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Evaluating the recommended safety distance of a recoil booster

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Summary

After a supplier course for the FN MINIMI 7.62 mm Tactical machine gun, it was noted that the accompanying recoil booster FN Herstal S. A. B0897 has a hole going through it, which is parallel to the line of fire. The hole has been identified as a potential safety hazard during training with blank ammunition, because if a foreign object (e.g. a small stone) gets stuck inside the hole it might be pushed out by the gas like a projectile.

The Norwegian Defence Research Establishment (FFI) have investigated this potential safety hazard experimentally. By firing realistic improvised ammunition such as sticks, stones and ice towards a skin simulant, we observe dangerous perforations in the simulant. At two meters, the branches, ice and stones could reach velocities between $140 - 520\,\mathrm{m/s}$, $110 - 260\,\mathrm{m/s}$, and $715 - 800\,\mathrm{m/s}$ respectively.

Sammendrag

Etter leverandørkurs på «FN MINIMI 7.62 mm Tactical machine gun» ble det lagt merke til at den tilhørende rekylforsterkeren «FN Herstal S. A. B0897» har et gjennomgående hull i skuddretningen. Gjennom eksperimenter utført ved FFI har hullet blitt identifisert som en potensiell sikkerhetshetsrisiko.

Skademekanismen oppstår hvis et fremmedlegeme setter seg fast i hullet, og blir akselerert til store hastigheter av kruttgassen. Ved å skyte realistisk improvisert ammunisjon, som kvist, stein og is, mot en hudsimulant har vi observert potensielt skadelige perforeringer. På to meters hold har vi målt at kvist, is og stein kan oppnå hastigheter mellom henholdsvis $140 - 520\,\mathrm{m/s}$, $110 - 260\,\mathrm{m/s}$ og $715 - 800\,\mathrm{m/s}$.

Contents

1 Introduction

A recoil booster is a device attached to the muzzle of the firearm, and designed to utilize the energy of the escaping propellant gas to increase the recoil on the firearm. A recoil booster is primarily used to make sure that recoil–operated firearms can perform their firing cycle as intended. For training purposes the recoil booster is invaluable when firing blank ammunition, because the interior pressure is otherwise too small to drive the firing cycle. A recoil booster used for these purposes are also known as a blank-firing adapter.

Usually the recoil booster is constructed in such a way that the escaping propellant gas is ejected more or less perpendicular to the line of fire. However, the blank firing device FN Herstal S. A. B0897 accompanying the Minimi 7.62 mm Tactical machine gun leads the escaping propellant gas parallel to the line of fire. The recoil booster, with spatial dimensions, is shown in Fig. 1.1. The volume of the hole perforating the recoil booster is approximately 1.43 cm^3.

During training a soldier may have to move in a manner such that the recoil booster may be submerged in a variety of elements such as freezing water, dirt, gravel, etc. If a foreign object were to get stuck inside the pipe, and then the Minimi were to be fired the escaping gas may be able to accelerate the foreign object such that it may act as a potentially lethal projectile.

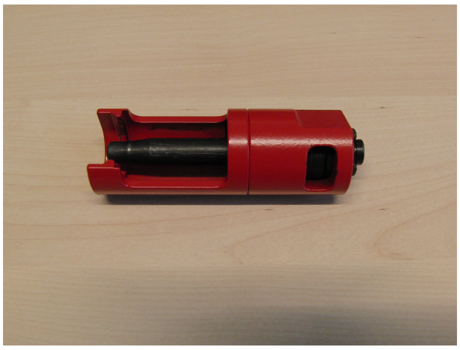
The Norwegian security criteria for land based military operations is documented in UD 2-1 [1]. On page 9.7, section 3.4.1.6 a table documenting the recommended safety distances for firing blank ammunition with various weapons with the corresponding recoil booster attached is given. The safety distance assumes that the soldier is wearing the recommended gear, including eye protection. For convenience, we include the table here as Tab. 1.1. The table includes three weapons where the

Table 1.1 Recommended safety distance for firing blank ammunition, with weapons where the recommended recoil booster is attached. The safety distance assumes that the soldier is wearing the recommended gear, including eye protection. The weapons marked with an asterisk (*) have the same caliber as the MINIMI 7.62 mm evaluated in this report. The table is taken from [1].

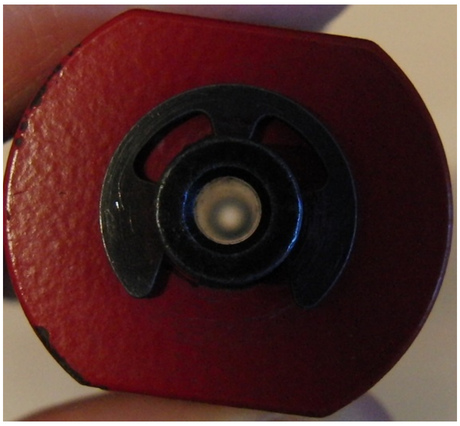
Weapon with attached recoil booster	Recommended safety distance
MP7	2 m
MP5	2 m
HK 416	2 m
HK 417*	2 m
MINIMI 5.56 mm	2 m
AG3*	2 m
MG3*	2 m
FN MAG*	2 m
12.7 MITR	10 m

blank firing ammunition has the same caliber as the MINIMI 7.62 mm we evaluate in this report. In all cases, the recommended safety distance is 2 m. Although not explicitly written down in UD 2-1 we interpret the recommend safety distance for the MINIMI 7.62 as also being 2 m.

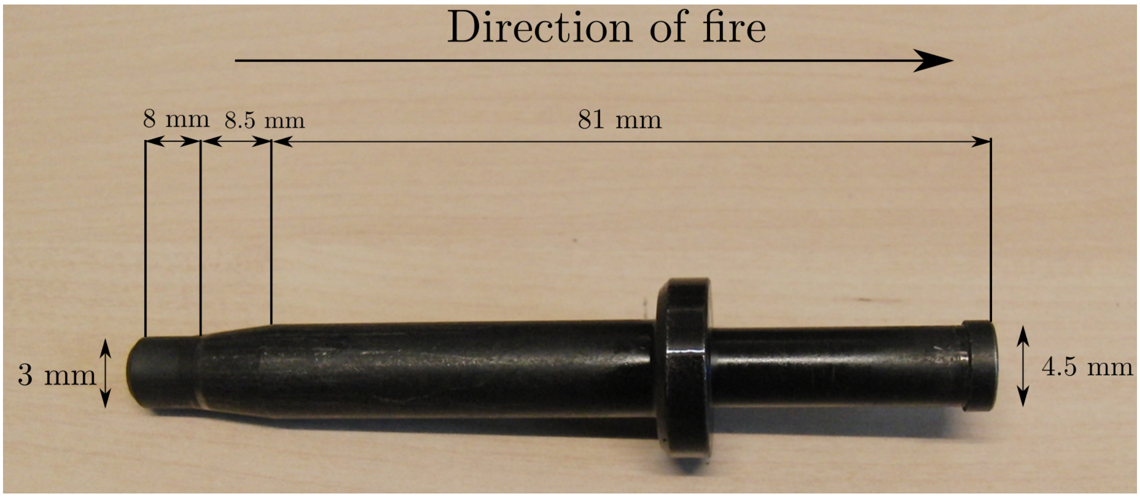
In this report, we have experimentally documented that if blank ammunition is fired with the MINIMI 7.62 mm, and there is a foreign object inside the recommended blank firing device FN Herstal S. A. B0897 dangerous perforations may occur even at the recommended safety distance.



(a) The recoil booster.



(b) The hole through the recoil booster.



(c) Dimensions of the hole through the recoil booster.

Figure 1.1 An overview of the recoil booster and the dimensions of the hole going through it.

2 Experimental method

The measurements were carried out from the 14th to the 16th of September, 2022, in the ballistics lab at the Norwegian Defence Research Establishment (FFI). The shooting and the handling of the weapons and ammunition were carried out by the FFI senior research technicians Lasse Sundem-Eriksen and Ole Andreas Haugland. The following list of technical equipment was utilized in the experiment:

- MINIMI 7.62 mm, Tactical machine gun.
- FN Herstal S. A. B0897, blank firing device.
- NM126F1 Blank ammunition, caliber 7.62 mm x 51, Lot number 01-BF-17.
- Firing bench.
- Skin simulant [2] (3 layers of 0.15 mm plastic).
- Velocity detector (LS-04, Prototypa).

The experimental setup is shown in Fig. 2.1. The blank firing device FN Herstal S. A. B0897 is attached to the MINIMI 7.62, and the complete weapon system is attached to a bench. The muzzle of the gun is pointing through a hole in a safety barrier. The recoil booster is filled with various improvised projectiles, a list of which is provided in Tab. 2.1. The improvised projectile is pushed out of the recoil booster by the pressure buildup in the interior of the gun. In all cases it was recorded whether the improvised projectile perforated the skin simulant or not. For most of the shots the distance between the MINIMI and skin simulant was 2 m. In some cases the distance was adjusted to 1 m. Where possible[1] the velocity of the improvised projectile was also recorded.

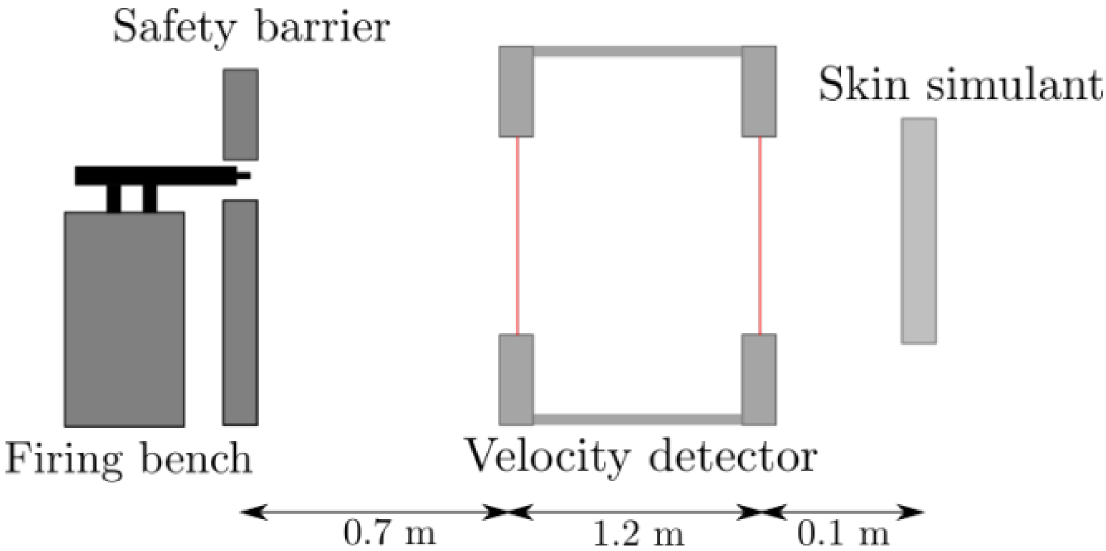
2.1 Improvised ammunition

The goal of the experiment was to establish whether it was possible to come up with a realistically occurring worst–case scenario where a foreign object may become stuck inside the blank firing device. To this end we chose several different improvised ammunition displayed in Tab. 2.1. We have provided examples of possible scenarios where the foreign object may become stuck inside the recoil booster. We emphasize that there are many other possible scenarios than the ones we wrote down.

Table 2.1 List of improvised ammunition used during the experimental tests.

Improvised ammunition	Possible scenario
No foreign object only gas	If shots fired in the early stages of training
Small tree branch & Matches	Maneuvering through trees/bushes
Mud (mixed sand and water) & Clay	Maneuvering through muddy areas
Ice (Naturally frozen or by liquid Carbon Dixoide)	Maneuvering through cold areas
Stone	Maneuvering alongside rivers, woods, roads or other gravel filled areas
Airgun steel BB bullets Cal. (4.5 mm)	As a worst case scenario

[1]It was not possible to measure the velocity if the improvised projectile split up into many pieces, or if the skin simulant is too close (1 m) to the MINIMI.



(a) A schematic of the experimental setup.

(b) Minimi 7.62 mm attached to bench.

(c) Velocity detector and safety barrier.

(d) Skin simulant and velocity detector.

(e) Skin simulant.

Figure 2.1 The experimental setup for the evaluation of the current recommended safety distance when firing with MINIMI 7.62 where the FN Herstal S. A. B0897 is attached.

3 Experimental results and discussion

A complete overview of the collected experimental data is shown in Tab. A.1. In Fig. 3.1 we present the data graphically. If no foreign object is placed in the recoil booster, we were not able to detect a perforation in the skin simulant at either 2 m or 1 m. However, we were able to obtain perforations through a piece of 80 g A4 paper at 2 m, giving clear indications that gunpowder residue is ejected parallel to the line of fire.

The situation changes drastically when a foreign object is stuck in the recoil booster. In this case the weapon system acts similar to an airgun, where the most important factors determining the final speed is, the mass of the foreign object, the length of the recoil booster, friction, and cross–sectional area as shown in App. B. We were able to produce perforations in the skin simulant at 2 m using several types of improvised ammunition: matches, branches, ice, stones, and a BB bullet. We were not able to detect perforations with mud or clay. Naturally, we find that the closer the resemblance of the improvised ammunition is to an actual bullet the more dangerous the situation.

In the cases where the improvised projectile did not fragment too much we were also able to measure the corresponding velocities. We find that the branches, ice, stones, and BB bullet could reach velocities between 140 – 520 m/s, 110 – 260 m/s, 715 – 800 m/s, and 380 m/s respectively.

Of course, the speed of the object is not the only important factor for determining whether skin will be perforated. One might for instance wonder why the ice perforated the skin simulant with a velocity 208 m/s, but not with the velocities 340 m/s and 263 m/s. The question can be answered qualitatively by considering the energy density defined as

$$\text{Energy/Area} = \frac{E_k}{A} \tag{3.1}$$

where E_k is the translational kinetic energy of the object, and A is the cross–sectional area. A detailed literature review performed in [3] argues that an approximate criteria for human skin perforation is that the projectile has an energy density in the range of 7 – 28 J/cm^2. This is of course highly dependent on the projectile shape, mass, and where on the body the projectile impacts the skin. For comparison the skin simulant at FFI is perforated by an energy density in the range 4.1 – 5.5 J/cm^2 [2].

At the bottom of Fig. 3.1 we have calculated the energy density for each shot. The calculation relies on the assumption that the projectile does not fragment, and that the projectile hits the target with its smallest surface area so that its impact pressure is the largest. The second assumption is especially important to keep in mind for elongated objects (e.g. branches), where the perforation probability strongly depends on the yaw angle. The calculation thus represents a worst case scenario. For branches, ice[2], and stone we observe that there are several shots that carry enough energy to completely perforate skin. Of course, we expect the frequency of dangerous shots to be the largest for stones as they are relatively resilient and spherical, indicating a low likelihood of fragmentation as well as yaw independence. Notably we find that the produced energy density is significantly larger for stones than BB bullets.

[2]Note that to obtain a worst–case scenario we have assumed in the calculation that the ice does not fragment. In reality, where fragmentation occurs, the energy density should be divided among the individual pieces giving a lower effective energy density. The fact that the ice fragmented, and consequently has a lower energy density than in the calculation, explains the two non–perforations for ice at the bottom of Fig. 3.1.

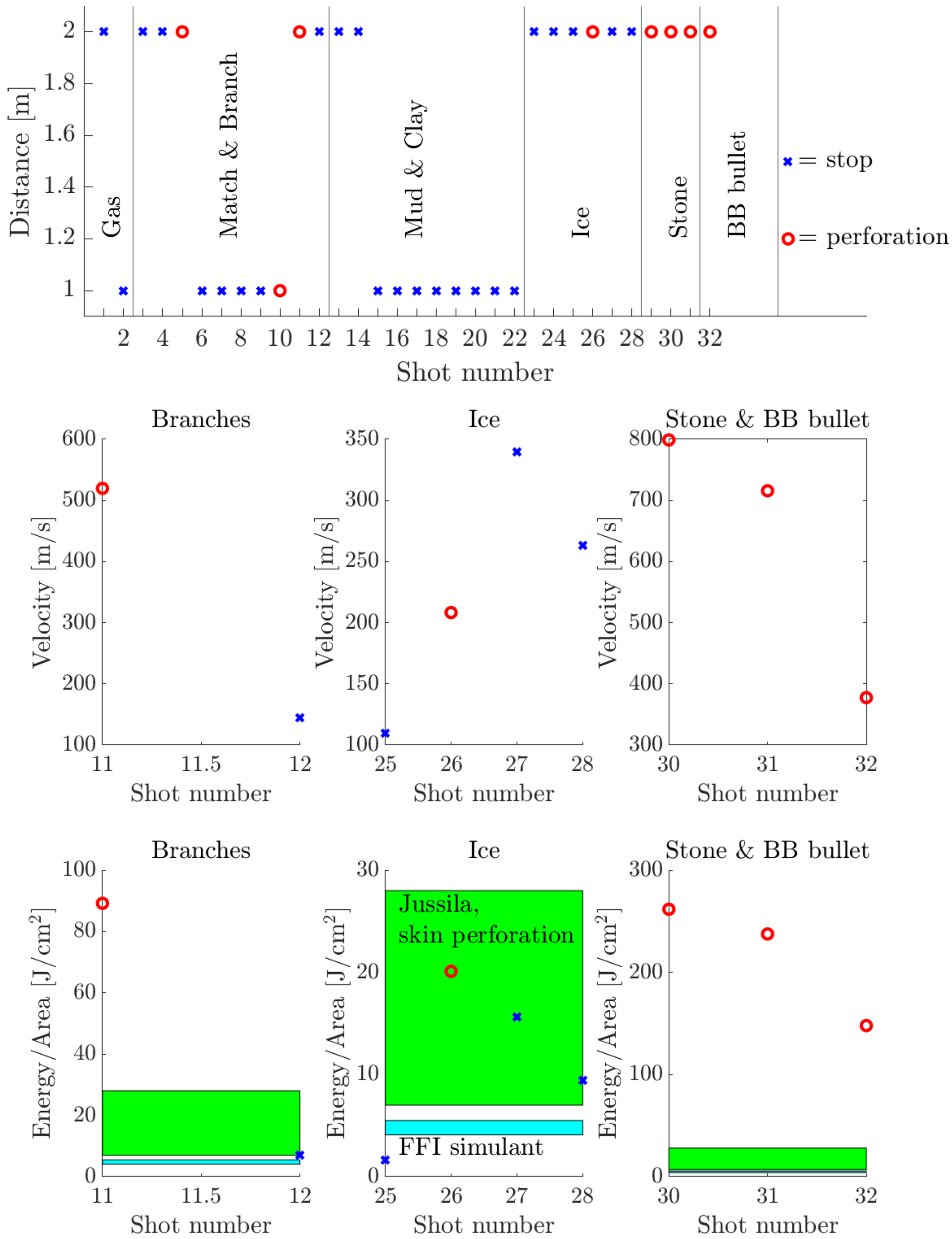


Figure 3.1 The experimental data illustrating the damage potential of firing the MINIMI 7.62 if a foreign object were to become stuck in the FN Herstal S. A. B0897 recoil booster.

4 Conclusion

The recoil booster FN Herstal S. A. B0897 accompanying the MINIMI 7.62 mm tactical machine gun has a hole going through it, parallel to the line of fire. FFI has been asked by the Norwegian army to determine if the hole may introduce a potential safety hazard if a foreign object were to become stuck in it, and the machine gun subsequently fired. To this end we have performed perforation experiments utilizing a skin simulant by jamming various types of improvised ammunition inside the recoil booster. Care has been taken to only utilize forms of improvised ammunition that may become jammed in the recoil booster during advanced maneuvering through realistic terrain. In the experiment we have observed several potentially dangerous perforations, using e.g. branches, ice, and stones.

References

[1] L. S. Lervik (Sjef hæren). Forsvarets sikkerhetsbestemmelser for landmilitær virksomhet. *Direktiv for landmilitær virksomhet*, 2022.

[2] S. Bergsrud and M. Huseby. Frangible sikkerhet - delrapport 1 9x19 mm. *Forsvarets Forskningsinstitutt*, 2012.

[3] J. Jussila, A. Leppaniemi, M. Paronen, and E. Kulomaki. Ballistic skin simulant. *Forensic Science International*, 150(1):63–71, 2005.

A Raw data for perforation experiment

The raw data from the experiment is provided in Tab. A.1.

Table A.1 Overview over shots performed against the skin simulant with various types of improvised ammunition.

Improvised ammunition	Distance [m] MINIMI–simulant	Perforation [Y/N]	Velocity [m/s]	Mass [g]
No foreign object only gas	2	Y	x	x
No foreign object only gas	1	N	x	x
Match (3 mm x 2.8 cm)	2	N	x	x
Match (3 mm x 2.8 cm)	2	N	x	x
Match (3 mm x 5.6 cm)	2	Y	x	x
Branch (4.5 mm x 25 mm)	1	N	x	x
Branch (4.5 mm x 30 mm)	1	N	x	x
Branch (4.5 mm x 70 mm)	1	N	x	x
Branch (4.5 mm x 15 mm)	1	N	x	x
Branch (4.5 mm x 10 mm)	1	Y	x	x
Branch (4.5 mm x 10 mm)	2	Y	519.7	0.105
Branch (4.5 mm x 10 mm)	2	N	144.2	0.105
Mud (4.5 mm x 10 mm)	2	N	x	x
Mud (4.5 mm x 10 mm)	2	N	x	x
Mud (4.5 mm x 10 mm)	1	N	x	x
Mud (4.5 mm x 10 mm)	1	N	x	x
Mud (4.5 mm x 10 mm)	1	N	x	x
Clay (4.5 mm x 6.5 mm)	1	N	x	x
Clay (4.5 mm x 17 mm)	1	N	x	x
Clay (4.5 mm x 12 mm)	1	N	x	x
Clay (4.5 mm x 24 mm)	1	N	x	x
Clay (4.5 mm x 27 mm)	1	N	x	x
Crushed ice cube	2	N	x	x
Crushed ice cube	2	N	x	x
Ice (0.430 ml water - Freezer)	2	N	109.9	0.430
Ice (1.47 ml water - Freezer)	2	Y	208.3	1.47
Ice (0.430 ml water - Liquid CO_2)	2	N	340.0	0.430
Ice (0.430 ml water - Liquid CO_2)	2	N	263.3	0.430
Stone (3 mm)	2	Y	x	0.0671
Stone (4 mm)	2	Y	799	0.103
Stone (2.5 mm)	2	Y	715.8	0.0455
Airgun steel BB bullets (4.5 mm)	2	Y	377.5	0.33

B The simplified airgun model

To obtain a qualitative understanding of which physical parameters are the most important for accelerating the foreign objects stuck inside of the recoil booster we consider the weapon system to act as a simplified airgun, as shown in Fig. B.1.

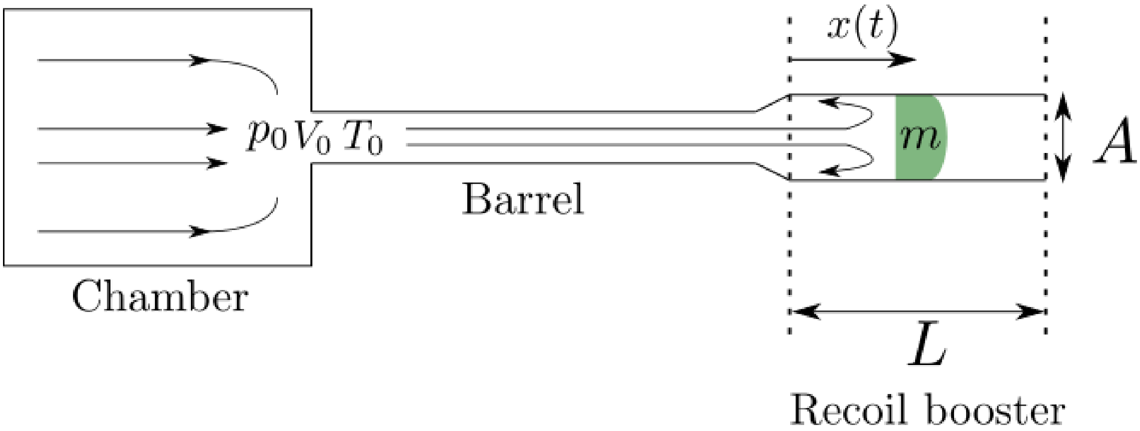


Figure B.1 Setup for the simplified airgun model.

The foreign object with cross sectional area A is being accelerated by the interior gas pressure, through the length of the recoil booster L. We let $x(t)$denote the position of the foreign object at time t. Before the gas reaches the foreign object the gas has pressure p_0, temperature T_0, and occupies a volume V_0. For simplicity, we assume that pressure and temperature is uniform at all times t, and that the gas obeys the ideal gas law. We also assume that the foreign object completely blocks the hole in the recoil booster, such that there is no leakage of gas around the foreign object. For convenience, the foreign object starts accelerating at $t = 0$.

With these assumptions, the pressure at time t can be expressed as

$$p(t) = \frac{T(t)}{T_0} \frac{p_0 V_0}{V(t)}, \quad \text{(B.1)}$$

where $T(t)$ and $V(t) = V_0 + Ax(t)$ is the temperature and volume of the gas at time t. Newton's second law dictates that the acceleration is given by the difference in the pressure force $p(t)A$ and the frictional force f, such that

$$m\ddot{x} = \frac{T(t)}{T_0} \frac{p_0 V_0 A}{V_0 + Ax(t)} - f. \quad \text{(B.2)}$$

If we assume that the temperature does not change appreciably during the acceleration of the foreign object we can use seperation of variables to integrate once, and obtain the energy equation[3] of the form

$$\frac{1}{2} m v^2(L) = p_0 V_0 \ln \left(1 + \frac{AL}{V_0}\right) - fL. \quad \text{(B.3)}$$

The energy equation expresses that the work done during the gas expansion is used to overcome friction as well as accelerating the foreign object. The energy equation can be solved to obtain the

[3]The inclusion of a varying temperature would give an additional heat loss term in the energy equation.

final velocity as

$$v(L) = \sqrt{\frac{2}{m}\left[p_0 V_0 \ln\left(1 + \frac{AL}{V_0}\right) - fL\right]}. \tag{B.4}$$

This expression shows that the most important factors determining the final speed of the foreign object is the projectile mass, powder type, cross–sectional area, friction, and length of the recoil booster. Interestingly there exists a special length which maximizes the final speed of the foreign object given by

$$L_{\max} = \frac{p_0 V_0}{f} - \frac{V_0}{A}. \tag{B.5}$$

The volume of the recoil booster AL is much smaller than the volume of the chamber and barrel V_0. Thus we perform a Taylor expansion on the logarithm and obtain a simple and more intuitive expressions for the final speed

$$v(L) \approx \sqrt{2p_0 A}\sqrt{1 - \frac{f}{p_0 A}}\sqrt{\frac{L}{m}}, \tag{B.6}$$

and energy density

$$\text{Energy/Area} = \frac{E_k}{A} \approx \left(p_0 - \frac{f}{A}\right) L. \tag{B.7}$$

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FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

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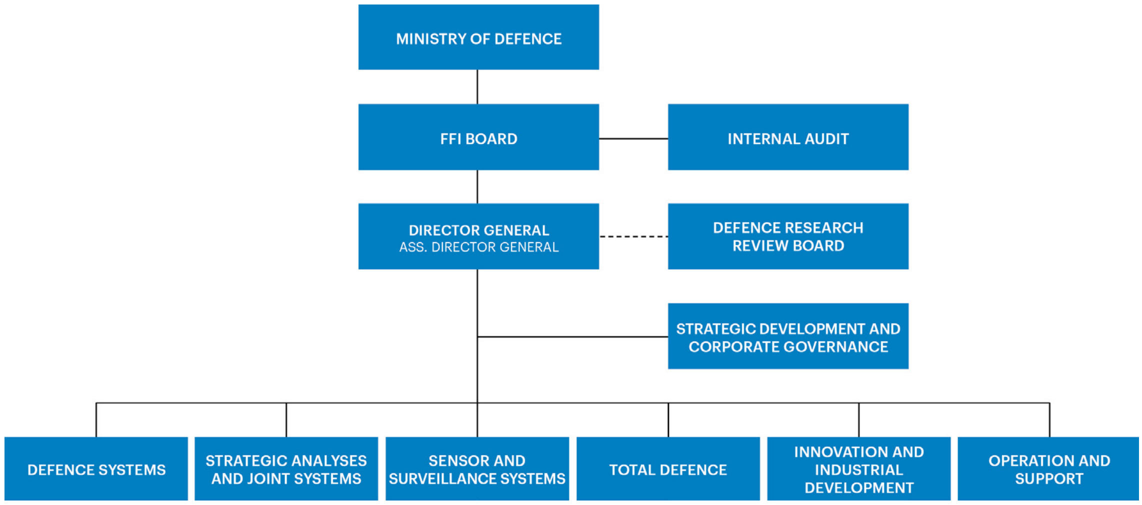

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