# INFLUENCE OF INITIAL PRESSURE ON THE IGNITION AND COMBUSTION OF A PROPELLING CHARGE

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It has been observed in a very small closed vessel that the ignition delay of a gun propellant is dependent on the initial pressure of the air or argon surrounding the propellant grain. The effect is not gas-dependent. Subsequent tests have been performed in a 20 mm gun simulator to identify the important factors (from the list: initial pressure, type of gas, type of igniter, igniter energy) which have a major impact on the ignition and burning of the propelling charge. The experimental design approach has shown that the addition of 50 bar of gas can greatly influence the interior ballistic process. In particular, the air addition in the combustion chamber allows the increase of the pressure and initial velocity and the reduction of ignition delays.

Another series of tests in a 60 mm gun simulator shows how the pressure, velocity and ignition delays are modified when the pressure is increased from 0.1 MPa to 10 MPa. There is a lot of scatter in the 0.1 to 2 MPa pressure range, but from 2 to 6 MPa, the effect of the initial pressure is relatively reproducible and significant (13% variation in the maximum pressure).

## INTRODUCTION

A study of ignition delays was initiated in 2002 with the aim of better understanding the initiation of propellants. Some of the first experiments were devoted to laser ignition experiments in a small closed vessel. They showed a distinctive reduction in ignition delays when a gas (air or argon) was added in the vessel before the experiment (see figure 1). It was decided to pursue the experiments in a 20 mm launcher to see if the gas pressure or the velocity of the projectile can also be sensitive to an initial pressure. It was also the opportunity of testing the concept of the experimental design [1] and to apply it to interior ballistic experiments. The experimental design allows, through a proper choice of experiments, a maximum of information to be obtained from a given number of experiments.

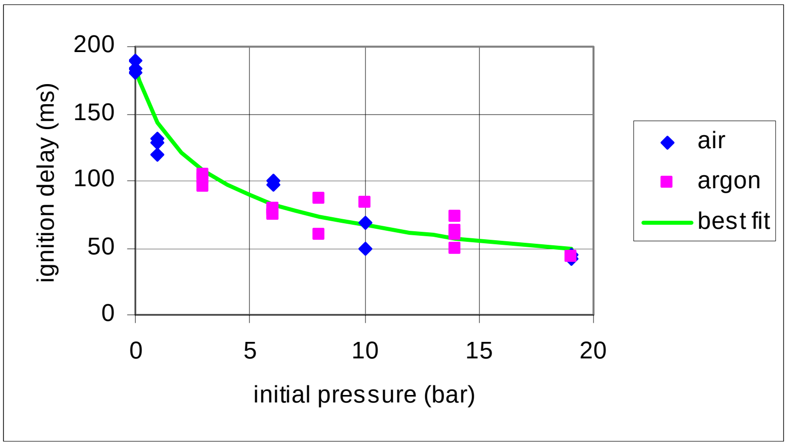

Figure 1: An initial pressure reduces the ignition delays in a very small closed vessel

## EXPERIMENTAL DESIGN FOR 20 MM FIRINGS

### 20 mm experimental setup

We used a 20 mm launcher, with a chamber volume of 38 cm$^3$ and a barrel length of 2.5 m. A more detailed description of the launcher can be found in [2]. The inner wall of the burning chamber was protected from a short circuit by a sleeve of polyethylene. For the plasma ignition a wire was connected between the rear central electrode and the front annular electrode (figure 2). For the pyrotechnical ignition a small wire was positioned at the top of the rear electrode. The heating of this wire by a current of a few amperes allowed the ignition of the black powder located inside a central tube made of paper. Two pressure measurements could be performed in the chamber and one at the beginning of the tube. At the axial position of the pressure gage in the tube a bore (not represented here) allowed the connection of a valve to pressurize the chamber before the firing. The projectile, also used as a duct admitting the gas, had a mass of 90 g.

The heterogeneous propellant used here has the composition given in table 1. In normal conditions, it is too large to burn fully in the 20 mm launcher. It was selected to see if the initial pressure could enhance the burning of the propellant. At the end of each firing 30 grains of partially burnt propellant were recovered and weighted. The loading density used was 0.7 g/cm$^3$.

### Experimental design

The NemrodW software [3] was used for the design of the experiment. The chosen factors for this screening study were: the type of igniter, the energy of the igniter, the initial pressure and thetype of gas. To keep a maximum of symmetry in the design of the experiment it was necessary to include the initial pressure and type of gas in the same factor. Air was chosen because it is common and oxygenated. Helium was selected because it has good transport properties (heat conductivity and mass diffusivity); and nitrogen was chosen because it is an inert gas. Finally the experiments carried out are given in table 2. Each experiment was repeated at least once, and in some cases twice.

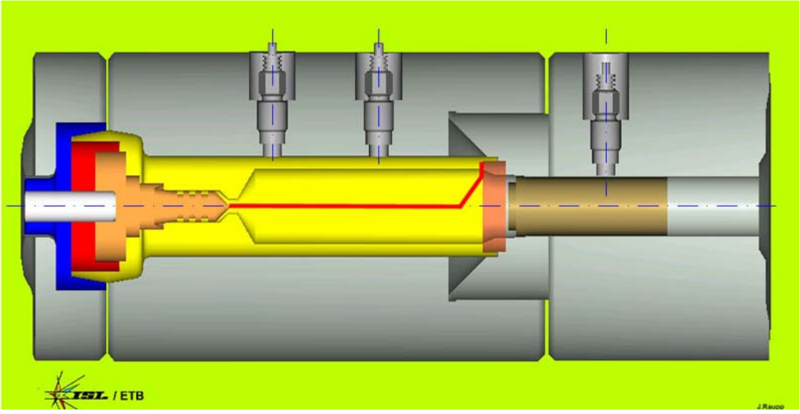

Figure 2: Sketch of the burning chamber of the 20 mm launcher

| | |
|---|---|
| Nitrocellulose | 35% |
| DEGN | 21% |
| Nitroguanidine | 33% |
| RDX | 8% |
| Additives | 3% |
| Web size | 0.78 mm |

Table 1: Composition and web of the propellant

| Experiment No. | Energy of the igniter | Type of igniter | Gas and pressure |
|---|---|---|---|
| 1 | 2 kJ | plasma | 0 bar air |
| 2 | 2 kJ | pyro | 50 bar air |
| 3 | 2 kJ | plasma | 50 bar $N_2$ |
| 4 | 2 kJ | pyro | 50 bar He |
| 5 | 10 kJ | pyro | 0 bar air |
| 6 | 10 kJ | plasma | 50 bar air |
| 7 | 10 kJ | pyro | 50 bar $N_2$ |
| 8 | 10 kJ | plasma | 50 bar He |

Table 2: Design of the experiment

## Results concerning the maximum pressure

After calculation by NemrodW, the results are presented in table 3 and 2 graphs in figure 3. It can be observed that all factors have an influence on the maximal pressure. The table gives the coefficient of the mathematical model describing the results, the standard deviation for each coefficient and specifies whether the coefficient is meaningful. When a line indicates more than 2 stars (**), it means that the effect is significant from a statistical point of view.

An increase in the ignition energy leads to a pressure increase.

The plasma ignition yields a higher pressure than the pyrotechnical ignition.

The addition of 50 bar of air increases the pressure in comparison with the reference case without the addition of gas. The addition of 50 bar of nitrogen decreases the pressure. Helium slightly increases the pressure.

The other results will be presented without the help of tables and graphs and will only be qualitatively described.

| Factor | Coefficient (MPa) | Standard deviation | Significant % |
|---|---|---|---|
| Constant | 157.981 | 3.636 | < 0.01 *** |
| Energy of igniter | -62.088 | 3.134 | < 0.01 *** |
| Type of igniter | -55.508 | 3.134 | < 0.01 *** |
| Gas: level 4-1 | -23.367 | 4.123 | < 0.01 *** |
| Gas: level 4-2 | 20.796 | 4.346 | 0.0356 *** |
| Gas: level 4-3 | -52.333 | 4.610 | < 0.01 *** |

Table 3: Results concerning the maximum pressure

## Results concerning the burnt mass

Two factors have a predominant influence:

- the burnt mass increases with the ignition energy,
- the burnt mass is higher with a pyrotechnical igniter.

The effect of the gas is not significant for helium and is weak for air or nitrogen. The addition of 50 bar of air slightly increases the burnt mass, whereas the addition of 50 bar of nitrogen reduces it. It is important to notice that an initial pressure will not allow the burnt mass to be notably increased.

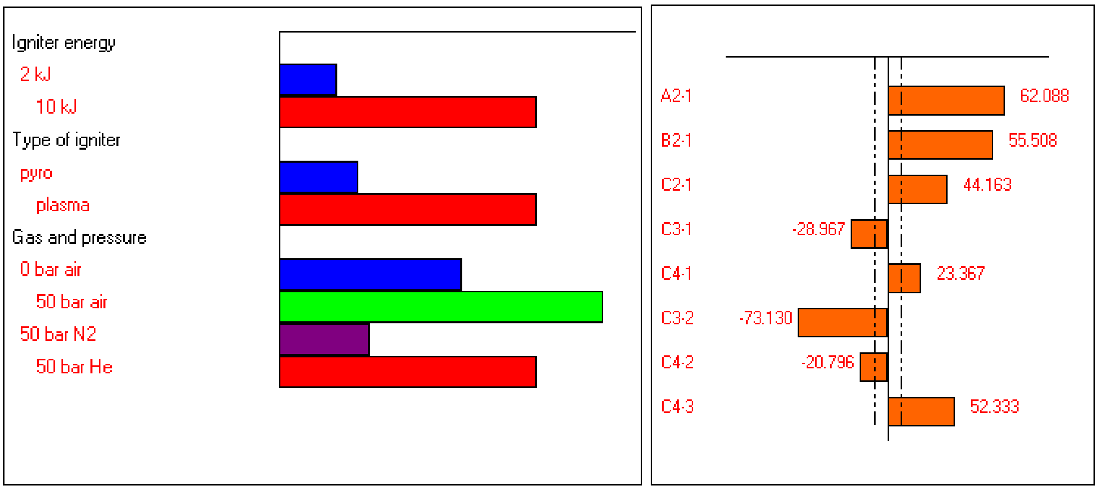

Figure 3: Effect of the factors on the maximum pressure response

## Results concerning the initial velocity

All factors have a significant influence on the initial velocity; the main effect comes from the energy of the igniter. A high energy produces a high velocity, so does a plasma igniter. The addition of 50 bar of air increases the initial velocity compared to a test at atmospheric pressure, this effect is greater than that provoked by the change of igniter. Nitrogen reduces the velocity. The increase due to helium is slight.

## Results concerning the rise time

Let us define the rise time as the absolute time from the beginning of the firing up to the maximum of pressure. One factor clearly has an influence: the type of igniter.

The plasma igniter shows the shortest rise time (this is an already known result). All other factors have a weak influence, or are not significant.

## Conclusion for the study in the 20 mm launcher

Another propellant of a single-base nature was also tested. The observed effects with the 2 propellants are similar.

An initial pressure allows the maximum pressure level and as a consequence, the velocity of the projectile to be changed. The effect is gas-dependent:

Air increases the maximum pressure and initial velocity. Nitrogen reduces both responses. The effect of helium is weaker and depends on the propellant.

The addition of air has little effect on the burnt mass.

As it seemed that the only interesting gas was air, it was decided to quantify the effect of this added air from the atmospheric pressure to a pressure of 10 MPa. This study was conducted with another gun of a 60 mm calibre and is reported below.

## EXPERIMENTS WITH A 60 MM GUN

### Description of the experiments

For this series of experiments, we only varied the level of initial pressure. The propellant was of the same type as that for the 20 mm experiments, it only had a larger web size: 1.15 mm. The loading density was 0.750 g/cm$^3$ and there is no unburnt propellant. Ignition was performed pyrotechnically by means of 8 g of black powder located in a steel primer tube; the results concern the ignition delays, pressure and initial velocity. The ignition delay is defined as the time from the beginning of the firing up to the time when the pressure in the chamber reaches 50 MPa.

### Results

The results are given in figures 4 and 5. The addition of 5 MPa of air increases the maximum pressure and the velocity compared to the reference case with no added air. This confirms the results obtained in the first part of the study. From 6 to 10 MPa of added air the effects do not vary significantly, they vary only from 0.1 to 6 MPa. But a huge scatter can be seen on the graphs of figure 4 for pressures between 0.1 and 2 MPa. Some causes of scatter have been examined (temperature of the propellant, mass and forcing band of the projectile), but none of these seems to be responsible for the scatter. On the other hand, the results are consistent: if we plot the initial velocity as a function of the maximum pressure (see figure 5), there is no more scatter. Concerning the ignition delays there is also little scatter. All our results, except for one, can be represented by a single curve. The addition of 5 MPa of air reduces the ignition delay by a factor 2. So we can consider that our results are not affected by an uncontrolled measurement noise, but that our data are physically correct.

### Discussion

If we consider that our data with the 60 mm gun are valid, it means that some physical phenomenon due to the added air is responsible for the scatter of the initial velocity and maximum pressure.

To understand the influence of air addition in the burning chamber one should consider at least the following phenomena occurring during ignition:

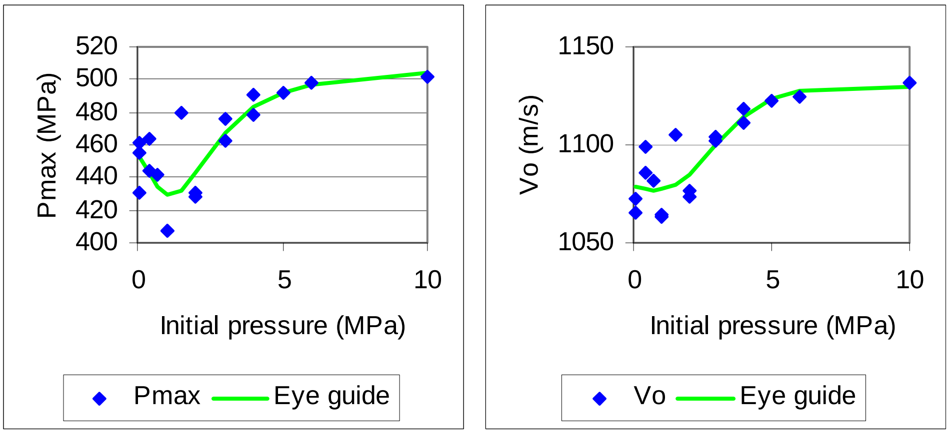

Figure 4: Influence of the initial pressure of air on $P_{max}$ and $V_o$

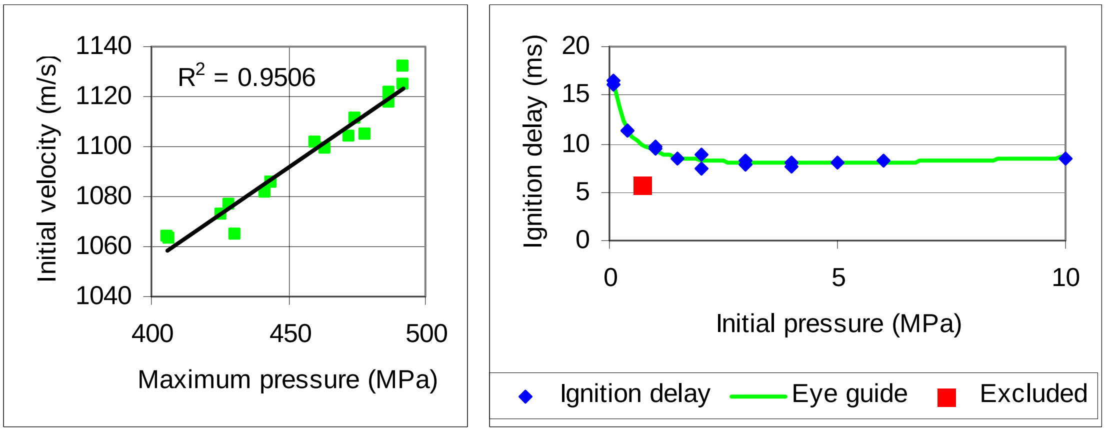

Figure 5: Pressure and velocity are consistent, ignition delays show little scatter

- the propagation of ignition products happens in a dense gas. This gas will slow down the propagation; this aspect is already implemented in interior ballistic models like MOBIDIC [4]; for simulation purposes it would be necessary to identify precisely the gases and their properties (equation of state, viscosity);

- the heat transfer is increased by the high density of the fluid. Again the equations are implemented in models, the properties of the gases need describing (heat conductivity);

- with a gas addition, the propellant starts to burn at a higher pressure. This should reduce the time needed for the combustion of the propellant. Codes like MOBIDIC should be able to take into account this aspect;

- the chemical reaction of the igniter products with the oxygen of the air produces energy. The latter should be taken into account in the energy balance, maybe through the implementation of a simple chemical kinetic model.

This list shows that in these conditions, ignition is a relatively complex process. The scatter probably arises from small variations in the functioning of the igniter that produce great effects. When the amount of air becomes significant (pressure above 3MPa), the added air tends to reduce the scatter.

## CONCLUSION AND OUTLOOK

A step-by-step study has shown that the addition of a gas in the burning chamber of a gun can influence the ignition and the combustion process. Air is the most efficient of the tested gases. Although the exact cause of the scatter when the initial pressure ranges between 0.1 and 2 MPa is still unknown, the scatter disappears above 2 MPa and up to 6 MPa.

Pressure and velocity can be varied with a 2 to 6 MPa initial pressure of air, the maximum pressure can be increased by 13% and the initial velocity by 5%.

This effect of added air could be used to compensate for the temperature dependency of propelling charges.

### Acknowledgements

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