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Parametric study on the interior ballistics of 105 and 155 mm artillery guns

Vincent Tanguay
DRDC Valcartier

Defence R&D Canada – Valcartier
Technical Memorandum
DRDC Valcartier TM 2007-350
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Canada

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Abstract

The interior ballistics code IBHVG2 was used to calculate the muzzle velocity and peak acceleration of projectiles ranging in mass from 10 to 50 kg. The simulations were performed with both 105 and 155 mm guns. These were the C3 and LG1 (105 mm) and the M777 (155 mm). For comparison purposes, extended length 52-calibre LG1 and 52-calibre M777 were also considered. Three propellants were investigated: the triple base M31, and two composite propellants, JA2 and the developmental propellant LCT. For every gun-propellant-projectile combination, the propelling charge mass and grain geometry (web) were optimized. The web was optimized to match the maximum breech pressure of the gun, while the charge mass was optimized according to two different criteria: projectile travel at burn-out and peak muzzle velocity. The results provide a good overview of the performance of conventional artillery systems.

Résumé

Le code de balistique intérieure IBHVG2 a été utilisé pour calculer la vitesse à la bouche et l'accélération maximale de projectiles de 10 à 50 kg. Les simulations ont été faites avec des canons de 105 et 155 mm. Ceux-ci sont les C3 et LG1 (105 mm) et le M777 (155 mm). Pour fins de comparaison, l'étude a aussi porté sur un LG1 et un M777 allongés à 52 calibres. Trois formulations de poudres ont été étudiées : la triple base M31, et deux poudres composites, la JA2 et la LCT en développement. Pour chaque combinaison canon-poudre-projectile, la masse de la charge propulsive ainsi que la géométrie du grain ont été optimisés. La géométrie a été optimisée pour atteindre la pression maximale en culasse du canon, tandis que la masse de la charge propulsive a été optimisée selon deux critères distincts : la distance parcourue par le projectile lorsque toute la poudre est brûlée et la vitesse maximale à la bouche. Les résultats donnent une idée globale des performances possibles de systèmes d'artillerie conventionels.

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Executive summary

Parametric study on the interior ballistics of 105 and 155 mm artillery guns

Vincent Tanguay; DRDC Valcartier TM 2007-350; Defence R&D Canada – Valcartier; March 2008.

Background: In the framework of the Artillery Precision Guided Munitions (APGM) project, it is necessary to have some knowledge of the muzzle velocity of conventional artillery systems to serve as initial conditions for exterior ballistics simulations. For this reason, the present study aims at calculating the muzzle velocity and peak acceleration of projectiles ranging from 10 to 50 kg in various artillery gun systems using various propellants to provide an overview of the performance of conventional artillery systems. The simulations were performed with both 105 and 155 mm guns. These were the C3 and LG1 (105 mm) and the M777 (155 mm). For comparison purposes, extended length 52-calibre LG1 and 52-calibre M777 were also considered. Three propellants were investigated: the triple base M31, and two composite propellants, JA2 and the developmental propellant LCT.

Principal results: It is found that muzzle velocity and peak acceleration decrease with increasing projectile mass. It is also found that the extended (52-calibre) guns produce higher muzzle velocity than the guns in service. All 155 mm guns out perform the 105 mm guns. The C3 gun is slightly better than the LG1. The LCT propellant gives better performance than JA2, which in turn, gives better performance than M31.

Significance of results: The results give a good overview of the possible performance of conventional artillery systems. These values are suitable for use as initial conditions for exterior ballistic simulations of guided munitions.

Sommaire

Parametric study on the interior ballistics of 105 and 155 mm artillery guns

Vincent Tanguay ; DRDC Valcartier TM 2007-350 ; R & D pour la défense Canada – Valcartier ; mars 2008.

Introduction : Dans le cadre du projet Artillery Precision Guided Munitions (APGM), il est nécessaire de connaître la vitesse à la bouche de systèmes d'artillerie conventionels qui servira de condition initiale pour des simulations de balistique extérieure. Pour cette raison, l'objectif de cette étude est de calculer la vitesse à la bouche et l'accélération maximale de projectiles de 10 à 50 kg dans divers canons avec diverse poudres pour faire un survol des performances de systèmes d'artillerie conventionels. Les simulations ont été faites avec des canons de 105 et 155 mm. Ceux-ci sont le C3, le LG1 (105 mm) et le M777 (155 mm). Pour fins de comparaison, l'étude a aussi porté sur un LG1 et un M777 allongés à 52 calibres. Trois poudres ont été étudiées : la triple base M31, et deux poudres composites, la JA2 et la LCT en développement.

Résultats principaux : La vitesse à la bouche et l'accélération maximale diminuent lorsque la masse du projectile augmente. La vitesse à la bouche est plus grande pour les canons allongés à 52 calibres que les canons actuellement utilisés. Tous les canons de 155 mm offrent de meilleures performances que les 105 mm. Le canon C3 est légèrement meilleur que le LG1. Le propulsif LCT donne de meilleurs résultats que le JA2, tandis que celui-ci donne de meilleurs résultats que le M31.

Importance des résultats : Les résultats constituent un bon survol des performances possibles des systèmes d'artillerie conventionels. Les données que l'on retrouve dans cette étude peuvent être utilisées comme conditions initiales pour la simulation de balistique extérieure pour les munitions guidées.

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1 Introduction

An important aspect of the Artillery Precision Guided Munitions (APGM) project is exterior ballistics simulations. However, to perform these simulations, one must have knowledge of the muzzle velocity as an initial condition. It is the objective of the present study to estimate the muzzle velocities that can be achieved with conventional artillery systems. These include conventional 105 and 155 mm guns with triple base and composite propelling charges. The muzzle velocities are obtained for various projectile masses from interior ballistics simulations.

2 Scope

The objective is to obtain realistic muzzle velocities in conventional artillery systems as a function of projectile mass. It is not an attempt to optimize the performance of these systems. For this reason, an extensive survey of all gun systems and propelling charges is not included here. Instead, only a limited number of representative gun systems and propelling charges are investigated to determine the performance that can be achieved with conventional artillery systems. A description of the gun systems, propelling charges and projectiles is given in Sections 2.1 to 2.3.

2.1 Gun systems

Two 105 mm gun systems in use by the Canadian Forces (CF) are studied: they are the LG1 and C3. Both these guns are 27 calibres long. For the sake of comparison, a 52 calibre gun system was investigated by considering an LG1 with a longer barrel (no other changes were made to the gun). In the case of the 155 mm, the recently acquired 39 calibre M777 is studied. A hypothetical 52 calibre M777 where only the barrel length was increased is included as well.

2.2 Propelling charges

Three different propellants were investigated: M31 (triple base), JA2 (composite) and LCT (composite). Cylindrical, 7-perforation grain is the grain geometry that was arbitrarily selected. The mass of propellant and the grain web were optimized for every gun system-propellant-projectile combination.

2.3 Projectiles

Since the objective of the Artillery Precision Guided Munition Applied Research Program (APGM ARP) is to develop concepts for gun launched PGMs, a specific projectile was not selected. Instead, the projectile mass was varied from 10 to 50 kg for every gun system-propellant combination. This was done for both the 105 and 155 mm systems. While 50 kg is a very large projectile for 105 mm systems, it could be representative of a heavy rocket-assisted projectile. Likewise, 10 kg is very small for 155 mm systems. It could be representative of a sub-calibre projectile.

3 Methodology

The interior ballistics simulations were performed with IBHVG2 [1]. This computer code uses a lumped-parameter model, i.e., it considers the gases inside the combustion chamber to be uniformly distributed in space. Doing so, an average pressure can be computed as a function of time. The pressure gradient in the gun is then estimated and used to relate the average pressure to the base pressure. This code allows parametric variations and optimization of parameters.

The methodology that was employed in the present study is described by Oberle [2] and used by Archambault [3]. For a given gun system-propellant-projectile combination, one must optimize the propellant mass and grain geometry (grain web). Given a propellant mass, IBHVG2 can optimize the grain web by iteration such that the peak pressure in the chamber just reaches the maximum breech pressure (parameter of the gun system). One can then run simulations for a number of propelling charge masses and select the mass that produces the highest muzzle velocity. Note that, in some systems, the propellant mass that produces that highest muzzle velocity is not necessarily the best choice. As the propellant mass is increased, the muzzle velocity generally increases. However, the distance traveled by the projectile at the time of burn-out (time at which the propellant has all been consumed) increases as well. While the highest muzzle velocity may be reached when the projectile just reaches the muzzle at burn-out, important muzzle velocity fluctuations will occur from shot to shot in such a case [4]. In order to have a reproducible muzzle velocity (very important for precision) one must have the projectile still well inside the barrel at burn-out. Therefore, one can select the optimal charge mass from an acceptable projectile travel at burn-out. In this study, the acceptable projectile travel is obtained from validation simulations of systems in service. It is assumed that these systems in service are reproducible enough and therefore are an appropriate benchmark. Note that since the projectiles to be launched are guided, the fluctuations in muzzle velocity may be compensated for without penalty. Therefore, one may not need to sacrifice muzzle velocity for reproducibility. For this reason, both criteria will be investigated. Further exterior ballistics simulations will determine if the extra muzzle velocity is an advantage.

Note that another limiting factor is the recoil system of the gun. However, since the objective here was not to increase the performance of existing systems, it is assumed that the recoil mechanisms of the guns can accommodate the recoil forces.

4 Simulations

4.1 Input data

The detailed input data for the gun systems and propellants that were used for the interior ballistics simulations are included in Annex A. Also, Annex B contains a sample IBHVG2 input file.

4.2 Validation of simulations

In order to validate the code and the input parameters, simulations were run for both a 105 and a 155 mm system. The 105 mm system is a C3 gun with a 12.86 kg HOW C132 projectile and a 2.165 kg propelling charge of B19T95. A simulation of this system produced a muzzle velocity of 723 m/s, which is in close agreement with the actual system (730.3 m/s [3]). The 155 mm system was a M777 with a 46.9 kg M795 projectile and a 11.7 kg propelling charge of M31. The predicted muzzle velocity is 794 m/s, while the firing tables [5] show a value of 792 m/s. Again, the calculations showed excellent agreement with the actual system.

These simulations show that the burn-out of the propellant charge occurs with the projectile located at 1.20 and 1.94 m from the muzzle for the 105 and 155 mm systems, respectively. Since these systems are in service, it is assumed that these burn-out locations result in acceptable reproducibility. These distances are therefore used to select the optimal propellant mass in other systems in this study.

4.3 Results

All results are tabulated in Annex C. Two tables are included for each gun/propellant combination. The first table shows results where the projectile travel at burn-out was used as a criterion (burn-out criterion), while the second simply optimizes the muzzle velocity, irrespective of projectile travel at burn-out (muzzle velocity criterion). As was previously mentioned, these results may produce important irreproducibility in the muzzle velocity. In some cases (e.g. 52-calibre LG1 gun system with all propellants), a single table is presented because both criteria were met simultaneously, i.e., the maximum muzzle velocity is obtained with a charge mass that results in a projectile travel at burn-out less than the maximum allowable travel. Finally, each table shows the projectile mass (PRWT) in kg, charge weight (CHWT) in kg), web (WEB) in m, maximum breech pressure (PMAX) in MPa, projectile travel at burn-out (X@BO) in m, muzzle velocity (VMUZ) in m/s and peak acceleration (AMAX)

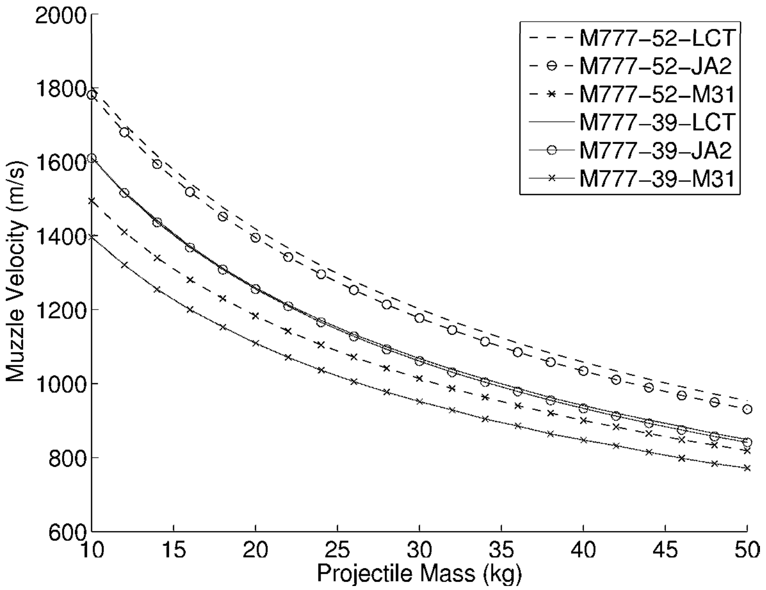

Figure 1: *Muzzle velocity as a function of projectile mass for 155 mm systems*

in Gs.

Figure 1 shows the muzzle velocity as a function of projectile mass for all the 155 mm systems. As expected, higher muzzle velocities are obtained with the 52 calibre gun, compared with the 39 calibre gun. Note that the 52 calibre system design studied was not optimized (chamber volume for example). Therefore, it is possible that even higher muzzle velocities could be achieved with a newly designed 52 calibre gun. The LCT and JA2 propellants both perform significantly better than the M31 propellant. LCT and JA2 produce very comparable results.

Figure 2 shows a the muzzle velocity as a function of projectile mass for the LG1 gun system. Again, the 52 calibre gun results in higher muzzle velocity than the 27 calibre gun. LCT produces slightly outperforms JA2, which in turn, outperforms M31.

Figure 3 is a similar plot for the C3 gun system. Relative propellant performance is the same. The C3 and the LG1 (27 calibre) produce very similar results with the C3 gun only slightly outperforming the LG1 gun.

Figures 4 to 6 show peak projectile acceleration for the various cases.

5 Discussion

The results show, as expected, that the muzzle velocity decreases with increasing projectile mass. The peak acceleration also decreases with increasing projectile mass.

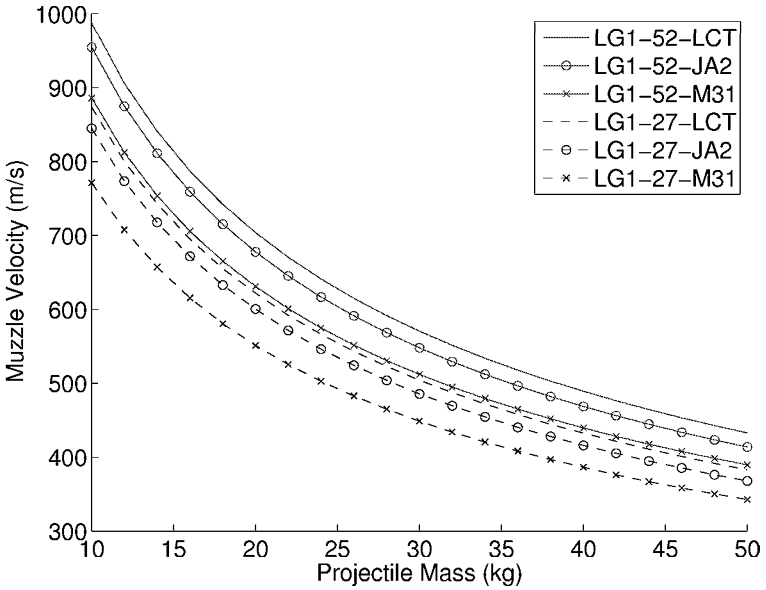

Figure 2: *Muzzle velocity as a function of projectile mass for the 105 mm LG1 gun systems*

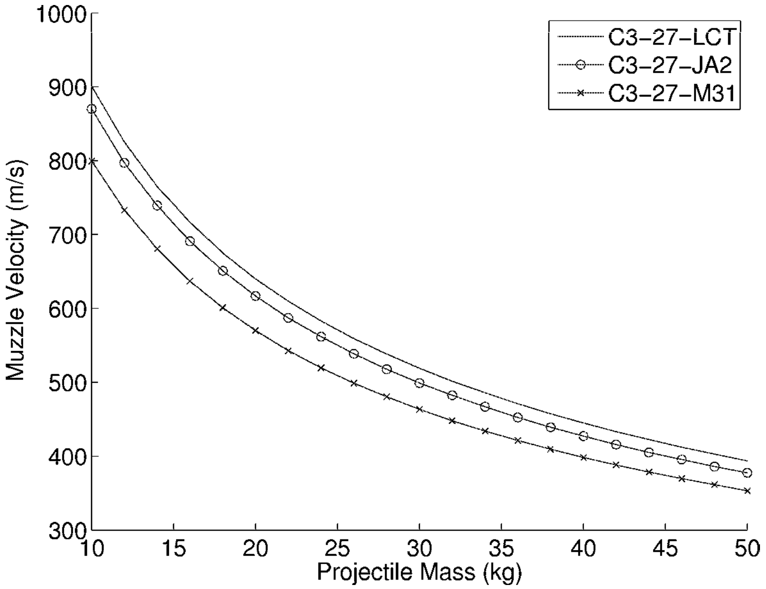

Figure 3: *Muzzle velocity as a function of projectile mass for the 105 mm C3 gun systems*

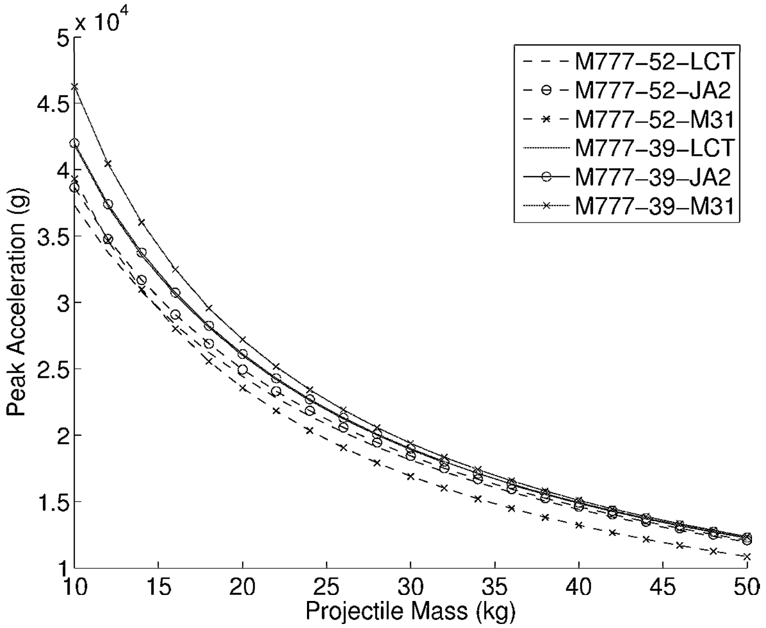

Figure 4: *Peak acceleration as a function of projectile mass for 155 mm systems*

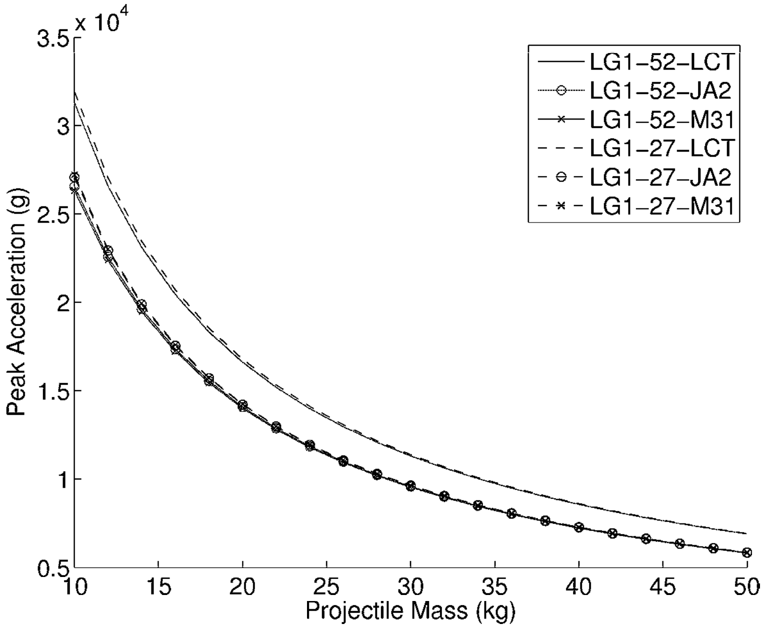

Figure 5: *Peak acceleration as a function of projectile mass for the 105 mm LG1 gun systems*

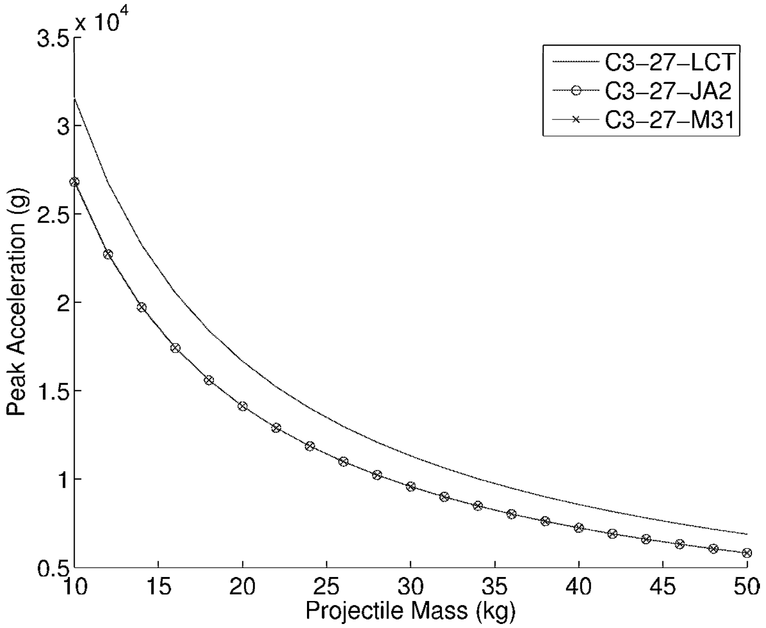

Figure 6: *Peak acceleration as a function of projectile mass for the C3 gun systems*

This is to be expected, since the peak acceleration occurs at peak base pressure which is limited by the gun system. Therefore, from Newton's second law, the peak acceleration should be inversely proportional to the projectile mass.

It was found that the developmental LCT propellant produced the best performance, followed by JA2 and finally M31. This is the case in every gun system that was considered. This is mainly due to the impetus (force) of the different propellants: higher impetus results in higher muzzle velocity.

In 105 mm systems, the extended length, 52-calibre LG1 resulted in the highest muzzle velocity. For the two existing 27-calibre guns, the C3 gun system produces slightly higher muzzle velocities than the LG1. This is mainly because the C3 is slightly longer than the LG1. In the 155 mm systems, the extended length 52-calibre M777 outperformed the standard 39-calibre gun. Finally, all 155 mm guns produce higher muzzle velocity than 105 mm guns (for the same projectile mass). The reason is that the larger calibre offers more surface area for the base pressure to accelerate the projectile.

6 Conclusions

It is found that muzzle velocity and peak acceleration decrease with increasing projectile mass. It is found that the extended (52-calibre) guns produce higher muzzle velocity than the guns in service. All 155 mm guns out perform the 105 mm guns. The C3 gun is slightly better than the LG1. The LCT propellant gives better performance than JA2, which in turn, gives better performance than M31.

References

[1] Anderson, Kurt D, Ronald D.; Fickie (1987), IBHVG2 (Interior Ballistics of High Velocity Guns, Version 2)–A User's Guide, (Technical Report ADB117104) Army Ballistic Research Lab, Aberdeen Proving Ground MD.

[2] Oberle, W. (2001), Methodology for Determining Propelling Charge Dimensions for Layered Propellant Charges, (Technical Report ARL-TN-178) Army Research Lab.

[3] Archambault, P. (2005), Ballistic Simulation for an Increasec Range 105 mm HOW Cartrige Layered Propellant, (Technical Report W7701-9-1326/001/XSK) SNC Technologies Inc., Le Gardeur, Canada.

[4] Corner, J. (1950), Theory of the Interior Ballistics of Guns, New York: John Wiley and Sons, Inc.

[5] (2006), Firing Tables (Abbridged Format) Cannon, 155 mm, Howitzer, M777, (Technical Report C-71-777-000/DF-001).

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Annex A: Input data

Table A.1: *Input parameters for various gun systems*

Parameter	M777-39	M777-52	LG1-27	LG1-52	C3
Chamber Volume (m^3)	0.019155	0.019155	0.0024362	0.0024362	0.0024362
Groove (m)	0.157582	0.157582	0.107	0.107	0.107
Land (m)	0.15499	0.15499	0.105	0.105	0.105
G/L	1.5	1.5	2.433	2.433	1.404
Length (m)	5.03	7.045	2.788	5.46	3.111
Twist (cal/turn)	20	20	55	55	27

Table A.2: *Input parameters for various propellants*

Parameter	LCT	JA2	M31
Density (kg/m^3)	1600	1571	1680
Gamma	1.2658	1.2246	1.258
Force (J/kg)	1180000	1174000	998000
Covolume (m^3)	0.0011765	0.0009649	0.001096
Temperature (K)	2910	3517	2631
Alpha	0.8734	0.9412	0.64
Beta (m/s MPa$^\alpha$)	0.00154	0.001379	0.0035

Annex B: Sample IBHVG2 input file

```
$COMMENT

Calcul des pression et velocite pour les cartouches 105 mm dans le LG1 en
zone 2

Le poids du projectile est de 10-50 kg

On utilise la fonction de pressittive pressure determin en C3

On utilise comme fichier de dpart ERG2Z21LG11BB

On reduitle poids du projectile de 13.225 kg a 12.86 kg

Le propulsif a t remplace par du JA2

Les courbes de pression gnr par ces courbes de rsistance matchent tres bien
la courbe experimentale

Rifling moyen 55:1 IBHVG2 ne simule pas le progressive twist

Le Volume de la chambre disponible pour les gaz est 0.0024362 m3 Le Volume
de la chambre disponible pour la poudre est 0.00220597m3 avec un TPA C20

La simulation est basee sur celle du coup en C3.  Ce coup a des performances
qui sont typiques de la valeur moyenne obtenue dans le C3 a 21C en zone
2 lors des essais de Propellant safety durant la qualification du EGRG2

Le Volume de l'intrusion du projectile ds la chambre est 0.0009322 m3

Le web interieur millieu et exterieur du lot de 7Be93 sont:  0.00113,0.00118
et 0.00106m

Le diametre et la longueur sont 0.00873 m et 0.01228 m Le diametre des perforations
est 0.0004

Les gauges sont positionnes a 56 mm et 212 mm de la face du tube cote culasse

Soit 355 mm-56mm et 355mm-212 mm.i.e, 299mm (0.299 m) et 143 mm (0.143 m)

$TDIS SHOW='TIME'

$TDIS SHOW='TRAV'

$TDIS SHOW='VEL'
```

```
$TDIS SHOW=’ACCL’ REMK = ’GRAVITIES’

$TDIS SHOW=’BRCH’

$TDIS SHOW=’GAGE(1)’

$COMM TDIS SHOW=’GAGE(2)’

$TDIS SHOW=’Z(1)’

$PDIS SHOW=’PRWT’ DECK=’PROJ’

$PDIS SHOW=’CHWT’ DECK=’PROP’

$PDIS SHOW=’WEB’ DECK=’PROP’

$PDIS SHOW=’PMAX’ DECK=’OUT’

$PDIS SHOW=’X@BO’ DECK=’OUT’

$PDIS SHOW=’VMUZ’ DECK=’OUT’

$PDIS SHOW=’AMAX’ DECK=’OUT’

$HEAT TSHL = 0.00011025 CSHL = 460.316 RSHL = 7861.0916 TWAL = 293 H0 =
11.3482 HL = 1

$GUN NAME = ’105MM GUN LG1’ CHAM = 0.0024362 GRVE = 0.107 LAND = 0.105 G/L
= 2.433 TRAV = 2.788 TWST = 55 CLEN = 0.386 NGAG = 2 GLOC= -0.143, -0.299

$PROJ NAME = ’GENERIC’ PRWT = 20

$RESI NPTS=10 FACT=0.05 RFPT=2 TRAV=0, 0.010, 0.013, 0.028, 0.038, 0.048,
0.063, 0.05207, 0.1143, 2.787 PRES=0, 0.0, 95., 85.0, 75.0, 40.0, 20.0,
15.0, 10.0, 5.0

$RECO

RECO=1 RCWT=550 NAME= ’Selon Nicolet’

$INFO RUN = ’ 105 MM GUN’ DELT = 0.0001 GRAD = 1 POPT = 1,0,0,0,2 CONP =
0

$PRIM NAME=’BLK POWDER’ CHWT=0.0332385299 GAMA=1.25 FORC=308760 COV=0.00108381
TEMP=2000
```

```
$PROP NAME ='JA2 19P ' CHWT=2.01 GRAN ='19P' RHO=1571.  GAMA = 1.2246 FORC
= 1174000.  COV=0.0009649 TEMP=3517 EROS= 0.000091 ALPH=0.9412 BETA=0.001379
D=0.00873 L= 0.01228 DP= 0.0004 WEB=0.00113

$PARA VARY='CHWT' DECK='PROP' NTH=1 FROM= 1.9 TO= 2.6 BY=0.01

$PARA VARY='PRWT' DECK='PROJ' FROM=10 TO=50 BY=2

$PMAX VARY ='WEB' DECK='PROP' NTH=1 TRY1=0.00133 TRY2=0.00233 PMAX=330

$END
```

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Annex C: Tabulated results

Table C.1: *Results for the M777 39 calibre gun system with LCT propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	12.9	1.26E-03	370	3.0596	1609.7	41822
12	13	1.33E-03	370	3.0719	1517.5	37229
14	13.1	1.40E-03	370	3.0932	1441.2	33543
16	13.1	1.46E-03	370	3.0856	1371.3	30589
18	13.1	1.52E-03	370	3.0792	1311.8	28113
20	13.1	1.57E-03	370	3.0767	1259.3	26008
22	13.1	1.62E-03	370	3.0758	1212.9	24195
24	13.1	1.67E-03	370	3.0779	1171	22619
26	13.1	1.72E-03	370	3.082	1133.1	21235
28	13.1	1.77E-03	370	3.0848	1099.4	20011
30	13.1	1.82E-03	370	3.0918	1067.7	18920
32	13.1	1.86E-03	370	3.0992	1038.7	17942
34	13.1	1.91E-03	370	3.1072	1012	
36	13.1	1.95E-03	370	3.1157	987.31	16260
38	13	1.98E-03	370	3.0743	962	15550
40	13	2.02E-03	370	3.0842	940.32	14884
42	13	2.06E-03	370	3.0942	920.16	14271
44	13	2.10E-03	370	3.1036	901.45	13708
46	13	2.14E-03	370	3.1141	883.67	13187
48	12.9	2.16E-03	370	3.0707	864.84	12716
50	12.9	2.20E-03	370	3.0819	848.82	12266

Table C.2: *Results for the M777 39 calibre gun system with LCT propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	16.5	1.72E-03	370	4.8581	1666.5	37709
12	16.3	1.77E-03	370	4.751	1575.3	34181
14	16.3	1.85E-03	370	4.7868	1496.5	31115
16	16.4	1.94E-03	370	4.902	1428.1	28495
18	16.5	2.04E-03	370	5.03	1368.1	26281
20	16.4	2.09E-03	370	5.03	1314.6	24473
22	16.3	2.14E-03	370	5.03	1267.1	22898
24	16.5	2.25E-03	370	5.03	1224.1	21413
26	16.3	2.28E-03	370	5.03	1184.9	20227
28	16.5	2.39E-03	370	5.03	1149.1	19059
30	16.3	2.41E-03	370	5.03	1116.4	18114
32	16.2	2.46E-03	370	5.03	1086	17237
34	16.4	2.57E-03	370	5.03	1058	16381
36	16.3	2.60E-03	370	5.03	1031.9	15660
38	16.2	2.64E-03	370	5.03	1007.4	15000
40	16.2	2.70E-03	370	5.03	984.64	14378
42	16.2	2.76E-03	370	5.03	963.18	13805
44	16.1	2.79E-03	370	5.03	943.1	13290
46	16.1	2.85E-03	370	5.03	924.07	12799
48	16	2.88E-03	370	5.03	906.13	12355
50	16	2.94E-03	370	5.03	889.2	11929

Table C.3: *Results for the M777 39 calibre gun system with JA2 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	12.76	1.94E-03	370	3.0896	1609.6	41988
12	12.82	2.06E-03	370	3.0934	1515.6	37398
14	12.84	2.17E-03	370	3.0879	1435.8	33745
16	12.86	2.28E-03	370	3.09	1367.7	30742
18	12.86	2.38E-03	370	3.0865	1308.4	28241
20	12.86	2.47E-03	370	3.0907	1255.2	26116
22	12.86	2.56E-03	370	3.0945	1209.1	24288
24	12.84	2.65E-03	370	3.0944	1165.9	22707
26	12.82	2.73E-03	370	3.093	1127.7	21319
28	12.8	2.81E-03	370	3.0944	1092.6	20091
30	12.78	2.88E-03	370	3.0966	1060.6	18996
32	12.74	2.95E-03	370	3.0865	1030.7	18019
34	12.72	3.03E-03	370	3.0901	1003.7	17134
36	12.7	3.10E-03	370	3.0946	978.5	16331
38	12.66	3.16E-03	370	3.0851	954.69	15604
40	12.64	3.23E-03	370	3.0903	932.82	14936
42	12.62	3.30E-03	370	3.0958	912.36	14322
44	12.58	3.36E-03	370	3.0858	892.92	13760
46	12.56	3.42E-03	370	3.0936	874.47	13237
48	12.52	3.48E-03	370	3.0846	856.94	12755
50	12.5	3.54E-03	370	3.0895	840.97	12305

Table C.4: *Results for the M777 39 calibre gun system with JA2 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	15.38	2.52E-03	370	4.8689	1649.8	38892
12	15.3	2.64E-03	370	4.8354	1556.6	35043
14	15.28	2.77E-03	370	4.8691	1477.2	31843
16	15.3	2.91E-03	370	5.03	1408.5	29153
18	15.32	3.05E-03	370	5.03	1347.9	26882
20	15.42	3.21E-03	370	5.03	1294.9	24903
22	15.32	3.30E-03	370	5.03	1246.9	23274
24	15.28	3.41E-03	370	5.03	1204	21824
26	15.38	3.58E-03	370	5.03	1164.9	20501
28	15.22	3.63E-03	370	5.03	1129.1	19401
30	15.16	3.72E-03	370	5.03	1096.2	18388
32	15.16	3.84E-03	370	5.03	1066	17461
34	15.1	3.93E-03	370	5.03	1038.1	16636
36	15.2	4.09E-03	370	5.03	1012.1	15856
38	15.12	4.16E-03	370	5.03	987.82	15176
40	15.04	4.24E-03	370	5.03	965.09	14552
42	14.98	4.32E-03	370	5.03	943.75	13975
44	15	4.44E-03	370	5.03	923.68	13430
46	15.02	4.56E-03	370	5.03	904.82	12927
48	14.96	4.63E-03	370	5.03	886.97	12469
50	14.92	4.72E-03	370.01	5.03	870.07	12041

Table C.5: *Results for the M777 39 calibre gun system with M31 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	9.7	4.76E-04	370	3.0942	1395.8	46244
12	10	5.32E-04	370	3.104	1320.5	40445
14	10.2	5.80E-04	370	3.0813	1254.6	36032
16	10.4	6.27E-04	370	3.0855	1200	32487
18	10.6	6.75E-04	370	3.1131	1153.1	29577
20	10.7	7.14E-04	370	3.0823	1109.1	27198
22	10.8	7.52E-04	370	3.0641	1070.6	25174
24	10.9	7.90E-04	370	3.0574	1036.3	23430
26	11	8.27E-04	370	3.0617	1005.1	21912
28	11.1	8.64E-04	370	3.0734	976.92	20579
30	11.2	9.01E-04	370	3.0909	951.5	19399
32	11.3	9.38E-04	370	3.1134	928.4	18347
34	11.3	9.64E-04	370	3.0654	904.35	17424
36	11.4	1.00E-03	370	3.0956	885.1	16571
38	11.4	1.02E-03	370	3.0572	864	15815
40	11.5	1.06E-03	370	3.0956	847.3	15108
42	11.6	1.10E-03	370	3.1356	831.99	14462
44	11.6	1.12E-03	370	3.1057	814.56	13883
46	11.6	1.14E-03	370	3.0768	798.4	13349
48	11.6	1.17E-03	370	3.1184	783.47	12854
50	11.7	1.20E-03	370	3.0997	771.33	12383

Table C.6: *Results for the M777 39 calibre gun system with M31 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	13.7	7.93E-04	370	5.03	1501.2	40797
12	14.1	8.76E-04	370	5.03	1417.9	36119
14	14.3	9.41E-04	370	5.03	1347.5	32556
16	14.3	9.85E-04	370	5.03	1287	29761
18	14.4	1.04E-03	370	5.03	1234.5	27353
20	14.6	1.10E-03	370	5.03	1187.8	25259
22	14.6	1.14E-03	370	5.03	1146.1	23543
24	14.8	1.20E-03	370	5.03	1108.6	21976
26	14.8	1.24E-03	370	5.03	1074.6	20665
28	15	1.31E-03	370	5.03	1043.6	19447
30	14.9	1.33E-03	370	5.03	1015.1	18439
32	15	1.38E-03	370	5.03	988.95	17485
34	15.1	1.43E-03	370	5.03	964.53	16625
36	15.1	1.46E-03	370	5.03	941.92	15864
38	15.1	1.50E-03	370	5.03	920.84	15170
40	15.2	1.55E-03	370	5.03	901.06	14518
42	15.2	1.58E-03	370	5.03	882.58	13934
44	15.1	1.60E-03	370	5.03	865.09	13409
46	15.3	1.66E-03	370	5.03	848.65	12885
48	15.2	1.68E-03	370	5.03	833.11	12434
50	15.3	1.73E-03	370	5.03	818.34	11993

Table C.7: *Results for the M777 52 calibre gun system with LCT propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	12.9	1.26E-03	370	3.0596	1609.7	41822
12	13	1.33E-03	370	3.0719	1517.5	37229
14	13.1	1.40E-03	370	3.0932	1441.2	33543
16	13.1	1.46E-03	370	3.0856	1371.3	30589
18	13.1	1.52E-03	370	3.0792	1311.8	28113
20	13.1	1.57E-03	370	3.0767	1259.3	26008
22	13.1	1.62E-03	370	3.0758	1212.9	24195
24	13.1	1.67E-03	370	3.0779	1171	22619
26	13.1	1.72E-03	370	3.082	1133.1	21235
28	13.1	1.77E-03	370	3.0848	1099.4	20011
30	13.1	1.82E-03	370	3.0918	1067.7	18920
32	13.1	1.86E-03	370	3.0992	1038.7	17942
34	13.1	1.91E-03	370	3.1072	1012	
36	13.1	1.95E-03	370	3.1157	987.31	16260
38	13	1.98E-03	370	3.0743	962	15550
40	13	2.02E-03	370	3.0842	940.32	14884
42	13	2.06E-03	370	3.0942	920.16	14271
44	13	2.10E-03	370	3.1036	901.45	13708
46	13	2.14E-03	370	3.1141	883.67	13187
48	12.9	2.16E-03	370	3.0707	864.84	12716
50	12.9	2.20E-03	370	3.0819	848.82	12266

Table C.8: *Results for the M777 52 calibre gun system with LCT propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	17.2	1.83E-03	370	5.3618	1802.1	37001
12	17.1	1.90E-03	370	5.3364	1702.8	33516
14	17.3	2.03E-03	370	5.5645	1618.3	30427
16	17.3	2.11E-03	370	5.6391	1544.5	27973
18	17.3	2.19E-03	370	5.7184	1479.7	25885
20	17.3	2.27E-03	370	5.8036	1422	24087
22	17.4	2.37E-03	370	5.9948	1370.3	22485
24	17.2	2.41E-03	370	5.8782	1323.7	21181
26	17.2	2.48E-03	370	5.9683	1281.3	19961
28	17.3	2.58E-03	370	6.1734	1242.7	18849
30	17.2	2.63E-03	370	6.1559	1206.9	17900
32	17.1	2.67E-03	370	6.1344	1174	17043
34	17.1	2.74E-03	370	6.2293	1143.6	16244
36	17	2.79E-03	370	6.2017	1115.2	15535
38	16.9	2.83E-03	370	6.1709	1088.7	14885
40	16.9	2.89E-03	370	6.2635	1063.9	14272
42	16.8	2.93E-03	370	6.2265	1040.7	13721
44	16.9	3.02E-03	370	6.452	1018.9	13186
46	16.9	3.09E-03	370	6.5494	998.24	12703
48	16.8	3.12E-03	370	6.5047	978.72	12265
50	16.8	3.19E-03	370	6.6011	960.24	11846

Table C.9: *Results for the M777 52 calibre gun system with JA2 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	15.6	2.58E-03	370	5.0816	1780.4	38653
12	15.6	2.73E-03	370	5.1368	1679.5	34778
14	15.5	2.84E-03	370	5.0982	1593.1	31682
16	15.4	2.94E-03	370	5.0641	1518	29091
18	15.3	3.04E-03	370	5.0317	1451.8	26893
20	15.3	3.17E-03	370	5.1136	1394.4	24958
22	15.2	3.26E-03	370	5.0801	1342.2	23322
24	15.2	3.38E-03	370	5.1718	1295.7	21852
26	15.1	3.47E-03	370	5.1357	1253	20588
28	15	3.54E-03	370	5.1006	1213.4	19461
30	14.9	3.62E-03	370	5.062	1177.1	18452
32	14.9	3.73E-03	370	5.1537	1144.9	17520
34	14.8	3.80E-03	370	5.1095	1113.9	16698
36	14.7	3.86E-03	370	5.0618	1085.1	15949
38	14.6	3.92E-03	370	5.1084	1058.2	15265
40	14.6	4.02E-03	370	5.1005	1034.1	14621
42	14.5	4.07E-03	370	5.0437	1010.4	14044
44	14.5	4.17E-03	370	5.1335	989.27	13497
46	14.4	4.22E-03	370	5.0715	968.13	13004
48	14.4	4.32E-03	370	5.1606	949.39	12534
50	14.3	4.36E-03	370	5.0917	930.48	12107

Table C.10: *Results for the M777 52 calibre gun system with JA2 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	16.2	2.75E-03	370	5.7204	1781.7	38015
12	16.1	2.87E-03	370	5.6926	1681.7	34345
14	16	2.99E-03	370	5.6712	1595.8	31322
16	16	3.14E-03	370	5.7798	1521.9	28727
18	16	3.28E-03	370	5.9014	1456.7	26529
20	16.2	3.50E-03	370	6.3357	1399.1	24556
22	16	3.56E-03	370	6.1727	1347.3	23009
24	16	3.70E-03	370	6.3221	1300.7	21577
26	16	3.84E-03	370	6.4803	1258.4	20313
28	15.9	3.93E-03	370	6.4676	1219.5	19215
30	15.9	4.06E-03	370	6.632	1184	18206
32	15.9	4.19E-03	370	6.8041	1151.2	17298
34	15.8	4.27E-03	370	6.7809	1120.8	16496
36	15.7	4.35E-03	370	6.7498	1092.5	15765
38	15.7	4.47E-03	370	7.0279	1066.1	15079
40	15.6	4.54E-03	370	6.8849	1041.4	14466
42	15.6	4.66E-03	370	7.045	1018.3	13886
44	15.6	4.79E-03	370	7.045	996.54	13351
46	15.5	4.85E-03	370	7.045	976.07	12868
48	15.5	4.97E-03	370	7.045	956.59	12408
50	15.4	5.02E-03	370	7.045	938.22	11990

Table C.11: *Results for the M777 52 calibre gun system with M31 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	11	6.25E-04	330	5.1622	1494.3	39302
12	11.2	6.82E-04	330	5.0731	1409.6	34650
14	11.4	7.39E-04	330	5.0488	1339.7	30983
16	11.6	7.96E-04	330	5.0715	1280.7	28018
18	11.8	8.52E-04	330	5.1306	1230	25570
20	11.9	8.98E-04	330	5.09	1183.1	23561
22	12	9.43E-04	330	5.0717	1141.7	21845
24	12.1	9.88E-04	330	5.0729	1104.6	20362
26	12.2	1.03E-03	330	5.0861	1071.6	19067
28	12.3	1.08E-03	330	5.1146	1041.4	17927
30	12.4	1.12E-03	330	5.1551	1013.8	16916
32	12.4	1.15E-03	330	5.073	986.51	16033
34	12.5	1.20E-03	330	5.13	963.43	15220
36	12.5	1.23E-03	330	5.0624	939.98	14502
38	12.6	1.27E-03	330	5.1326	920.22	13833
40	12.6	1.30E-03	330	5.0758	899.9	13237
42	12.7	1.34E-03	330	5.1574	882.69	12677
44	12.7	1.37E-03	330	5.1099	864.76	12175
46	12.7	1.40E-03	330	5.0662	847.87	11711
48	12.8	1.44E-03	330	5.1584	833.84	11271
50	12.8	1.47E-03	330	5.1224	818.63	10872

Table C.12: *Results for the M777 52 calibre gun system with M31 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	13.7	8.68E-04	330	7.045	1543.8	36175
12	13.8	9.27E-04	330	7.045	1458.1	32280
14	14	9.96E-04	330	7.045	1385.8	29073
16	14.3	1.08E-03	330	7.045	1324.1	26389
18	14.4	1.13E-03	330	7.045	1269.7	24254
20	14.5	1.19E-03	330	7.045	1221.7	22438
22	14.6	1.25E-03	330	7.045	1178.9	20876
24	14.7	1.30E-03	330	7.045	1140.3	19517
26	14.8	1.36E-03	330	7.045	1105.3	18324
28	14.9	1.41E-03	330	7.045	1073.3	17268
30	15	1.47E-03	330	7.045	1044	16328
32	15	1.51E-03	330	7.045	1016.9	15504
34	15	1.55E-03	330	7.045	991.81	14759
36	15.1	1.60E-03	330	7.045	968.51	14067
38	15.1	1.64E-03	330	7.045	946.77	13451
40	15.1	1.67E-03	330	7.045	926.41	12887
42	15.1	1.71E-03	330	7.045	907.31	12368
44	15.1	1.75E-03	330	7.045	889.32	11890
46	15.2	1.80E-03	330	7.045	872.37	11436
48	15.2	1.83E-03	330	7.045	856.34	11026
50	15.2	1.87E-03	330	7.045	841.14	10644

Table C.13: *Results for the LG1 27 calibre gun system with LCT propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.13	8.81E-04	390	1.5816	873.8	31905
12	2.12	9.46E-04	390	1.5761	799.94	27039
14	2.12	1.01E-03	390	1.5884	742.82	23453
16	2.11	1.07E-03	390	1.5807	695.06	20713
18	2.1	1.12E-03	390	1.5722	654.97	18546
20	2.1	1.17E-03	390	1.5835	621.94	16786
22	2.09	1.22E-03	390	1.575	591.8	15334
24	2.09	1.27E-03	390	1.5879	566.31	14111
26	2.08	1.30E-03	390	1.5761	543.11	13070
28	2.08	1.35E-03	390	1.5887	522.86	12171
30	2.07	1.38E-03	390	1.5766	503.99	11389
32	2.07	1.43E-03	390	1.5881	487.43	10700
34	2.06	1.46E-03	390	1.5738	471.84	10091
36	2.06	1.50E-03	390	1.5862	457.8	9546.3
38	2.05	1.53E-03	390	1.5718	444.41	9058.6
40	2.05	1.56E-03	390	1.5831	432.51	8617.2
42	2.05	1.60E-03	390	1.5948	421.45	8216.8
44	2.04	1.62E-03	390	1.577	410.77	7852.9
46	2.04	1.66E-03	390	1.5893	401	7519.1
48	2.03	1.68E-03	390	1.5717	391.46	7213.2
50	2.03	1.71E-03	390	1.5828	382.89	6930.5

Table C.14: *Results for the LG1 27 calibre gun system with LCT propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.41	1.05E-03	390	2.2702	891.27	31509
12	2.4	1.13E-03	390	2.2907	817.21	26754
14	2.41	1.21E-03	390	2.3763	758.36	23231
16	2.42	1.30E-03	390	2.4659	710.15	20528
18	2.39	1.34E-03	390	2.4047	669.63	18407
20	2.41	1.43E-03	390	2.5327	635.05	16664
22	2.4	1.48E-03	390	2.5439	604.88	15233
24	2.38	1.52E-03	390	2.5067	578.5	14030
26	2.38	1.58E-03	390	2.5532	555.07	12999
28	2.37	1.63E-03	390	2.5527	534.17	12111
30	2.37	1.68E-03	390	2.5979	515.15	11335
32	2.34	1.70E-03	390	2.5023	497.87	10657
34	2.37	1.79E-03	390	2.6883	482.1	10047
36	2.35	1.81E-03	390	2.6312	467.65	9509.4
38	2.32	1.82E-03	390	2.5244	454.31	9027.7
40	2.33	1.88E-03	390	2.6115	441.94	8588.2
42	2.32	1.91E-03	390	2.6003	430.38	8191.4
44	2.34	1.98E-03	390	2.7426	419.67	7827.1
46	2.3	1.97E-03	390	2.5694	409.57	7498.5
48	2.31	2.03E-03	390	2.6571	400.16	7192.8
50	2.32	2.08E-03	390	2.7499	391.23	6911.1

Table C.15: *Results for the LG1 27 calibre gun system with JA2 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.03	1.37E-03	330	1.5923	844.8	27075
12	2.02	1.48E-03	330	1.5811	773.49	22930
14	2.01	1.57E-03	330	1.5683	717.57	19886
16	2.01	1.67E-03	330	1.5866	671.76	17551
18	2	1.76E-03	330	1.5782	632.74	15710
20	2	1.85E-03	330.01	1.5953	600.51	14215
22	1.99	1.92E-03	330	1.5865	571.52	12983
24	1.98	1.99E-03	330	1.5765	546.11	11948
26	1.98	2.07E-03	330	1.5953	524.27	11063
28	1.97	2.13E-03	330	1.5839	504.06	10302
30	1.96	2.19E-03	330	1.5738	485.54	9639.4
32	1.96	2.26E-03	330	1.592	469.59	9055.3
34	1.95	2.32E-03	330	1.5781	454.45	8538.9
36	1.94	2.37E-03	330	1.5657	440.26	8078.6
38	1.94	2.43E-03	330	1.5834	427.93	7664.1
40	1.93	2.48E-03	330.01	1.569	415.82	7291.3
42	1.93	2.54E-03	330	1.5861	405.25	6952
44	1.92	2.58E-03	330	1.5711	394.63	6643.5
46	1.92	2.64E-03	330	1.5885	385.34	6360.9
48	1.91	2.67E-03	330	1.5703	376.15	6101.8
50	1.91	2.73E-03	330	1.5879	367.91	5862.4

Table C.16: *Results for the LG1 27 calibre gun system with JA2 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.34	1.70E-03	330	2.6535	862.61	26703
12	2.29	1.78E-03	330	2.4974	790.67	22697
14	2.28	1.90E-03	330	2.5254	733.27	19711
16	2.28	2.03E-03	330	2.602	686.4	17414
18	2.28	2.15E-03	330	2.6843	646.79	15596
20	2.29	2.29E-03	330	2.788	612.96	14119
22	2.27	2.36E-03	330	2.788	583.7	12905
24	2.25	2.44E-03	330	2.7464	558	11884
26	2.24	2.52E-03	330	2.7612	535.09	11011
28	2.22	2.58E-03	330	2.7056	514.62	10259
30	2.22	2.67E-03	330	2.7803	496.1	9599.5
32	2.21	2.74E-03	330	2.7849	479.32	9021.3
34	2.2	2.81E-03	330	2.7873	464.01	8508.8
36	2.2	2.90E-03	330	2.788	449.85	8050.5
38	2.19	2.96E-03	330	2.788	436.8	7639.9
40	2.19	3.05E-03	330	2.788	424.75	7268.3
42	2.18	3.10E-03	330	2.788	413.54	6932
44	2.17	3.16E-03	330	2.788	403.05	6625.4
46	2.17	3.23E-03	330	2.788	393.24	6344.1
48	2.16	3.28E-03	330	2.788	384.02	6086.3
50	2.14	3.30E-03	330	2.788	375.39	5849.3

Table C.17: *Results for the LG1 27 calibre gun system with M31 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	1.92	5.82E-04	330	1.5762	771.21	27215
12	1.93	6.35E-04	330	1.5897	707.58	23013
14	1.93	6.79E-04	330	1.5864	657.22	19942
16	1.93	7.21E-04	330	1.5856	615.45	17594
18	1.93	7.60E-04	330	1.5849	580.66	15740
20	1.93	7.97E-04	330	1.5845	551.05	14240
22	1.93	8.33E-04	330	1.5842	525.47	13001
24	1.93	8.66E-04	330	1.5852	502.7	11961
26	1.93	8.98E-04	330	1.5856	482.77	11074
28	1.93	9.29E-04	330	1.5864	464.89	10310
30	1.93	9.59E-04	330	1.5878	448.63	9644.6
32	1.93	9.87E-04	330	1.5887	434	9059.8
34	1.93	1.01E-03	330	1.5902	420.54	8541.9
36	1.93	1.04E-03	330	1.5913	408.3	8080
38	1.93	1.07E-03	330	1.5929	396.9	7665.5
40	1.93	1.09E-03	330	1.5947	386.32	7291.5
42	1.92	1.11E-03	330	1.5748	375.96	6953
44	1.92	1.13E-03	330	1.5761	366.88	6643.9
46	1.92	1.16E-03	330	1.5779	358.28	6361
48	1.92	1.18E-03	330	1.5794	350.26	6101.3
50	1.92	1.20E-03	330	1.5813	342.67	5862

Table C.18: *Results for the LG1 27 calibre gun system with M31 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.4	8.26E-04	330	2.5697	801.88	26632
12	2.39	8.85E-04	330	2.5804	734.92	22611
14	2.38	9.39E-04	330	2.5863	681.92	19645
16	2.4	1.01E-03	330	2.6771	638.44	17352
18	2.39	1.06E-03	330	2.6779	602.14	15550
20	2.37	1.09E-03	330	2.645	571.04	14091
22	2.38	1.15E-03	330	2.7036	544.06	12874
24	2.37	1.18E-03	329.99	2.6966	520.5	11855
26	2.36	1.22E-03	330	2.6881	499.47	10985
28	2.38	1.28E-03	330	2.7792	480.71	10229
30	2.35	1.29E-03	330	2.6989	463.75	9578.5
32	2.35	1.33E-03	330	2.7195	448.42	9001.5
34	2.35	1.37E-03	330	2.74	434.35	8489.9
36	2.35	1.40E-03	330	2.7599	421.44	8033.4
38	2.33	1.42E-03	330	2.7067	409.53	7625.5
40	2.34	1.46E-03	330	2.7617	398.46	7254.3
42	2.32	1.47E-03	330	2.7052	388.22	6920.1
44	2.32	1.50E-03	330	2.7221	378.62	6613.7
46	2.31	1.52E-03	330	2.7005	369.69	6334.1
48	2.32	1.57E-03	330	2.7545	361.25	6075.8
50	2.31	1.58E-03	330	2.7318	353.32	5838.9

Table C.19: *Results for the LG1 52 calibre gun system with LCT propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.57	1.17E-03	390	2.839	988.06	31288
12	2.59	1.28E-03	390	3.0278	905.86	26565
14	2.57	1.35E-03	390	3.0304	840.83	23111
16	2.57	1.44E-03	390	3.1246	787.09	20440
18	2.56	1.51E-03	390	3.1663	742.11	18327
20	2.54	1.56E-03	390	3.1445	703.75	16614
22	2.52	1.61E-03	390	3.1173	670.33	15194
24	2.53	1.69E-03	390	3.2532	640.99	13989
26	2.52	1.74E-03	390	3.2737	614.92	12966
28	2.52	1.81E-03	390	3.352	591.58	12080
30	2.51	1.85E-03	390	3.3651	570.51	11310
32	2.49	1.89E-03	390	3.312	551.34	10633
34	2.48	1.93E-03	390	3.3156	533.91	10031
36	2.48	1.99E-03	390	3.385	517.78	9493
38	2.48	2.04E-03	390	3.455	502.93	9009.4
40	2.47	2.08E-03	390	3.4515	489.22	8573.7
42	2.46	2.11E-03	390	3.4481	476.36	8178.3
44	2.45	2.15E-03	390	3.4384	464.42	7817.7
46	2.45	2.20E-03	390	3.5022	453.24	7486.7
48	2.44	2.23E-03	390	3.4894	442.73	7183.4
50	2.44	2.27E-03	390	3.5515	432.85	6903

Table C.20: *Results for the LG1 52 calibre gun system with JA2 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.47	1.87E-03	330	3.3966	954.65	26550
12	2.44	1.99E-03	330	3.3532	874.76	22570
14	2.42	2.12E-03	330	3.3628	811.14	19621
16	2.4	2.23E-03	330	3.3597	758.96	17353
18	2.39	2.34E-03	330	3.4228	715.16	15552
20	2.39	2.48E-03	330	3.5652	677.65	14086
22	2.38	2.58E-03	330	3.621	645.21	12875
24	2.36	2.66E-03	330	3.5815	616.59	11858
26	2.36	2.78E-03	330	3.7196	591.18	10986
28	2.35	2.87E-03	330	3.761	568.41	10236
30	2.33	2.93E-03	330	3.6954	547.88	9582.6
32	2.32	3.01E-03	330	3.7239	529.19	9006.5
34	2.32	3.11E-03	330	3.8533	512.18	8494.5
36	2.31	3.18E-03	330	3.8749	496.48	8038.7
38	2.29	3.23E-03	330	3.7786	482.01	7630.2
40	2.3	3.35E-03	330	4.0209	468.59	7258.7
42	2.29	3.42E-03	330	4.0297	456.13	6923.2
44	2.27	3.45E-03	330	3.9109	444.51	6618.1
46	2.27	3.53E-03	330	4.0334	433.6	6337.4
48	2.26	3.59E-03	330	4.0281	423.39	6080.2
50	2.26	3.68E-03	330	4.1509	413.76	5842.4

Table C.21: *Results for the LG1 52 calibre gun system with M31 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.67	1.00E-03	330	3.3956	886.14	26310
12	2.66	1.07E-03	330	3.4415	812.27	22378
14	2.64	1.13E-03	330	3.4403	753.49	19475
16	2.64	1.20E-03	330	3.5078	705.57	17229
18	2.63	1.25E-03	330	3.531	665.23	15451
20	2.62	1.30E-03	330	3.5482	630.87	14006
22	2.6	1.34E-03	330	3.5181	600.98	12811
24	2.6	1.39E-03	330	3.5692	574.77	11799
26	2.58	1.42E-03	330	3.5289	551.55	10939
28	2.58	1.47E-03	330	3.5739	530.78	10193
30	2.57	1.51E-03	330	3.5717	511.97	9543.3
32	2.56	1.54E-03	330	3.5666	494.91	8971.6
34	2.55	1.58E-03	330	3.5588	479.35	8464.5
36	2.56	1.63E-03	330	3.6449	465.02	8009.5
38	2.54	1.65E-03	330	3.5846	451.8	7603.9
40	2.55	1.70E-03	330	3.6696	439.58	7234.6
42	2.53	1.71E-03	330	3.604	428.2	6902.1
44	2.54	1.76E-03	330	3.688	417.6	6596.5
46	2.53	1.79E-03	330	3.6696	407.63	6318.2
48	2.53	1.82E-03	330	3.7015	398.31	6061.9
50	2.51	1.83E-03	330	3.6273	389.53	5826.7

Table C.22: *Results for the C3 27 calibre gun system with LCT propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.28	9.71E-04	390	1.9183	900.54	31544
12	2.27	1.04E-03	390	1.9243	825.16	26760
14	2.25	1.10E-03	390	1.9005	764.77	23244
16	2.25	1.17E-03	390	1.9276	716.53	20533
18	2.23	1.22E-03	390	1.8977	674.91	18397
20	2.22	1.27E-03	390	1.8939	639.78	16660
22	2.22	1.33E-03	390	1.9193	609.73	15220
24	2.21	1.37E-03	390	1.9122	582.96	14011
26	2.2	1.41E-03	390	1.9048	559.09	12981
28	2.2	1.46E-03	390	1.9265	538.24	12089
30	2.19	1.50E-03	390	1.917	518.89	11314
32	2.18	1.54E-03	390	1.9061	501.34	10633
34	2.18	1.58E-03	390	1.926	485.73	10027
36	2.17	1.61E-03	390	1.9143	470.84	9487.8
38	2.16	1.65E-03	390	1.8991	457.29	9003.7
40	2.16	1.69E-03	390	1.9192	444.92	8565.6
42	2.15	1.71E-03	390	1.904	433.05	8169.1
44	2.15	1.75E-03	390	1.9219	422.44	7806.8
46	2.14	1.78E-03	390	1.9049	412.08	7476.1
48	2.14	1.81E-03	390	1.9223	402.74	7171.5
50	2.13	1.84E-03	390	1.9038	393.6	6891.5

Table C.23: *Results for the C3 27 calibre gun system with LCT propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.46	1.09E-03	390	2.4399	907.72	31293
12	2.45	1.17E-03	390	2.4698	832.1	26580
14	2.45	1.25E-03	390	2.5327	772.07	23093
16	2.43	1.31E-03	390	2.5159	722.84	20426
18	2.43	1.38E-03	390	2.5726	681.62	18303
20	2.4	1.42E-03	390	2.5036	646.42	16590
22	2.42	1.51E-03	390	2.6414	615.84	15155
24	2.41	1.56E-03	390	2.6498	588.93	13956
26	2.4	1.61E-03	390	2.6556	565.05	12933
28	2.4	1.67E-03	390	2.7072	543.55	12048
30	2.39	1.71E-03	390	2.7075	524.32	11278
32	2.39	1.77E-03	390	2.7566	506.72	10599
34	2.36	1.78E-03	390	2.6524	490.69	10001
36	2.36	1.83E-03	390	2.6962	475.92	9463.8
38	2.34	1.86E-03	390	2.6372	462.28	8983.2
40	2.35	1.92E-03	390	2.7303	449.69	8546.1
42	2.35	1.96E-03	390	2.773	438	8150.4
44	2.33	1.98E-03	390	2.705	427.02	7791.4
46	2.34	2.04E-03	390	2.8012	416.79	7460.4
48	2.33	2.07E-03	390	2.7855	407.12	7157.8
50	2.33	2.11E-03	390	2.8247	398.12	6878.1

Table C.24: *Results for the C3 27 calibre gun system with JA2 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.15	1.49E-03	330	1.9246	869.87	26804
12	2.14	1.61E-03	330	1.9252	796.85	22719
14	2.13	1.72E-03	330	1.9247	739.11	19715
16	2.11	1.80E-03	329.99	1.8915	690.72	17417
18	2.1	1.90E-03	330	1.8903	650.78	15596
20	2.09	1.98E-03	330	1.8876	616.69	14119
22	2.08	2.06E-03	330	1.8844	587.01	12898
24	2.08	2.15E-03	330	1.916	561.72	11868
26	2.07	2.22E-03	330	1.9111	538.46	10993
28	2.06	2.29E-03	330	1.9045	517.64	10239
30	2.05	2.35E-03	330	1.8955	498.96	9580.6
32	2.05	2.43E-03	330	1.9275	482.39	9000.8
34	2.04	2.49E-03	330	1.916	466.86	8488.3
36	2.03	2.55E-03	330	1.9055	452.37	8031.2
38	2.02	2.60E-03	330	1.892	439.14	7620.7
40	2.02	2.67E-03	330	1.9224	427.24	7249.2
42	2.01	2.71E-03	329.99	1.907	415.79	6913
44	2	2.76E-03	330	1.891	405.04	6606.8
46	2	2.82E-03	330	1.9188	395.48	6325.8
48	1.99	2.86E-03	330	1.9012	385.96	6068.4
50	1.99	2.93E-03	330	1.9288	377.5	5830.5

Table C.25: *Results for the C3 27 calibre gun system with JA2 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.35	1.72E-03	330	2.7159	878.53	26567
12	2.33	1.84E-03	330	2.7077	805.22	22557
14	2.32	1.97E-03	330	2.7484	746.64	19593
16	2.31	2.09E-03	330	2.7914	698.8	17317
18	2.31	2.21E-03	330	2.88	658.48	15511
20	2.28	2.28E-03	330	2.785	624.13	14056
22	2.27	2.38E-03	330	2.8131	594.2	12845
24	2.27	2.49E-03	330	2.8971	567.96	11824
26	2.25	2.55E-03	330	2.8457	544.72	10957
28	2.24	2.63E-03	330	2.86	523.79	10207
30	2.23	2.71E-03	330	2.8702	504.93	9553.2
32	2.22	2.78E-03	330	2.8767	487.82	8977.9
34	2.22	2.87E-03	330	2.9581	472.12	8466.9
36	2.21	2.94E-03	330	2.9593	457.78	8011.8
38	2.21	3.03E-03	330	3.0407	444.47	7602.3
40	2.2	3.09E-03	330	3.0377	432.17	7233.5
42	2.2	3.17E-03	330	3.111	420.77	6898
44	2.18	3.20E-03	330	3.0219	410.07	6593.7
46	2.18	3.28E-03	330	3.111	400.11	6313.9
48	2.18	3.36E-03	330	3.111	390.71	6056.7
50	2.18	3.44E-03	330	3.111	381.86	5819.8

Table C.26: *Results for the C3 27 calibre gun system with M31 propellant (burn-out criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.1	6.68E-04	330	1.9007	799.37	26869
12	2.1	7.23E-04	330	1.9082	733	22757
14	2.1	7.73E-04	330	1.9152	680.69	19737
16	2.09	8.14E-04	330	1.9022	636.75	17430
18	2.09	8.58E-04	330	1.9092	600.81	15602
20	2.09	8.99E-04	330	1.9166	570.01	14120
22	2.08	9.32E-04	330	1.9007	542.83	12899
24	2.08	9.69E-04	330	1.9072	519.46	11869
26	2.08	1.00E-03	330	1.9135	498.77	10992
28	2.08	1.04E-03	330	1.9194	480.3	10236
30	2.08	1.07E-03	330	1.9261	463.45	9576.4
32	2.07	1.10E-03	330	1.9074	447.82	8998.5
34	2.07	1.13E-03	330	1.9134	433.9	8485.1
36	2.07	1.16E-03	330	1.919	421.17	8027.3
38	2.07	1.19E-03	330	1.9246	409.41	7616.1
40	2.06	1.20E-03	330	1.9041	398.14	7246
42	2.06	1.23E-03	330	1.9096	387.98	6909.4
44	2.06	1.26E-03	330	1.915	378.49	6602.7
46	2.06	1.28E-03	330	1.9201	369.65	6322
48	2.06	1.31E-03	330	1.9253	361.34	6064.2
50	2.05	1.32E-03	330	1.9034	353.14	5827.2

Table C.27: *Results for the C3 27 calibre gun system with M31 propellant (muzzle velocity criterion).*

PRWT	CHWT	WEB	PMAX	X@BO	VMUZ	AMAX
10	2.46	8.66E-04	330	2.7404	816.2	26436
12	2.46	9.34E-04	330	2.7868	748.11	22445
14	2.45	9.91E-04	330	2.8033	694.01	19508
16	2.41	1.02E-03	330	2.7154	649.78	17266
18	2.42	1.08E-03	330	2.7806	612.7	15465
20	2.42	1.13E-03	330	2.8129	581.17	14008
22	2.41	1.18E-03	330	2.8111	553.64	12805
24	2.39	1.21E-03	330	2.7719	529.61	11795
26	2.38	1.24E-03	330	2.764	508.24	10930
28	2.4	1.30E-03	330	2.8596	489.12	10178
30	2.39	1.33E-03	330	2.8489	471.89	9527.5
32	2.39	1.37E-03	330	2.8732	456.21	8953.8
34	2.39	1.41E-03	330	2.897	441.87	8445.3
36	2.37	1.43E-03	330	2.8442	428.72	7993.7
38	2.37	1.46E-03	330	2.8653	416.6	7585.9
40	2.37	1.50E-03	330	2.886	405.37	7217.7
42	2.37	1.53E-03	330	2.9062	394.94	6883.5
44	2.37	1.57E-03	330	2.9262	385.18	6579.1
46	2.34	1.56E-03	330	2.8256	376.05	6302.4
48	2.35	1.61E-03	330	2.8836	367.47	6045.5
50	2.35	1.64E-03	330	2.9012	359.43	5809.3

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The interior ballistics code IBHVG2 was used to calculate the muzzle velocity and peak acceleration of projectiles ranging in mass from 10 to 50 kg. The simulations were performed with both 105 and 155 mm guns. These were the C3 and LG1 (105 mm) and the M777 (155 mm). For comparison purposes, extended length 52-calibre LG1 and 52-calibre M777 were also considered. Three propellants were investigated: the triple base M31, and two composite propellants, JA2 and the developmental propellant LCT. For every gun-propellant-projectile combination, the propelling charge mass and grain geometry (web) were optimized. The web was optimized to match the maximum breech pressure of the gun, while the charge mass was optimized according to two different criteria: projectile travel at burn-out and peak muzzle velocity. The results provide a good overview of the performance of conventional artillery systems.

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