projectile exiting velocity between 75-100 m/s (246-328 ft/s).
- Maximum pressure will be 820 kPa (120 PSI) – Check components rating for the build!.
- Barrel length and pressure chamber size will be optimized.

CANNON' SOURCE OF ENERGY



Combustion	
Pros	**Cons**
• BOOM is cool • No valve is needed	• Unreliable stoichiometry • Availability of fuel

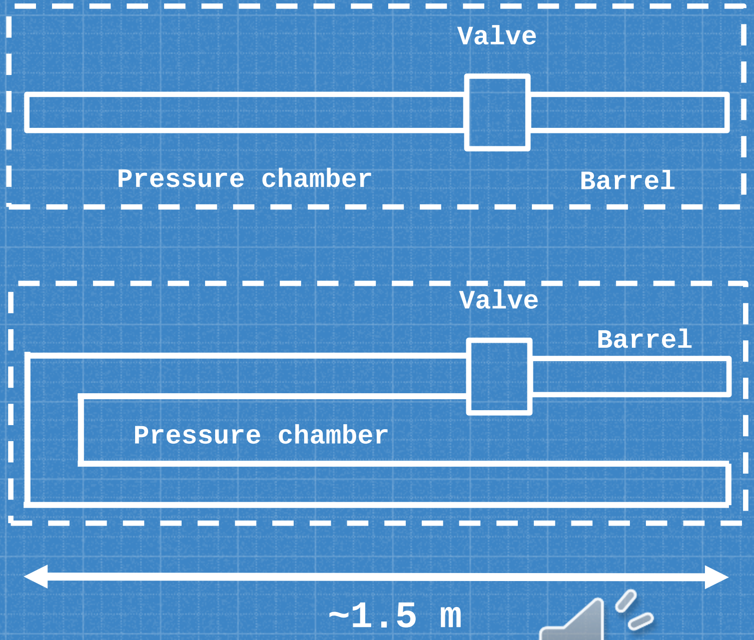
Pressurized air	
Pros	**Cons**
• Availability of fuel • Reliable pressure	• Pressurizing air takes time • Opening time of the valve is key

Dry ice	
Pros	**Cons**
• Dry ice is cool *(get it?)*	• Availability of fuel • Opening time of the valve is key

Combustion + Pressurized air	
Pros	**Cons**
• BIG BOOM is cooler than BOOM	• Outright dangerous and scary • Stronger materials for extra safety

Overall shape for the pneumatic cannon

- Total length ~1.5 m (590 in).
- Barrel diameter 50 mm (1.96 in).
- Ergonomic to be aimed from the hip.
- Pressure chamber to barrel volume ratio is TBD.



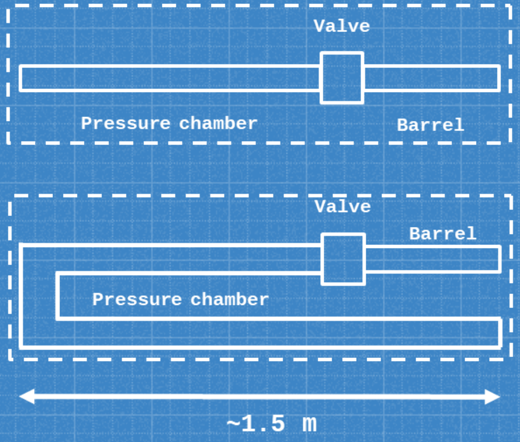
Sizing the pressure chamber and barrel length
Problem description and simplifications

So long as $P_c > P_{atm}$, the projectile will keep accelerating towards the exit.

Ideally the barrel is long enough to allow the pressure chamber to reach P_{atm}.

To find the appropriate size I will assume:

- The projectile works as a perfect seal.
- No friction projectile-barrel ($F_{f1} = \mu N = 0$).
- No friction projectile-air ($F_{f2} = c\dot{x} = 0$).
- Adiabatic expansion of the air.
- Air is an ideal gas ($\frac{C_p}{C_v} = 1.38$).
- No losses in pressure due to bends and such.
- <u>*Cows are spherical.*</u>



Sizing the pressure chamber and barrel length
Modeling the problem

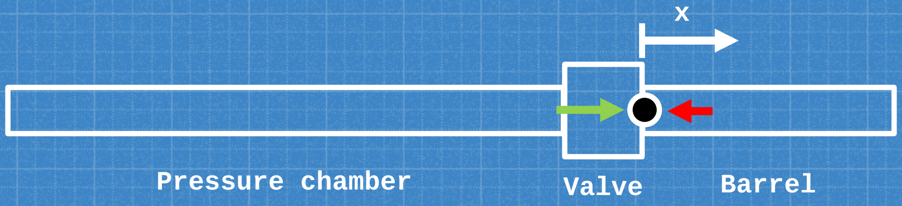
$$\sum F_x = m\ddot{x}$$

$$F_{atm} = -A_b P_{atm}$$

$$F_{exp} = +A_b P_{exp}$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma \rightarrow P_2 = \frac{P_1 V_1^\gamma}{V_2^\gamma} \rightarrow P_{exp} = \frac{P_i V_c^\gamma}{V_{exp}^\gamma} \left\{ V_{exp} = V_c + A_b x \right\} \rightarrow P_{exp} = \frac{P_i V_c^\gamma}{(V_c + A_b x)^\gamma}$$

$$\frac{P_i V_c^\gamma}{(V_c + A_b x)^\gamma} A_b - P_{atm} A_b = m\ddot{x}$$

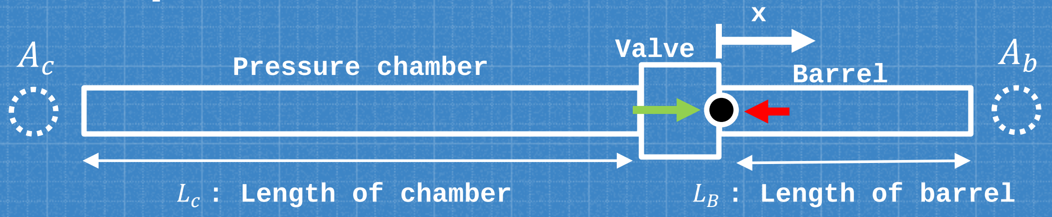


m : Mass of projectile	x : Projectile's position
$\dot{x}$: Projectile's speed	$\ddot{x}$: Projectile's acceleration
A_b : Cross section of barrel	P_{atm} : Atmospheric pressure
P_{exp} : Expanding gas's pressure	V_c : Chamber's volume
P_i : Initial chamber pressure	γ : Adiabatic expansion coefficient

NOTE: Remember to use absolute pressures for these calculations.

Sizing the pressure chamber and barrel length
Solving the differential equation

$$\ddot{x} = \frac{\frac{P_i V_c^{\gamma}}{(V_c + A_b x)^{\gamma}} A_b - P_{atm} A_b}{m}$$



Numerical solution

Discretization of the problem in steps with constant acceleration

$$\dot{x}_{i+1} = \ddot{x}_i \Delta t + \dot{x}_i$$

$$x_{i+1} = \frac{1}{2}\ddot{x}_i \Delta t^2 + \dot{x}_i \Delta t + x_i$$

Boundary conditions

$\dot{x}_0 = 0$ & $x_0 = 0$

NOTE: Remember to use absolute pressures for these calculations.

Sizing the pressure chamber and barrel length
Results from the differential equation

$$\ddot{x} = \frac{\frac{P_i V_c^{\gamma}}{(V_c + A_b x)^{\gamma}} A_b - P_{atm} A_b}{m} \quad \{\dot{x}_0 = 0\,;\ x_0 = 0\}$$

P_i = 820000 + 101325 Pa *(relative pressure + 1 atm)*. Check components rating!.

A_b = 0,001963 m^2 *(50mm diameter tubes)*.

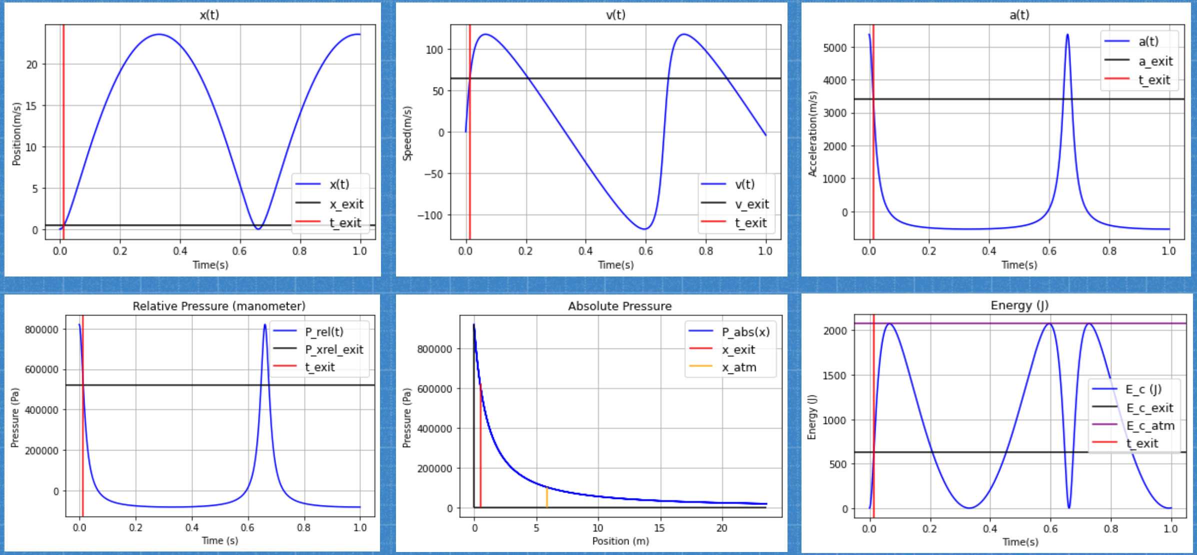
m = 0.3 kg.

I will solve this equation for different values of

- length of the chamber (L_c) which determines the volume of the pressurized tank ($V_c = L_c A_c$) and therefore the potential energy stored in the system.
- length of the barrel (L_b) which determines the exit point for the projectile where it will stop acquiring energy from the pressure chamber.

NOTE: Remember to use absolute pressures for these calculations.

Sizing the pressure chamber and barrel length
Results from the differential equation
L_c = 1.5m & L_b = 0.5m



RESULTS	
Exit velocity	65 m/s
Exit energy	630 J
System's exergy	2074 J
Energy efficiency w.r.t. exergy	30%
Total energy of the compressed gas	7140 J
Energy efficiency w.r.t. energy	8%
I could increase the length of the barrel and reduce the chamber.	

NOTE: Remember to use absolute pressures for these calculations.

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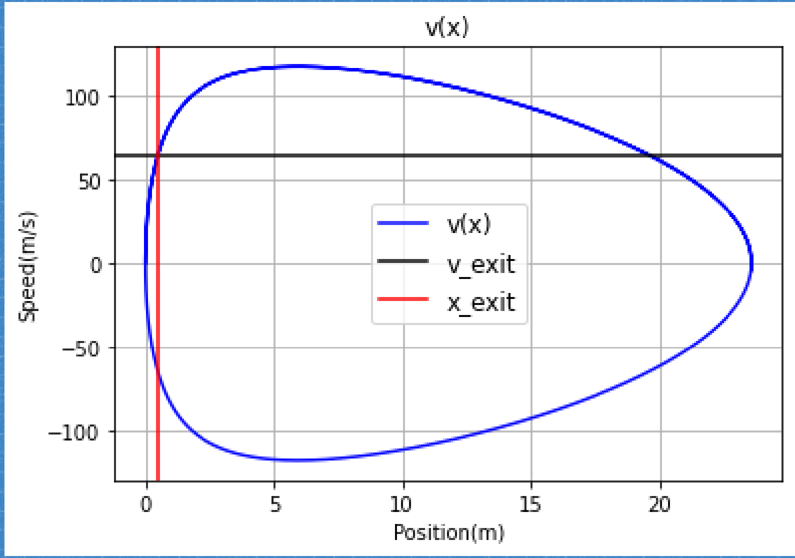

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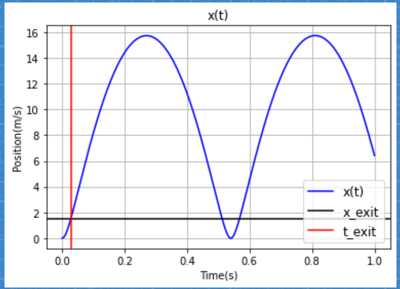
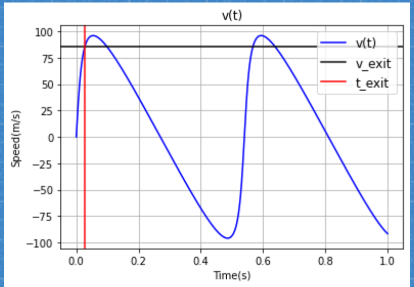
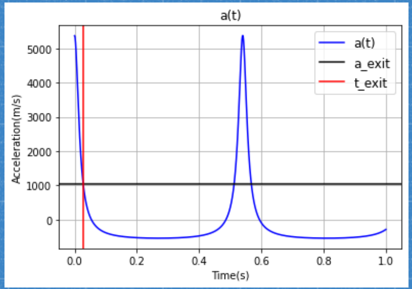
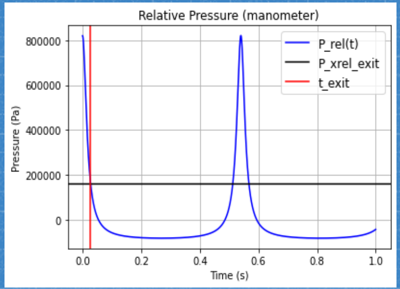
Sizing the pressure chamber and barrel length
Results from the differential equation

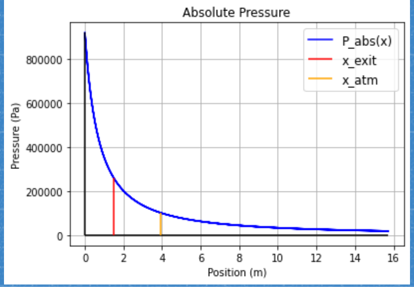
L_c = 1m & L_b = 1.5m

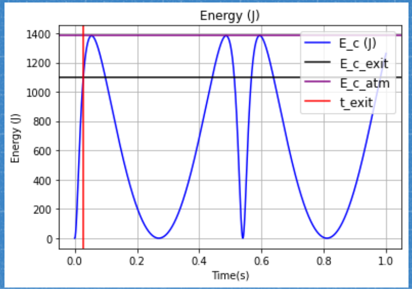










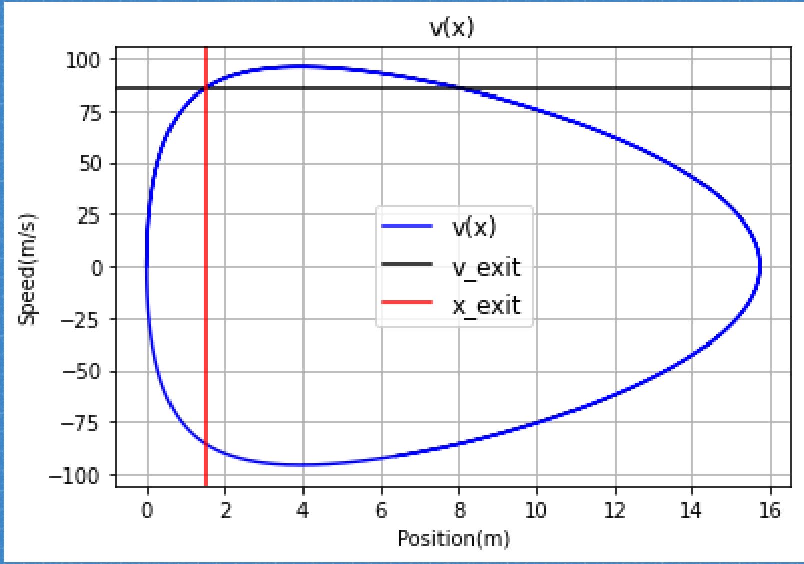


RESULTS	
Exit velocity	85 m/s
Exit energy	1098 J
System's exergy	1382 J
Energy efficiency w.r.t. exergy	79%
Total energy of the compressed gas	4760 J
Energy efficiency w.r.t. energy	23%
More efficient use of energy to achieve about the same exiting speed as before. Smaller pressure chamber means less energy → Less pumping and safer	

NOTE: Remember to use absolute pressures for these calculations.

Sizing the pressure chamber and barrel length
Results from the differential equation

L_c = 1m & L_b = 1.5m



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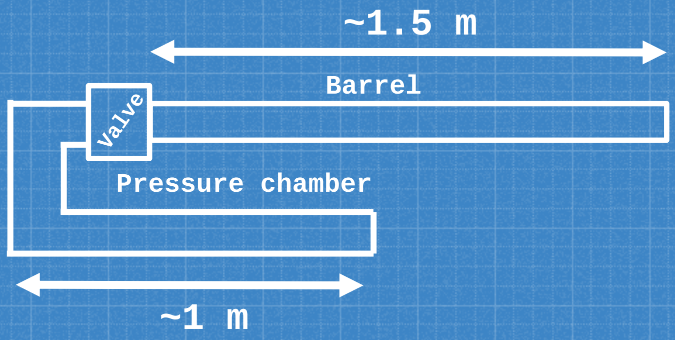
Final concept for the pneumatic cannon



Characteristics		
MAX pressure (Check components!)	820 kPa	120 PSI
Exit velocity (m≈0.3kg)	85 m/s	279 ft/s
Exit energy	1098 J	-
System's exergy	1382 J	-
Energy efficiency w.r.t. exergy	79%	-

Related recommended videos

Channel	Video	Thumbnail	Comments
Hardware Unknown	How to Make a Simple Air Cannon		Straight to the point. Clear instructions & materials used. Modified sprinkler valve for improved flow. Emphasis on safety instructions when handling it.
Pneumatic launcher (aka "Air Cannon")	Halfmoon TechLabser (aka "Air Cannon")		Build of a U-shape cannon to have a bigger pressure chamber. It keeps the original solenoid from the sprinkler valve.
Woods2Table	DOES BARREL LENGTH MATTER for a Bait Cannon??? How to get the MAXIMUM DISTANCE for a BAIT CANNON!		Actual empirical tests to check the distance travelled by the projectile as a function of the length of the barrel for a given system *(pressure chamber size, diameter of the cannon, initial pressure of the system, etc.)*. Remember: “In theory, theory and practice are the same. In practice, they are not.”

Thanks!

Now let’s engage in some interesting conversation in the comments section.