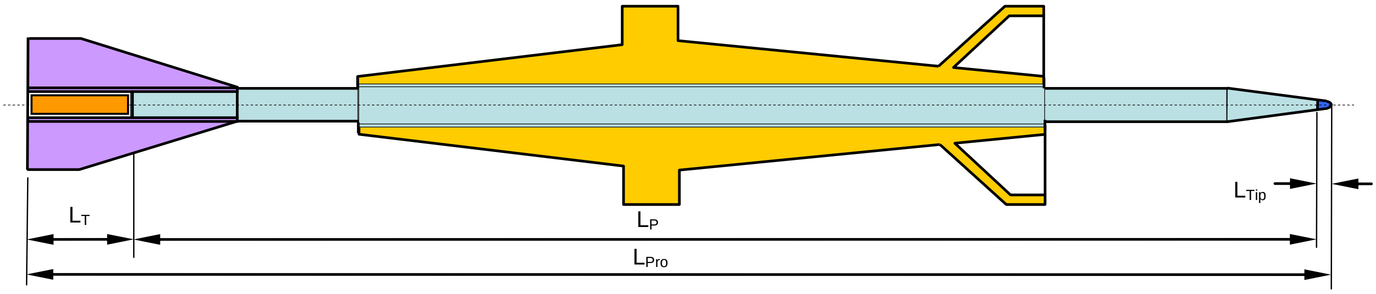
120mm Smooth Bore
Design of Tungsten Penetrators and Corresponding Sabots

The perforation performance of long rod penetrators can be estimated with a simplified proceeding with including the entire gun-ammunition system. The basis are freely chosen penetrator dimensions, which must be chosen sensibly of course. The necessary sabot dimensions are calculated automatically and the accelerated projectile mass is determined. The muzzle velocity is calculated with the elected propellant mass with an approximation equation. The resultant perforation performance into RHA can be determined with the perforation equation. The optimal penetrator can be found with geometry variations.



Accelerated Projectile:

For the penetrator, different **diameters** can be chosen, so with the free length in the front D_{FP}, the buttress area D_{BG} and the tail area D_{RP}. In the tail area, a reduced diameter is assumed where the fins are attached. The tip is equipped with a metal (steel or alu) insole. The sabots consist of an aluminum-alloy.

Using the Spread Sheet

Input: On the spread sheet fill all green colored fields in.

1. *Gun design*
   - Tube length in caliber
   - Propellant charge mass
   - Design pressure

   Present version supports only the caliber 120mm.
2. *Penetrator properties*
   - Frustum: length and diameter of upper base
   - Diameter of the front part
   - Buttress part: diameter in the grooves and outside
   - Diameter of the rear part
   - Yield strength
   - Penetrator density
3. *Projectile*
   - Total projectile length
   - Estimated velocity drop
   - Length of the tip

4. *Sabot*

   Guiding length
   Density of the aluminum alloy

5. *Fin assembly*

   Number of fins
   Dimensions
   Fin thickness
   Tracer tube thickness
   Density of the fins
   Tracer length
   Tracer mass

6. *Target properties*

   Density
   Brinell Hardness Number
   Obliquity NATO

Output: As a result of an iteration process (brown colored fields).

1. *Penetrator*

   Length of frontal part
   Length of buttress part
   Length of rear part
   Mean diameter
   Working length
   Aspect ratio L / D
   Mass

2. *Projectile*

   Accelerated mass
   Flying mass
   Muzzle velocity

3. *Sabot*

   Mass
   Length

4. *Fin assembly*

   Mass

5. *Velocity and perforation*

   At muzzle and in steps of 1 km up to 3 km

Calculation Steps

The sabot length as well as the free penetrator lengths can be investigated by an iterative process only.

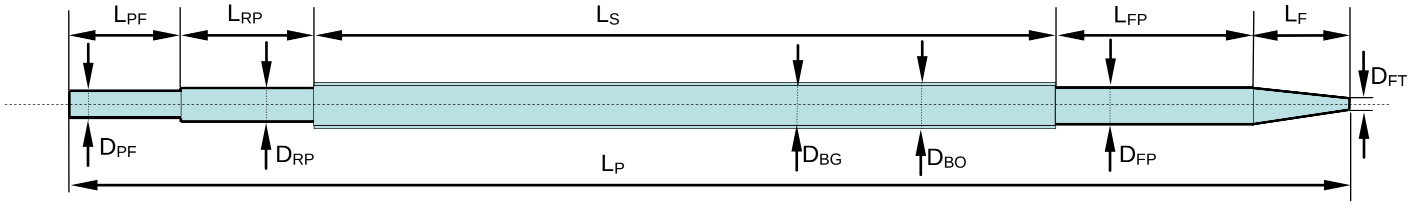
1. Start

Calculate the sabot and the frontal rod length with the following approximations:

Sabot length	= 0.6 x penetrator length	$L_S = 0.6 \times L_P$
Length of the frontal cylinder	= 6 x diameter of frontal part	$L_{FP} = 6 \times D_{FP}$

2. Calculating of the masses

2.1 Penetrator



Frustum

$$m_{Fru} = \frac{\pi}{12} \cdot L_{Fru} \cdot D_{FP}^2 \cdot \rho_P \cdot \left[1 + \frac{D_{FT}}{D_{FP}} + \left(\frac{D_{FT}}{D_{FP}}\right)^2\right]$$

Frontal part

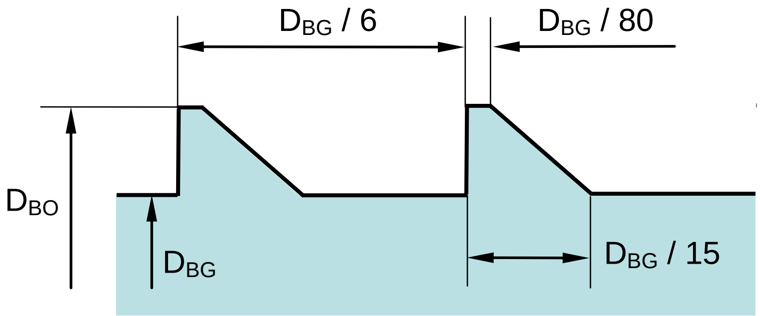
$$m_{FP} = \frac{\pi}{4} \cdot L_{FP} \cdot D_{FP}^2 \cdot \rho_P$$

buttress cylindrical part

$$m_{BC} = \frac{\pi}{4} \cdot L_S \cdot D_{BG}^2 \cdot \rho_P$$

Buttress part

$$m_{BP} = \frac{n_B \cdot \pi}{2880} \cdot D_{BG} \cdot \rho_P \left(22 \cdot D_{BO}^2 + 13 \cdot D_{BO} \cdot D_{BG} - 35 \cdot D_{BG}^2\right)$$



$$n_B = \mathrm{int}\left(\frac{6 \cdot L_B}{D_{BG}} + 1\right)$$

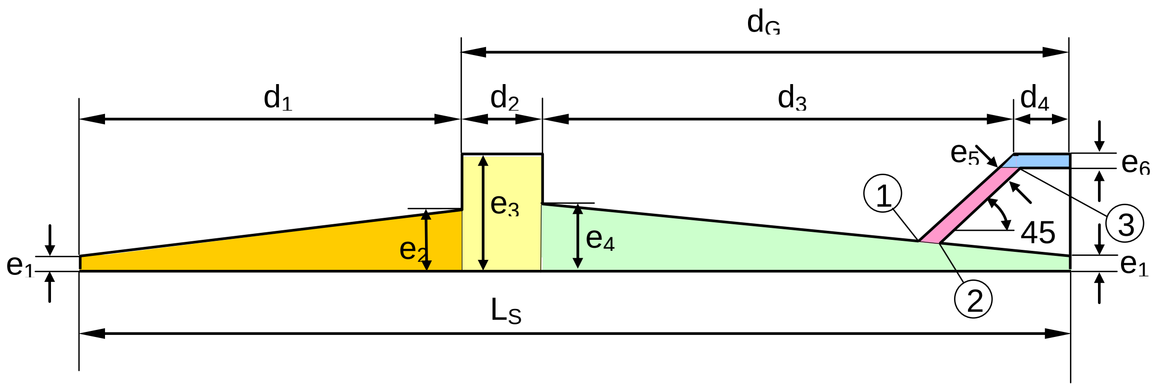
Rear part

$$m_{RP} = \frac{\pi}{4} \cdot L_{RP} \cdot D_{RP}^2 \cdot \rho_P$$

Tracer part

$$m_{TP} = \frac{\pi}{4} \cdot (L_F - L_T) \cdot (D_{RP} - 2 \cdot t_{FT})^2 \cdot \rho_P$$

2.2 Sabot



Empirically established figures for caliber 120mm:

$d_1 = L_S - d_G$	$e_1 = 0.2 * D_{BG}$
$d_2 = 40 * p_{MAX} / p_0$	$e_2 = 0.55 * e_3$
$d_3 = d_G - d_2 - d_4$	$e_3 = (cal - D_{BG})/2$
$d_4 =$ 25 mm	$e_4 = 0.6 * e_3$
	$e_5 = 8$ mm
$d_G = d_2 + d_3 + d_4$	$e_6 = 6$ mm

Cylindrical part

$$m_{SCP} = \frac{\pi \cdot d_2 \cdot \rho_S}{4} \cdot \left(cal^2 - D_{BG}{}^2\right)$$

Frontal part

$$m_{SFP} = \frac{\pi \cdot (d_3 + d_4) \cdot \rho_S}{6} \cdot \left(2 \cdot \left(e_1{}^2 + e_1 \cdot e_4 + e_4{}^2\right) + 3 \cdot D_{BG} \cdot (e_1 + e_4)\right)$$

Rear part

$$m_{SRP} = \frac{\pi \cdot d_1 \cdot \rho_S}{6} \cdot \left(2 \cdot \left(e_1{}^2 + e_1 \cdot e_2 + e_2{}^2\right) + 3 \cdot D_{BG} \cdot (e_1 + e_2)\right)$$

Cup

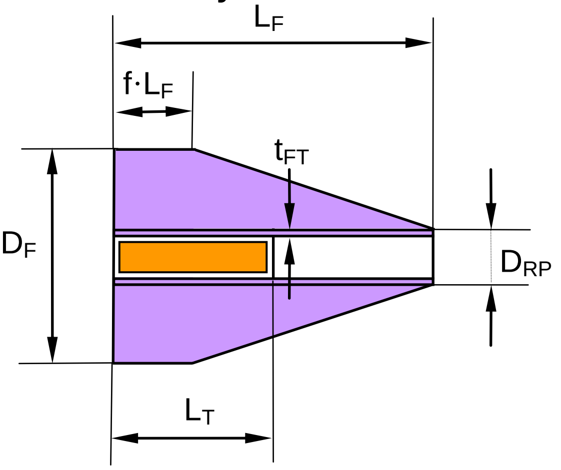
$$m_{C_1} = \frac{\pi \cdot \rho_S}{6} \cdot e_6 \cdot \left(3 \cdot cal \cdot e_6 - 4 \cdot e_6{}^2 + 6 \cdot cal \cdot d_4 - 6 \cdot d_4 \cdot e_6\right)$$

$$m_{C2} = \frac{\pi \cdot \rho_S \cdot \sqrt{2} \cdot e_5 \cdot \left((cal - 2 \cdot e_6)^2 - (D_{BG} + y_1 + y_2)^2\right)}{4}$$

Total sabot weigth:

$$m_S = m_{SCP} + m_{SFP} + m_{SRP} + m_{SCup}$$

2.3 Fin Assembly



n_F	Number of fins
t_F	Fin thickness
t_{FT}	Tube thickness
ρ_F	Density of tail fins
m_T	Mass of tracer

$$\boxed{m_{FA} = L_F \cdot \rho_F \cdot \left[\frac{n_F \cdot t_F}{4} (1+f) \cdot (D_F - D_{RP}) + \pi \cdot (D_{RP} - t_{FT}) \cdot t_{FT} \right] + m_T}$$

3. Accelerated mass and maximum acceleration

The sum of masses of penetrator, fin assembly and sabot results in the accelerated projectile mass m_{acc} .

The maximum acceleration b_{max}, which the projectile has to endure, can be calculated from the accelerated projectile mass m_{acc}, the charge mass m_C, the caliber and the design pressure p_{max}.

$$\boxed{b_{max} = \frac{cal}{p_{max} \cdot (m_{acc} + 0.5 \cdot m_C)}}$$

4. Lengths of sabot, frontal and rear part of the penetrator

4.1 Frontal part

1. Case: Compressive resistance is decisive

$$\boxed{L_{FP} = \frac{1}{\rho_P} \left(\frac{R_m}{b_{max}} - \frac{4 \cdot m_{FRU}}{\pi \cdot D_{FP^2}} \right)}$$

2. Case: Buckling is decisive

$$\boxed{L_{crit} = \sqrt[3]{\frac{1.9594 \cdot E \cdot D_{FP}^2}{4 \cdot \rho_P \cdot b_{max}}}}$$

Buckling is decisive if

$$\boxed{L_{crit} \le L_{FP} + \frac{4 \cdot m_{Fru}}{\pi \cdot \rho_P \cdot D_{FP}^2}}$$

In this case is

$$\boxed{L_{FP} = L_{crit} - \frac{4 \cdot m_{Fru}}{\pi \cdot \rho_P \cdot D_{FP}^2}}$$

4.2 Rear part

$$L_{RP} = \frac{1}{\rho_P}\left(\frac{R_m}{b_{max}} - \frac{4}{\pi \cdot D_{FP^2}} \cdot (m_{FA} + m_T)\right)$$

4.3 Sabot length

The sabot length can be calculated from the entire penetrator length and the free lengths in front and rear.

$$L_S = L_P - L_{Fru} - L_{FP} - L_{RP} - L_{PF}$$

5. Iteration stop

If the difference between old and new sabot length is less then 0.1 mm then go to step 6, else go to step 2 for the next iteration.

Remark: In the spread sheet I am using 5 steps because I am not familiar with “do loops” in Excel. In the main sheet the difference between step 4 and 5 for the sabot length is indicated.

6. Muzzle velocity v_0

The muzzle velocity can be calculated with an empirical equation:

$$v_{0\_L44} = a_c \cdot \tanh\left(b_c \cdot \frac{m_C}{m_{acc}} + c_c\right)$$

m_C = charge weight

m_{acc} = accelerated projectile mass

a_c = 2.6 km/s

b_c = 0.35

c_c = 0.39

v_0 between L44 and L55: Linear interpolation (Δv = 80 m/s)

7. Perforation

The calculation takes place with the Odermatt equation:

Working length

$$L_W = L_P - L_{Fru} \cdot \left(1 - \frac{1}{3} \cdot \left(1 + \frac{D_{FT}}{D_{FP}} + \left(\frac{D_{FT}}{D_{FP}}\right)^2\right)\right)$$

Mean Diameter

$$D_{mean} = \sqrt{\frac{4 \cdot m_P}{\pi \cdot L_W \cdot \rho_P}}$$

Perforation

$$P = a \cdot L_W \frac{1}{\tanh\left(b_0 + b_1 \cdot \frac{L_W}{D_{mean}}\right)} \cdot \cos^m \theta \cdot \sqrt{\frac{\rho_P}{\rho_T}} \cdot e^{\frac{-(c_0 + c_1 \cdot BHNT) \cdot BHNT}{\rho_P \cdot v_T^2}}$$

a	=	0.994
b_0	=	0.283
b_1	=	0.0656
m	=	-0.224
c_0	=	134.5
c_1	=	-0.148

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