

A Method for Selective Hornet *Vespa Velutina* Baited Traps Using a Compressed Air Cannon

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The efficiency and selectiveness of baited traps to control the invasive hornet *Vespa velutina* has been often questioned. Recent studies show that capture of *Vespa velutina* accounted for less than 1% of all captures, reflecting the extremely low selectiveness of the method. Here, a novel technique for selective capture of *Vespa velutina* in baited traps is outlined. The concept is based on the use of a compressed cannon air driven by an air-cartridge. In this technique, when the insect, attracted by the bait, is crossing the front of the air canon, a prompt signal is triggered and then the insect receives an instantaneous air-shot. The air shot will propel the insect away from the cannon in a quasi-rectilinear trajectory. By a proper design of a cavity located in front the cannon it is possible to allow that bees and other insects of similar size can pass through the cavity but at the same time blocking the pass of the bigger *Vespa velutina* which after bouncing against the surrounding walls will fall into the bait. Utilizing a simplified physical and geometrical model, preliminary calculations for the air cannon- cavity system were derived. Additional R&D is required in order to arrive at a reliable practical and safe design.

Keywords. control, *Vespa velutina* in Europe, baited Traps for *Vespa velutina*

I. INTRODUCTION

The efficiency and selectiveness of baited traps to control the invasive hornet *Vespa velutina* is often questioned. In a recent study, (2018), [1], sponsored by the European Framework Programm for research and Innovation (H20H20) several traps and baits in a full factorial design were tested in order to prove their selectiveness and impact on nontarget insects. The results were self-explanatory: *Vespa velutina* accounted for less than 1% of all captures, reflecting the extremely low selectiveness of the method, and then a call for the need for improving both attractants and trap designs was urgently lunched. Invasive non-native *Vespa velutina* in Europe represent a significant threat to the endemic insect fauna and the biodiversity,[2]-[10].

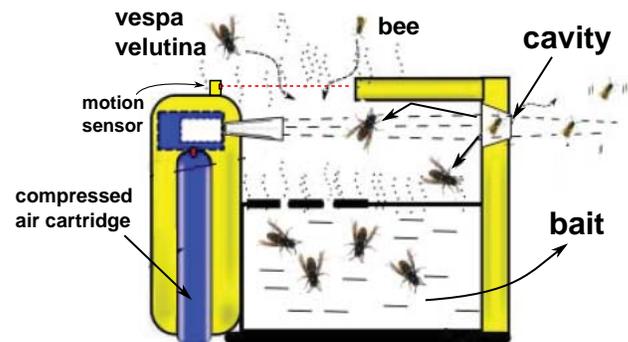


FIG. 1: Sketch of the core idea for selective separation of bees and *Vespa velutina* assisted by a compressed air cannon.

A. state-of-the-art for *Vespa velutina* control

Today, although there are many different proposed techniques for *Vespa velutina* control, e.g., spring queen trapping, poisoned baits, bucket poisoned bait, poisoned skewer, beehive muzzle, rackets, nest gunshot destruction, electric traps, pheromone traps, electric harps, just to name a few, however, all these techniques can be catalogued more or less into two main categories, [11],

namely, those who would affect *Vespa velutina* nest larvae, (nest localization, poisoned baits, biological control, DNA technology) and those who can only affect hornet workers (rackets, all traps, muzzles, etc.). For the interested reader on techniques for *Vespa velutina*, it is recommended the recent up-to-date review [11].

As regard traps (either commercial or home-made), they are based in the use a vessel, box, or dome with one or more entrances that hinder the exit of insects and a chamber where they die of exhaustion and/or drowning. On the other hand, baits consists mainly of sugary or protein substances attractive to social vespids or chemical compounds similar to the volatile released

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by fruits or animals in decomposition, with an alcoholic component added as a repellent for honey bees, [12], [13]. The specific characteristics of the traps and the type of baits as well as diverse environmental factors can influence the effectiveness and selectiveness of trapping campaigns.

The search for methods to endow current commercial baited traps with selective performance, led the group of fluid mechanics at the University Polytechnic of Catalunya (UPC) to explore possible aerodynamic new techniques based in the different sizes between common bees and the *Vespa velutina*. Although the different size between the common bee and the *Vespa velutina* for selective capture has been proposed in the past other techniques (electric traps and/or electric harps, [11]), however those techniques require grid and wire systems mostly intended to be near the hives. Here, by aerodynamic technique is understood a technique which imply the use of induced currents of air which can translate into a different magnitude of some of the aerodynamic magnitudes as for example, the drag, lift or inertial forces acting on the insect.

Among theses aerodynamic techniques, inertial impaction or also known as aerosol impaction was studied. In this technique particles can be removed from an air stream by forcing the air to make a sharp bend. Particles above a certain size possess so much momentum that they can not follow the air stream and strike a collection surface. This technique although a priori could be interesting for the case of *Vespa velutina*, nevertheless it was found unsuitable because the large sizes involved in the bodies to be separated (around centimeters) and then resulting in very large Stokes numbers for both the common bee as and the *Vespa velutina* which translate into the impossibility to use the technique for selective capture unless the impactor has prohibitive dimensions. However, it was found a technique not yet been explored, as far as the authors know, which is conspicuous by its simplicity, economy and robustness. This technique is based in the use of a simple -almost home-made, compressed air cannon driven by a simple cartridge as will be explained in the next sections.

II. STATEMENT OF THE CORE IDEA

To begin with, consider a system composed by a simple compressed air cannon driven by a pressurized air cartridge which is able to release a prompt shot of compressed air initially contained in a small chamber which open after receiving a signal from a motion sensor (e.g., photovoltaic, laser, capacitor, etc.) when an insect is crossing the front of the cannon (see Fig. 1).

On the other hand, just in front of the cannon there is a cavity or hole with a certain diameter. The idea is to allow -by the proper design of the cannon and the dimensions of the cavity, that only insects with a

certain dimension (the effective diameter of the insect) be able to pass through the cavity. The actual shape, and physical model used in the next analysis are shown in Fig. 2.

First, consider that at certain time, say, $t = 0$ a common bee with an effective diameter Φ_b is being attracted by a certain bait and suppose also that during the travel, the bee generate a trigger signal when is crossing a motion sensor. This signal open the main valve of the air cannon and then a certain volume V_o of compressed air at a pressure, say, P_o is promptly discharged. As a result, the air-shot gives an initial horizontal velocity v_o to the bee. After that, the bee -with an initial velocity v_o , will start to be decelerated because the air drag force until after a certain traveling time t arrives at a cavity located at a distance, say, L in front of the cannon and with a diameter D . Now, to stay in the conservative and safe side of the calculations, let us assume that at the moment the bee receives the air-shot, the bee is able to react with an infinite acceleration and then attaining the maximum full speed which the bee is able to attain, let us call this velocity as v_b .

Bearing in mind this simple scheme, we can proceed with certain calculations as follows.

The differential equation for the motion of the bee is given by equating the force with the air drag force

$$m_b \frac{dv}{dt} \approx - \frac{c_d A_b \rho_a v^2}{2} \quad (1)$$

where m_b is the mass of the bee; c_d is the drag coefficient; A_b is the effective cross section area of the bee; ρ_a is the density of the air. In Eq.(1) it was considered that $v_o^2 \gg v_b^2$ and a result only the horizontal drag force is considered. Taking into account that the mass of the bee as well as the cross section area may be expressed as a function of the effective diameter of the bee Φ_b , as $m_b = \frac{\pi \rho_b \Phi_b^2}{6}$ being ρ_b the density of the bee, and $A_b = \frac{\pi \Phi_b^2}{4}$, then, Eq.(1) can be rewritten as

$$\frac{dv}{v^2} = - \frac{3 \rho_a c_d}{4 \rho_b \Phi_b} t \quad (2)$$

which after integration one obtains

$$\frac{1}{v(t)} = \frac{3 \rho_a c_d}{4 \rho_b \Phi_b} t + \frac{1}{v_o} \quad (3)$$

where at $t = 0$ the horizontal velocity of the bee is the velocity impressed by the air-shot, i.e., $v(0) = v_o$. By integrating Eq.(3) between $x = 0$ and $x = L$, i.e., the total traveling length (see Fig. 2), we obtain the traveling time as

$$t = \frac{4}{3} \frac{\rho_b \Phi_b}{\rho_a c_d v_o} \left[\exp^{\frac{3 \rho_a c_d L}{4 \rho_b \Phi_b}} - 1 \right] \quad (4)$$



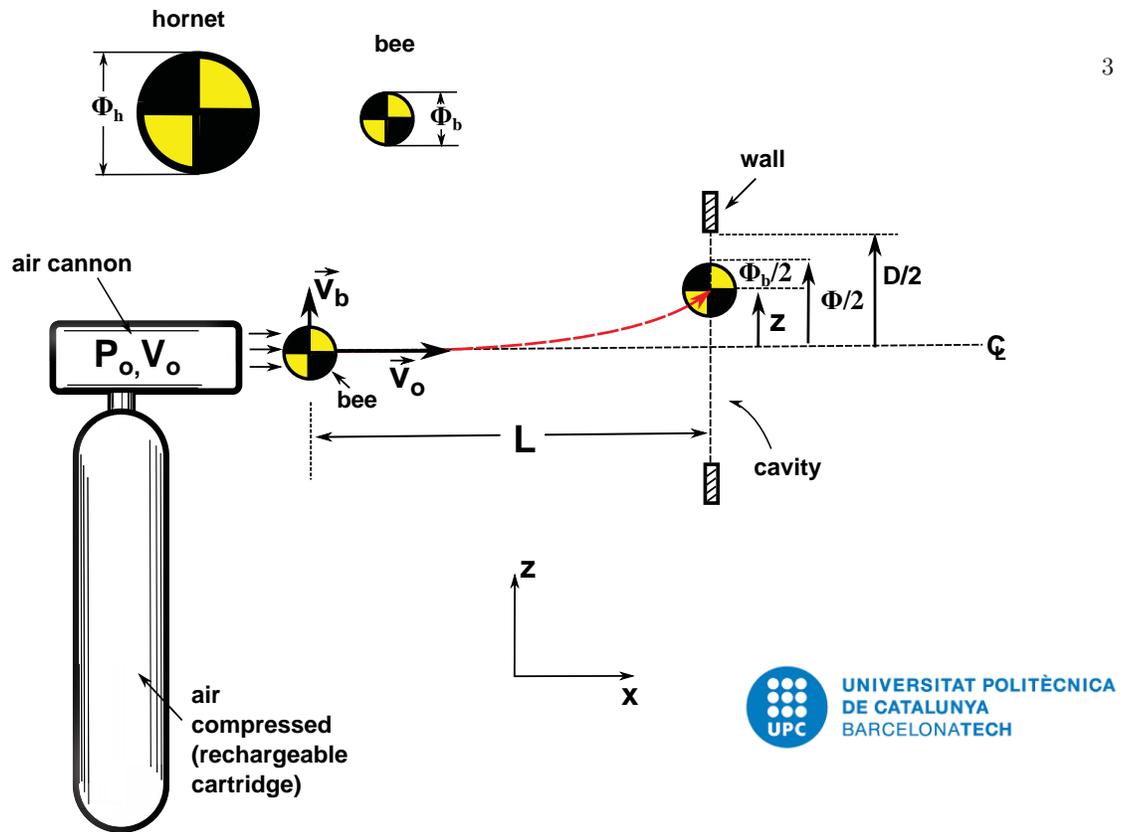


FIG. 2: Physical model and sketch of a simple compressed air cannon for selective capture of *Vespa velutina*. In this, a pulse of compressed air from a mini air cannon is shot when the insect is in front of the cannon (triggered by the signal from a sensor of motion, e.g., laser, capacitance, photovoltaic, etc). As a result, the insect is propelled away from the cannon with a certain initial velocity and in a quasi-rectilinear trajectory towards a cavity located just in front of the cannon. By proper design of the cannon and the dimensions of the cavity, it is possible promote that only common bees and insects of similar size be able to pass through the cavity. Hornets, however, will be unable and then will bounce against the walls and finally fall into the bait.

On the other hand, the total vertical distance traveled by the bee is given by $z = v_b t$ where v_b is as mentioned before, the maximum velocity attained by the bee (assuming an instantaneous reaction of the bee). Then taking into account Eq.(4), the vertical distance traveled is given by

$$z = \frac{4}{3} \frac{\rho_b \Phi_b}{\rho_a c_d v_o} \left[\exp \frac{3 \rho_a c_d L}{4 \rho_b \Phi_b} - 1 \right] \cdot v_b \quad (5)$$

Finally the total vertical distance of the bee from the center of the cavity $\frac{\Phi}{2}$ (see Fig. 2), is the vertical distance traveled z plus the effective radius of the bee, i.e., $\frac{\Phi}{2} = z + \frac{\Phi_b}{2}$, which taking into account Eq.(5) gives

$$\Phi = \left[1 + \frac{8}{3} \frac{\rho_b v_b}{\rho_a c_d v_o} \left[\exp \frac{3 \rho_a c_d L}{4 \rho_b \Phi_b} - 1 \right] \right] \cdot \Phi_b \quad (6)$$

The condition for selective capture is that the diameter of the cavity, D fulfill de following relationship

$$\Phi < D < \Phi_h \quad (7)$$

where Φ_h is the effective diameter of the hornet *Vespa velutina*. With this dimension, only insects

with a size equal or less than the bee will be able to pass through the cavity but *Vespa velutina* will be unable owing to its larger size (common bees are ≈ 1.5 cm in comparison with the ≈ 3 cm of the *Vespa velutina*).

• Discussion

To obtain some idea of the curves predicted by Eq.(7), we assume some typical values of the parameters: an average insect density $\rho_b = 800 \text{ kg/m}^3$, [15]; air density $\rho_a = 1.25 \text{ kg/m}^3$; a full speed velocity for a bee $v_b \approx 2 \text{ m/s}$; an effective diameter for the bee $\Phi_b = 1.5 \text{ cm}$, and the hornet $\Phi_h = 3.5 \text{ cm}$; a drag coefficient $c_d = 0.5$ which seems acceptable considering the range in the Reynolds numbers \mathbf{Re} : $10^3 < \mathbf{Re} < 10^4$. The resulting curves are shown in Fig. 3 for several values of the length L . It is seen that for practical lengths from 5 cm or higher - and then allowing a certain minimum open room between the environment and the bait as schematically shown in Fig. 1, the minimum velocity required by the air-shot is around 10 m/s. It can be seen also that when the velocity increases, the size of the cavity tends to be equal to the diameter of the bee, which is easy to grasp meaning that the departure from a perfect rectilinear trajectory caused by the bee will be negligible inas-

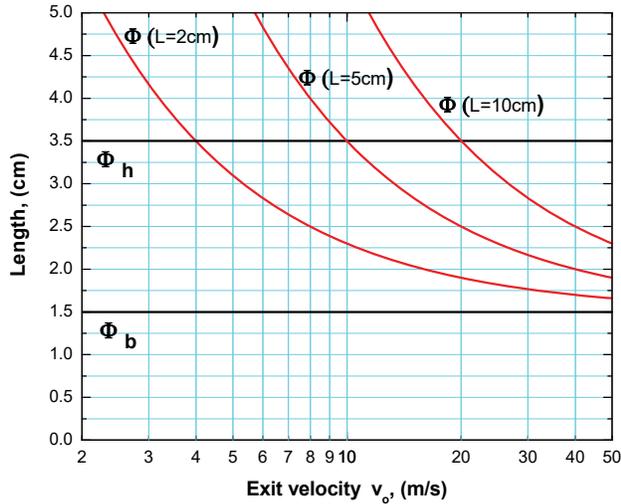


FIG. 3: The diameter of the cavity D as function of the velocity of the air-jet and some values of the length path.

much that the velocity of the horizontal velocity is higher.

A. Cannon air conditions

From Fig. 3 we are able to find the required exit velocity v_o which must be generated by the air shot from the cannon air. In this Figure, we are deducing that from a practical design with $L \geq 5$ cm, approximately a velocity around 10 m/s will be required. We need to know now the condition in which a mini compressed air cannon can attain such a velocity, which may be reckoned as follows.

In Fig. 4 it is shown the most simple working sequence of an air cannon system which is basically composed by a small chamber at a certain pressure P_o and volume V_o connected to a compressed air cartridge acting as a reservoir of air which, of course, must be always at higher pressure than P_o if the cartridge must supply air to the chamber. The chamber is closed by a valve which is triggered by a sensor of motion (e.g., laser, photovoltaic, capacitor, etc.) as is illustrated in Fig. 4. Initially, the chamber with volume V_o is full of compressed air at pressure P_o and with the main valve closed (1); then, when the bee is approaching, a prompt signal is triggered just before the bee is in front of the cannon (2); by the time the bee is in front of the cannon she receives the instantaneous push of air (3); after that, the main valve is closed and at the same time a small valve connecting the air cartridge reservoir of high pressure with the chamber allows the refill of the chamber to its initial pressure P_o . The cartridge with an initial pressure $P > P_o$, is losing a certain amount of pressure

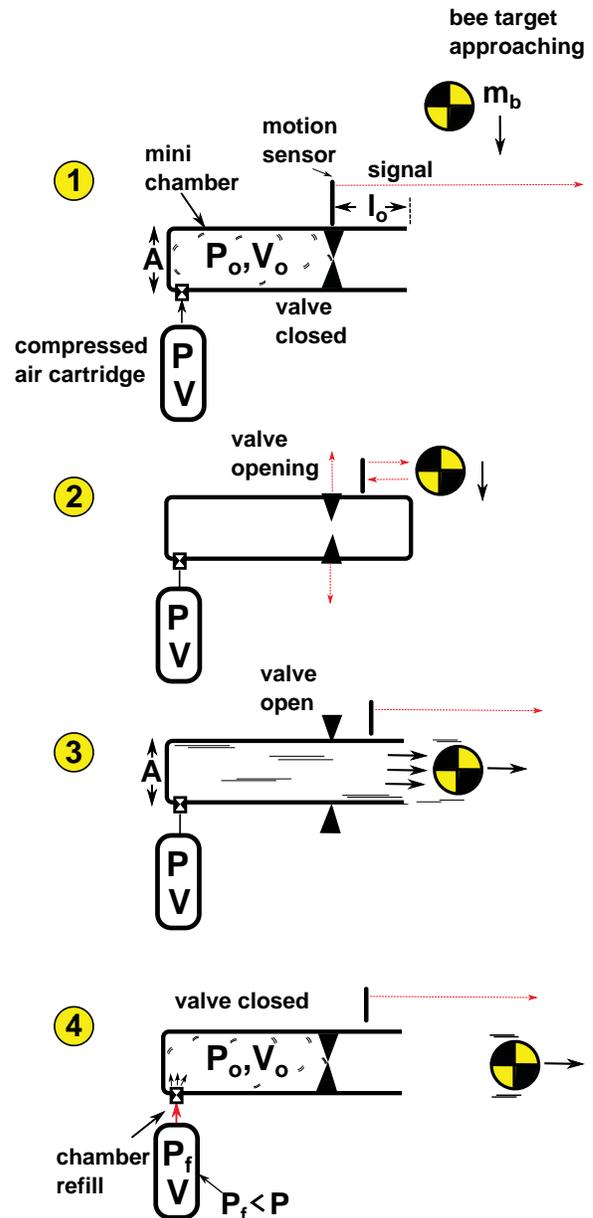


FIG. 4: Simple physical model for a mini compressed air cannon.

because the refilling of the chamber, and then the cycle can be repeated until the pressure of the cartridge drops to the pressure of the chamber P_o at which time will be unable to refill the chamber anymore and the cartridge must be refilled with compressed air or replaced.

With this simple sequence we can do preliminary calculations on the pressure P_o and volume V_o required in order to obtain the desired exit velocity v_o calculated previously. To begin with, the cross area of the cannon, A ,

should be similar than the area of the bee, i.e., $A \approx A_b$ as depicted in Fig. 4. On the other hand, if the expansion length inside the camber is very small it may be allowable to assume that the bee is being propelled during the short time of the adiabatic expansion l_o , and also, considering that the traveling length $L \gg l_o$, this length also can be neglected for the calculation of the distance traveled. Thus, as preliminary estimation, the exit velocity for an adiabatic expansion of an air cannon is approximately calculated as, [14]

$$v_o \approx \sqrt{\frac{2P_o V_o}{m_b(\gamma - 1)} \left[1 - \left[\frac{V_o}{Al_o + V_o} \right]^{\gamma - 1} \right] - \frac{2Al_o P_a}{m_p}} \quad (8)$$

where γ is the heat capacity ratio of the air, m_p is the mass of the bee (the object being pushed by the expansion of the air); A the cross section area of the cannon; P_a the atmospheric pressure; and P_o and V_o the initial pressure and volume of the chamber, respectively. If it is considered that the mass of the bee is given as function of its effective diameter as $m_b = \frac{\pi \rho_b \Phi_b^2}{6}$ and that the cross section area of the cannon should be around the same than the bee, i.e., $A \approx A_b = \frac{\pi \Phi_b^2}{4}$, then , Eq.(8) becomes

$$v_o \approx \sqrt{\frac{12P_o V_o}{\pi \Phi_b^3 \rho_b (\gamma - 1)} \left[1 - \left[\frac{4V_o}{\pi \Phi_b^2 l_o + 4V_o} \right]^{\gamma - 1} \right] - \frac{3l_o P_a}{\rho_b \Phi_b}} \quad (9)$$

• Discussion

Fig. 5 shows the exit velocity as function of the discharged volume per shoot V_o , i.e., the volume of the air cannon chamber, for some pressures P_o and assuming a practical expansive length of the chamber $l_o = 1$ cm and the capacity ratio of the air $\gamma = 1.4$. Referring to Fig. 5, it is seen that, in order to obtain a velocity around $v_o = 15$ m/s and minimizing as much as possible the working pressure to, say, $P_o = 2$ bars (minimizing the pressure P_o is , of course, desired in order to maximizing the total number of shots which can be generated by a given pressurized cartridge before to be refilled as we will see next), it will require a dedicated volume of the chamber around $V_o \approx 4$ cm³ or thereabouts or which is to say 4 cm³ per shot.

• Cartridge refilling

One important parameter to be considered is the total number of "shots" which can be generated before refilling (re-pressurizing) the cartridge by the farmer. The total number of shots which can be produced by a given cartridge with initial pressure P and volume V can be calculated as follows.

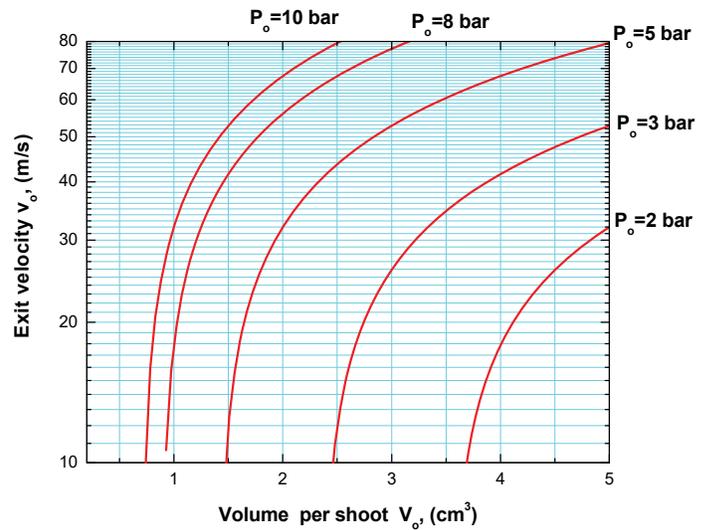


FIG. 5: The exit velocity v_o as a function of the dedicated volume per shoot V_o for some practical pressures for a cartridge.

According with our previous calculations, every shoot of compressed air the chamber is discharging a volume V_o with a pressure P_o . On the other hand, if the initial pressure of the cartridge is P where $P > P_o$ and a volume V , we have that, every time the chamber is discharged a certain number of moles of air n_o is discharged, and therefore the cartridge must to provide this number of moles. The total number of moles of air contained in the chamber at a given (environment) temperature is given by

$$n_o = \frac{P_o V_o}{RT} \quad (10)$$

where R and T are the gas constant and the environment temperature, respectively. Likewise, the initial number of moles of air contained in the compressed cartridge n_c is given by

$$n_c = \frac{PV}{RT} \quad (11)$$

On one hand, every time that the cartridge refill the chamber is losing a number of moles n_o needed to refill the chamber, and on the other hand, the cartridge only will able to supply air to the chamber up to its pressure drops to the working pressure of the chamber, i.e., P_o at which time the cartridge must be re-pressurized (refilled) to its initial pressure P by the farmer. Therefore the total number of moles of air N_T which can provide a cartridge with volume V and initial pressure P to the chamber with a working pressure P_o and volume V_o is

$$N_T = \frac{V}{RT} (P - P_o) \quad (12)$$



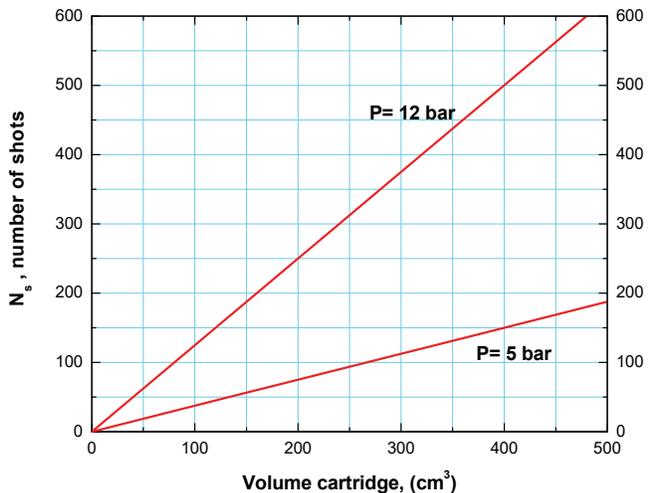


FIG. 6: Total number of shots as function of the volume of the cartridge V_o .

and the total number of "shots" N_s is given approximately by dividing N_T by the number of moles discharged per shot i.e., $N_s \approx \frac{N_T}{n_o}$ and yields

$$N_s \approx \frac{V}{V_o} \left[\frac{P}{P_o} - 1 \right] \quad (13)$$

• Discussion

Fig. 6 shows the total number of shoots N_s as function of the volume of the cartridge in the range of pressures allowable for a small commercial cartridge as used in bikes tires and assuming a pressure of the chamber $P_o = 2$ bars and a volume $V_o = 4$ cm³ which translates into an exit velocity around 17 m/s according with Fig. 5. It is seen that with a small cartridge around 300 cm³ it is possible to get around 100 to 350 shots for a pressurized cartridge around 5 bars and 12 bars, respectively.

III. SUMMARY OF RESULTS AND CONCLUSIONS

In this report the basis of a novel technique for selective capture of *Vespa velutina* baited traps was outlined. The concept is based on the use of an inexpensive compressed cannon air driven by a small rechargeable air-cartridge similar than that used to inflate bike tires. In this technique, when the common bee approaches the bait receives

an instantaneous air-shot which from the compressed air cannon which propels the insect away in almost quasi-rectilinear trajectory towards a cavity located in front of the cannon. By proper design of the air cannon and the dimensions of the cavity it is possible capture only *Vespa velutina* or insects with similar size but allowing smaller common bees be returned to the environment.

It was found that with a practicable air cartridge of ≈ 300 cm³ and pressurized up to 12 bars, it is possible attain up to 350 shots before it is necessary the refill by the farmer. Additional R&D is required in order to arrive at a reliable practical and safe design.

Nomenclature

A = cross section area
 c_d = drag coefficient
 D = diameter of cavity
 l_o = length expansion chamber
 L = travel distance
 m = mass
 n = moles
 N_s = total number of shots
 N_T = total number of moles delivered by the crtridge
 P = pressure
 Re = Reynolds number
 t = time
 v = velocity
 V = volume
 x = length co-ordinate
 z = vertical co-ordinate

Greek symbols

ρ = density
 Φ = diameter
 γ = heat capacity ratio of the air

subscripts symbols

a = air
 b = bee
 c = cartridge
 h = hornet
 o = reference, initial
 T = total

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