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See AC/225 STANAG distribution

STANAG 4110 JAS (EDITION 4) – DEFINITION OF PRESSURE TERMS AND THEIR INTERRELATIONSHIP FOR USE IN THE DESIGN AND PROOF OF CANNONS OR MORTARS AND AMMUNITION

References: A. MAS/197-LAND/4110, dated 8 May 1998 (Edition 3)
B. PFP(NAAG)D(2002)20, dated 27 September 2002

1. The enclosed NATO Standardization Agreement, which has been ratified by nations as reflected in the **NATO Standardization Document Database (NSDD)**, is promulgated herewith.

2. The references listed above are to be destroyed in accordance with local document destruction procedures.

ACTION BY NATIONAL STAFFS

3. National staffs are requested to examine **their ratification status of the STANAG** and, if they have not already done so, advise the Defence Investment Division through their national delegation as appropriate of their intention regarding its ratification and implementation.

J. MAJ
Brigadier General, POL(A)
Director, NSA

Enclosure:
STANAG 4110 (Edition 4)

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STANAG 4110
(Edition 4)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

NATO STANDARDIZATION AGENCY
(NSA)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: DEFINITION OF PRESSURE TERMS AND THEIR INTERRELATIONSHIP FOR USE IN THE DESIGN AND PROOF OF CANNONS OR MORTARS AND AMMUNITION

Promulgated on 30 November 2005

J. MAJ
Brigadier General, POL(A)
Director, NSA

RECORD OF AMENDMENTS

No.	Reference/date of amendment	Date entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Director, NSA under the authority vested in him by the NATO Military Committee.

2. No departure may be made from the agreement without consultation with the tasking authority. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

4. Ratification, implementation and reservation details have been provided to NSA. They are available on request or through the NSA websites (internet hrrp://nsa.nato.int ; NATO Secure WAN http://nsa.hq.nato.int).

FEEDBACK

5. Any comments concerning this publication should be directed to NATO/NSA - Bvd Leopold III, 1110 Brussels-BE

NATO STANDARDISATION AGREEMENT
(STANAG)

DEFINITION OF PRESSURE TERMS AND THEIR INTERRELATIONSHIP FOR USE IN THE DESIGN AND PROOF OF CANNONS OR MORTARS AND AMMUNITION

Annexes:

A - Definition of Extreme Service Conditions and Calculation of Extreme Service Condition Pressure and Standard Deviation
B - Diagrammatic Representations of the Cannon System Pressure Terms and Relationships (including A Numerical Example).
C - Calculation of System Recoil Impulse using an Empirical Approximation based on the Hugoniot Theory.

Related documents:

STANAG 4113 - Pressure Measurement by Crusher Gauges (with AEP-23)

STANAG 4224 - Large Calibre Artillery and Naval Gun Ammunition Greater than 40mm, Safety Suitability for Service Evaluation

STANAG 4225 - The Safety Evaluation of Mortar Bombs

STANAG 4367 - Thermodynamic Interior Ballistic Model with Global Parameters

STANAG 4425 - Procedure to Determine the Degree of Interchangeability of NATO Indirect Ammunition

STANAG 4493 - Tank Ammunition, Safety and Suitability for Service Evaluation

AIM

1. The aim of this agreement is to standardize the definitions of pressure terms used in the design and safety testing of those cannons, mortars and associated ammunitions that are used by NATO Naval and Army Forces, in order to facilitate interchangeability. It is the intention that these definitions and their interrelationship should be applied as far as is possible to all gun type weapon systems.

AGREEMENT

2. Participating nations agree to adopt the definitions of pressure terms and their interrelationship for use in the design and safety test of cannons or mortars and associated ammunition as set out in this document..

GLOSSARY OF PRINCIPAL TERMS

3. At certain stages during the design and proof of cannons and ammunition it is necessary to specify quantitatively a value for the pressure in the cannon. It is considered necessary to have a NATO list of definitions so that there can be only one interpretation and mistakes are avoided. The following list sets out the essential definitions and their interrelationship. Also included to support interchangeability requirements, is a standard definition of System Recoil Impulse together with an empirical approximation for its calculation.

For the purposes of these definitions the following terms will be used:

The **cannon or mortar** generally consists of

a. The barrel assembly,
b. The breech assembly, and
c. auxiliary equipment.

The **system** consists of a specified combination of

a. cannon,
b. projectile,
c. charge and
d. recoiling mass.

The **chamber pressure** is assumed to be the maximum pressure recorded anywhere in the cannon.

The **standard deviation in pressure** is an overall standard deviation for a specified system and represents the statistical distribution about the mean which is attributable to the summation of variances occurring between cannons, propellant lots, firing occasions and rounds. The method of calculating standard deviation is included in Annex A.

DEFINITION OF PRESSURE TERMS

4. The following list of pressure terms is divided into four groups:

a. Cannon related
b. Projectile related
c. System related
d. Charge related

The definition of these pressure terms includes an explanation of the interrelationships between these groups.

4.1 Cannon Related

4.1.1 Cannon Design Pressure (Cannon DP)
Is the chamber pressure which should not be exceeded statistically by more than one round in 1,000,000 rounds under extreme service conditions as defined in Annex A.

4.1.2 Cannon Design Pressure Curve (Cannon DP Curve)
Is a pressure vs location curve which specifies the particular value of pressure at each point along the tube. Statistically the pressure values should not be exceeded by more than one round in 1,000,000 rounds under extreme service conditions as defined in Annex A.

> **Note:** The Cannon DP and its related DP Curve are based on a theoretical Ballistic Design Pressure Curve derived from preliminary internal ballistic modelling and this may be used for mechanical design of the cannon.

4.1.3 Cannon Safe Maximum Pressure Curve (Cannon SMP Curve)
Is a pressure vs location curve which specifies, as a result of design, the particular value of pressure at each point along the tube which, if exceeded, could result in the occurrence of permanent deformation.

4.1.4 Margin of Safety
Is the difference between the Cannon SMP Curve and Cannon DP Curve at any point along the tube.

4.1.5 Cannon Permissible Maximum Pressure (Cannon PMP)
Is the chamber pressure which should not be exceeded statistically by more than 13 rounds in 10,000 rounds under extreme service conditions as defined in Annex A. Cannon PMP is to be ideally 1.75 standard deviations in pressure less than Cannon DP but may be lower than this (see paragraph 4.1.6).

4.1.6 Cannon Proof Pressure (Cannon PP)
Is the chamber pressure at which a cannon is proofed. A pressure tolerance band about this pressure should be specified. The Maximum Cannon PP is not to exceed the Cannon DP. The Minimum Cannon PP should be ideally, 1.75 standard deviations in pressure less than Cannon DP, ie Cannon PMP. If this does not provide a sufficiently large tolerance to enable proof firings to be kept within this pressure band, a Minimum Cannon PP lower than the optimum Cannon PMP will have to be specified. In this instance Cannon PMP must be reduced in order to coincide with Minimum Cannon PP.

> **Note:** It is the responsibility of the developing nation(s) to demonstrate that the Cannon design adheres to the above at some stage during the development of the Cannon. Tests of individual production Cannon to ensure safety and serviceability are carried out according to respective national policies.

4.1.7 Cannon Fatigue Design Pressure (Cannon FDP)
Is the chamber pressure specified for the fatigue design and test of the cannon components and is the pressure associated with the stated fatigue life. Unless otherwise specified, it shall not be less than the Extreme Service Condition Pressure (See paragraph 4.3.3).

4.1.8 Cannon Fatigue Design Pressure Curve (Cannon FDP Curve)
Is the pressure vs location curve which specifies the particular value of pressure at each point in the tube, consistent with the Cannon FDP.

4.2 Projectile Related

4.2.1 Projectile Design Pressure (Projectile DP)
Is the chamber pressure which should not be exceeded statistically by more than one round in 1,000,000 rounds under extreme service conditions as defined in Annex A.

4.2.2 Projectile Safe Maximum Pressure (Projectile SMP)
Is the chamber pressure which, if exceeded, could result in mechanical or structual damage to the projectile.

4.2.3 Projectile Permissible Maximum Pressure (Projectile PMP)
Is the chamber pressure to which the projectile should not be subjected more frequently than 13 rounds in 10,000 rounds. Projectile PMP is to be ideally 1.75 standard deviations in pressure for a specified system less than Projectile DP but may be lower than this (see paragraph 4.2.4). Projectile PMP is to be specified by the developer. Normally a projectile will be capable of withstanding Cannon PMP. It is only when a projectile has to be limited to some lower pressure that a Projectile PMP will be significant.

4.2.4 Projectile Proof Pressure (Projectile PP)
Is the chamber pressure at which a projectile is proofed. A pressure tolerance band about this pressure should be specified. The Maximum Projectile PP is to be Projectile DP or its corresponding value depending on National design policy. The Minimum Projectile PP is not to be less than Projectile PMP.

> **Note:** If this does not provide a sufficiently large tolerance to enable proof firings to be kept within this pressure band, a Minimum Projectile PP lower than the optimum Projectile PMP will have to be specified. In this instance, Projectile PMP must be reduced in order to coincide with Minimum Projectile PP.

4.3 System Related

4.3.1 System Design Pressure (System DP)
Is the value of Cannon DP or Projectile DP whichever is the lower for a specified system.

4.3.2 System Permissible Maximum Pressure (System PMP)
Is the value of Cannon PMP or Projectile PMP whichever is the lower for a specified system.

4.3.3 Extreme Service Condition Pressure (ESCP)
Is the chamber pressure developed when firing the specified system under extreme service conditions. The method of calculating ESCP is explained in Annex A.

4.3.4 System Recoil Impulse (System RI)
Is the impulse acting on the total recoiling mass of the ordnance due to the pressure exerted by the propellant gas while accelerating the projectile down the bore to a point just outside the muzzle and includes the contribution made by the gases after projectile exit. System Recoil Impulse is an ammunition parameter and is calculated without taking into account the actions of any type of muzzle brake system that may be fitted.

Note: Where a measured value is not available, recoil impulse should be calculated using the internal ballistic code defined in STANAG 4367. (This capability is being planned for Edition 4 of STANAG 4367.) The empirical approximation included at Annex C can be used in lieu of the code or by agreement for exchange of information in support of interchangeability. Other codes and equations may be used to suit national preferences or requirements for systems design.

4.4 Charge Related

4.4.1 Extreme Maximum Operating Pressure (EMOP)
Where the ESCP (population mean) and the corresponding pressure standard deviation σ (populations) are known, then EMOP is the ESCP plus 4.75 standard deviations estimated during the cannon design phase. The EMOP may be equal to but not greater than System DP.

Note: EMOP may be less than System DP because either the pressure standard deviation in production may prove to be less than that estimated during the design phase or the System PMP has been lowered (ie to more than 1.75 standard deviations below System DP) to enable proof firings to be kept within the proof band. (See paragraphs 4.1.6 and 4.2.4.)

4.4.2 Maximum Operating Pressure (MOP)
Where the ESCP (population mean) and the corresponding pressure standard deviation σ (populations) are known, then MOP is the ESCP plus three standard deviations estimated during the cannon design phase. The MOP may be equal to but not greater than System PMP.

Note: MOP may be less than System PMP because the pressure standard deviation in production may prove to be less than that estimated during the design phase.

4.4.3 Upper Pressure Limit for Propellant Proof (UPLPP)
Is that value of chamber pressure which is specified in the propellant specifications as the upper limit of average pressure at 21^{o}C, which may be developed by an acceptable propellant in the form of propelling charges and will impart the specified muzzle velocity to the specified projectile at its standard zone weight, under stated conditions in the specified cannon.

4.4.4 Lower Pressure Limit for Propellant Proof (LPLPP)
Is that value of chamber pressure which is specified in the propellant specifications as the lower limit of average pressure at 21^{o}C, which may be developed by an acceptable propellant in the form of propelling charges and will impart the specified muzzle velocity to the specified projectile at its standard zone weight, under stated conditions in the specified cannon.

4.4.5 Differential Pressure Time Curve (DPT Curve)
Is the pressure vs time curve obtained by subtraction of pressure at the forward end of the chamber from pressure at the breech end of the chamber. The optimum measuring positions are as close to the base of the projectile and the breech face as possible.

4.4.6 Initial Negative Differential Pressure (INDP)
Is the negative value of the differential pressure vs time curve which occurs initially if the projectile base pressure rises faster than the breech pressure. This value is correlated with maximum chamber pressure in pressure oscillation sensitivity tests.

DIAGRAMMATIC PRESENTATIONS

5. Diagrammatic presentations of the interrelationship of the defined pressure terms are attached at Annex B. A numerical example is included at Appendix to Annex B.

IMPLEMENTATION OF THE AGREEMENT

6. This STANAG is implemented when the ratifying nations comply with the definitions in this document in the design and proof of cannons, mortars and associated ammunition for use by the NATO Naval and Army Forces.

DEFINITION OF EXTREME SERVICE CONDITIONS AND CALCULATION OF EXTREME SERVICE CONDITION PRESSURE AND STANDARD DEVIATION

Appendix : Calculation of Mean ESCP and Overall Standard Deviation

1. Introduction

This Annex describes extreme service conditions and calculation of Extreme Service Condition Pressure (ESCP). An Appendix describes the test design and statistical analysis required to estimate overall pressure variance (standard deviation) for the determination of Maximum Operating Pressure (MOP) and Extreme Maximum Operating Pressure (EMOP). The method described, (Appendix), aggregates the relevant information from several independent tests and may be used in the exploratory, experimental, design or development stages of a new system or the introduction of a new component to an existing system when only a limited amount of test data is available. Such estimates can be updated as more data becomes available, and can be used to aid progress towards the undertaking of a full MOP/EMOP test to finalise specification of system safety. Also included in this annex is a brief explanation of the statistical philosophy and related engineering considerations that have been used to develop the methodology described in Appendix. It should be noted that use of this Annex enables calculation of mean maximum safe pressure levels that apply to the cannon chamber. Complete assessment of pressure safety in any system should also take into account pressure levels and limits that apply to the shot travel section of the particular cannon (see paragraph 4.1.2 of the STANAG).

2. Extreme Service Conditions

Extreme service conditions are those at which the highest chamber pressures are experienced and normally occur when firing:

- at the Upper Firing Temperature (UFT)[1], (or at that temperature at which pressures are designed to be at a maximum),

- in a new tube at the peak of any ballistic hump effect, and
  - “ with the projectile which gives the highest pressure, and
  - ” with propellant at Upper Pressure Limit for Propellant Proof (UPLPP).

3. Calculation of the Extreme Service Conditions Pressure (ESCP)

a. The chamber pressure is recorded when firing

- at UFT, (or at that temperature at which pressures are at a maximum),
- on not less than two occasions,
- using not less than two new tubes[2] at the peak of any ballistic hump effect, (or if not available, early first quarter tubes with suitable correction), and
- using not less than two propellant lots, preferably at the UPLPP or otherwise with suitable correction.

[1] Upper Firing Temperature is the temperature to which test items are subjected for hot test firing. This temperature is based on the climatic region that the testing nation and the using nations predict to be the worst-case hot environment that the test item will encounter during operations.

[2] For mortars, only a single instrumented tube may be available.

Each individual series for the above tests should include at least five rounds to disclose possible trends and outliers, preceded by a minimum of two warmer rounds.

A new occasion is defined as when the cannon has been taken out of action for a sufficient period for the cannon to return to ambient temperature combined with at least one of the following circumstances:

- another day;
- a new location;
- a change in ambient conditions.

As many occasions, cannons and lots as possible should be used to provide a large sample and consequently the best estimates of both the ESCP and of the overall standard deviation.

(**Note:** the total number of rounds fired in the test series should not be less than 54.)

The recorded chamber pressures are adjusted to allow for the projectile which gives the highest pressure if different from the projectile used.

The mean adjusted recorded chamber pressure is one estimate of ESCP.

b. Another estimate of the ESCP is calculated by adjusting the UPLPP to

- the UFT using a temperature/pressure coefficient derived by firing, and
- the projectile which gives the highest pressure.

c. The higher of the two estimates made as explained in sub-paragraphs a and b above is the ESCP, which can be used in calculating rough upper limits for MOP and EMOP from aggregated independent tests.

4. Statistical Philosophy and Related Engineering Considerations

In order to help ensure the proper use of the Appendix, the following brief explanation of the concepts is provided.

a. **Standard Deviation**

In this context the Standard Deviation (s) is defined as the overall standard deviation of the adjusted recorded chamber pressures, as determined by the procedures stated in paragraph 3a.

b. **Estimation and Use of Standard Deviations derived from Samples**

The Appendix shows formulas for obtaining estimates of standard deviations, s.
They can be obtained in different ways.

(1) By pooling or averaging

Based on the formula

$$s_p^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2 + ... + (N_m - 1)s_m^2}{N_1 + N_2 + ... + N_m - m}$$

The use of this formula assumes that the samples are drawn from populations with the same σ. If, in addition, all the population means are the same, then the pooled s_p^2 is an unbiased estimate of the common σ^2 (the "within" σ^2). If the population means are different, s_p^2 still remains an unbiased estimate of σ^2, because fixed biased effects or random effects between the populations are eliminated. From the safety point of view, it is important to observe that

$$\left(s_i^2\right)_{min} \leq s_p^2 \leq \left(s_i^2\right)_{max}$$

(2) By grouping the different samples into ONE large sample

Based on a typical formula:

$$s_g^2 = \frac{\sum_i \sum_j \left(x_{ij} - \bar{x}\right)^2}{N-1}$$

where $\bar{x}$ is the overall mean and N is the total number of observations (ie. the total number of rounds fired).

This formula can be used if the different samples are drawn from populations with the same means. However, if they differ significantly, the resulting s_g^2 might considerably overestimate the "within" σ^2.

Grouping may be less reliable than averaging, especially if it is the purpose of estimating the "within" σ^2.

c. **Calculation of the overall standard deviation**

Since $$\frac{\sum_i \sum_j \left(x_{ij} - \bar{x}\right)^2}{N-1}$$
is in general a biased estimator, a better estimator of the overall standard deviation is obtained as the square root of the sum of all variance components.

The following formula is sufficient only to give a first order approximation of overall standard deviation:

$$s = \sqrt{\left(s_a^2 + s_b^2 + s_c^2 + s_d^2\right)}$$

where s_a, s_b, s_c and s_d are round to round, lot to lot, cannon to cannon and occasion to occasion standard deviations respectively.

CALCULATION OF MEAN ESCP AND OVERALL STANDARD DEVIATION

1. Test Approach

In this approach the mean ESCP and its standard deviation are computed using the data from a set of independent tests. The results are used to calculate MOP and EMOP.

2. Calculation of the Mean ESCP

The mean ESCP is calculated by computing the weighted average of the sample means from the selected tests:

$$\overline{x} = \frac{\sum_{i=1}^{m} N_i \overline{x_i}}{\sum_{i=1}^{m} N_i}$$

where

N_i = sample size for test i,

m = total number of tests, and

$\overline{x_i}$ = sample mean ESCP for test i.

The following rules should be observed:

Since the underlying physics of the situation support the premise that the samples are drawn from the same population, usually all of the sample means can be combined as shown. However, as a precaution, the analyst should perform an *F*-test (Fisher) on the equality of the means (as in a one-way ANOVA). The *F*-test should be conducted at the 5% significance level. If any samples are found to be inconsistent, then they should not be used in the weighted average.

3. Calculation of the Overall Standard Deviation

The standard deviation of the ESCP is calculated from the sum of the variances:

Overall Standard Deviation, $s = \sqrt{\left(s_a^2 + s_b^2 + s_c^2 + s_d^2\right)}$

where s_a, s_b, s_c and s_d are the pooled variances for the round to round, lot to lot, cannon to cannon and occasion to occasion variability in ESCP from the set of valid tests. The usual formula for pooling the variances for a particular parameter, say lot to lot, is

$$s_b^2 = \frac{(N_1 - 1)b_1^2 ..... + (N_m - 1)b_m^2}{N_1 + ... + N_m - m}$$

where

N_i = the number of observations from test i ,
m = the number of independent tests,

$$b_i^2 = \frac{N_i \sum_{j=1}^{N_i} x_{ij}^2 - \left(\sum_{j=1}^{N_i} x_{ij} \right)^2}{N_i (N_i - 1)}$$

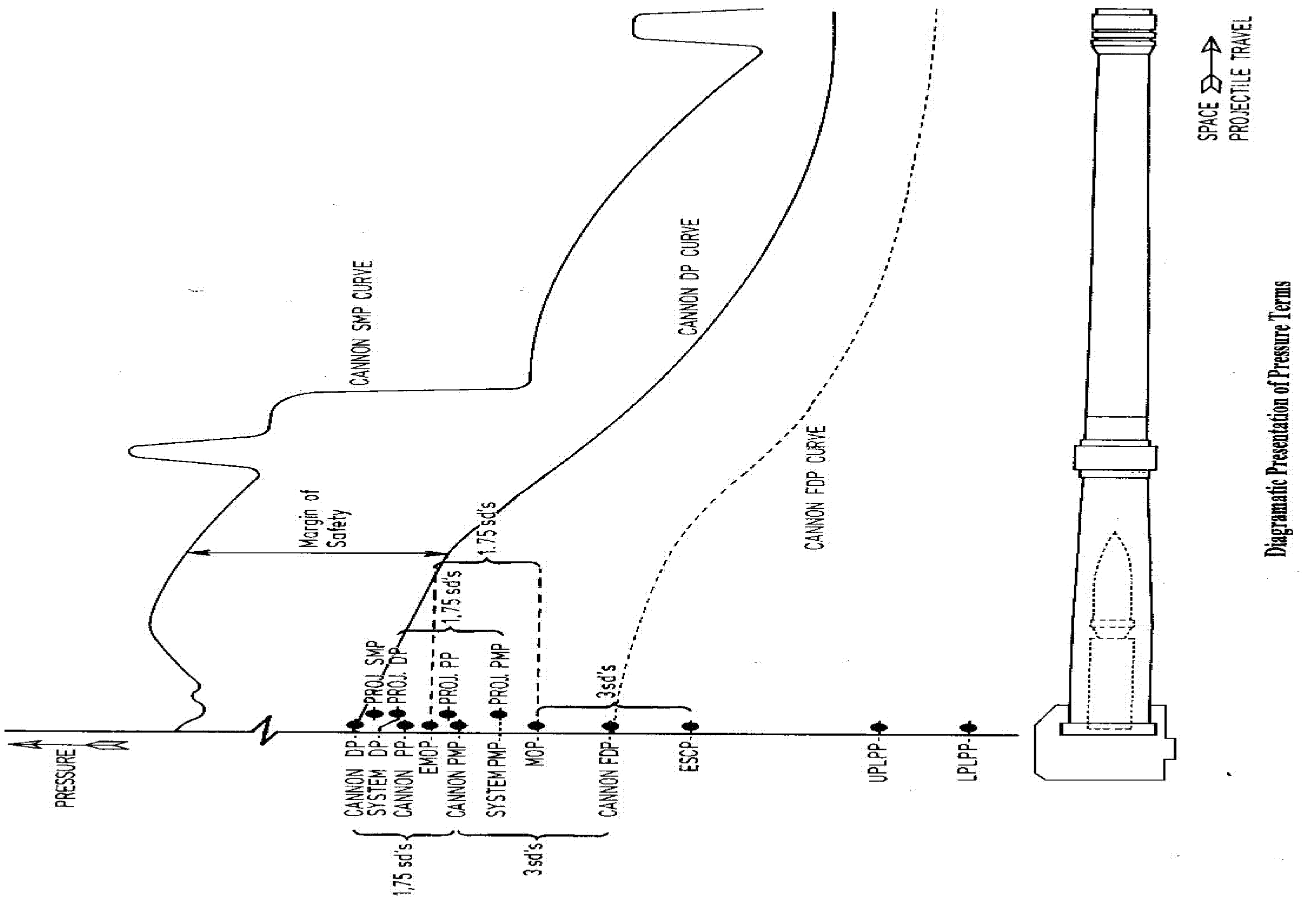
x_{ij} = the pressure of the jth round of the I th group.

The following assumptions apply:

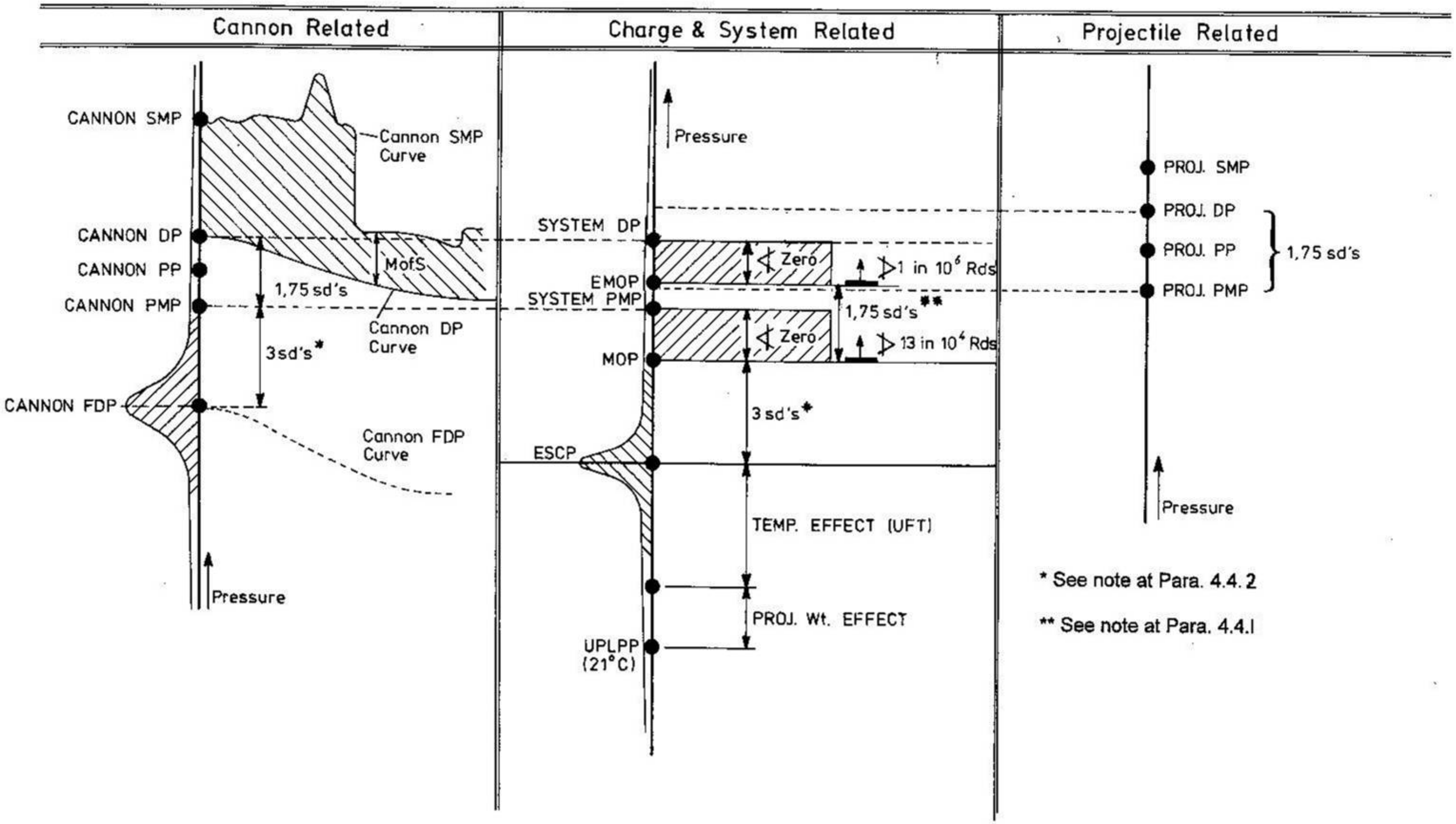
- Outliers have been removed (eg. Grubbs' test for the univariate case, Ref. 1. Barnett and Lewis method for the bivariate case, Ref 2).
- Homogeneity of the variances should be examined before pooling (eg. Bartlett's test, Ref 3 or Levene's test, Ref 4).
- Main factor variations (cannons, occasions, lots) have been isolated, ie. Do not contain other sources of variation (eg. Measurement error, interaction).
- The tests are independent (eg. When estimating gun to gun variability the same cannon should not be used in more than one test).

References:

1. Grubbs, F.E. Procedures for Determining Outlying Observation in samples.
2. Barnett, V. and Lewis, T. Outliers in Statistical Data. Edition 2, Chapter 10. Wiley, 1984.
3. Dixon, W.J. and Massey F.J. Jnr. Introduction to Statistical Analysis. McGraw-Hill, 1969.
4. Levene, H. Robust Tests for Equality of Variances, Contributions to Probability and Statistics in Honor of H. Hotelling, Ed. By Olkin I. et al. Stanford, pp 278-292. 1960. (see also STANAG 4106 for details of Levene's test).



DIAGRAMATIC REPRESENTATIONS OF THE CANNON SYSTEM PRESSURE TRMS AND RELATIONSHIPS (INCLUDING A NUMERICAL EXAMPLE)



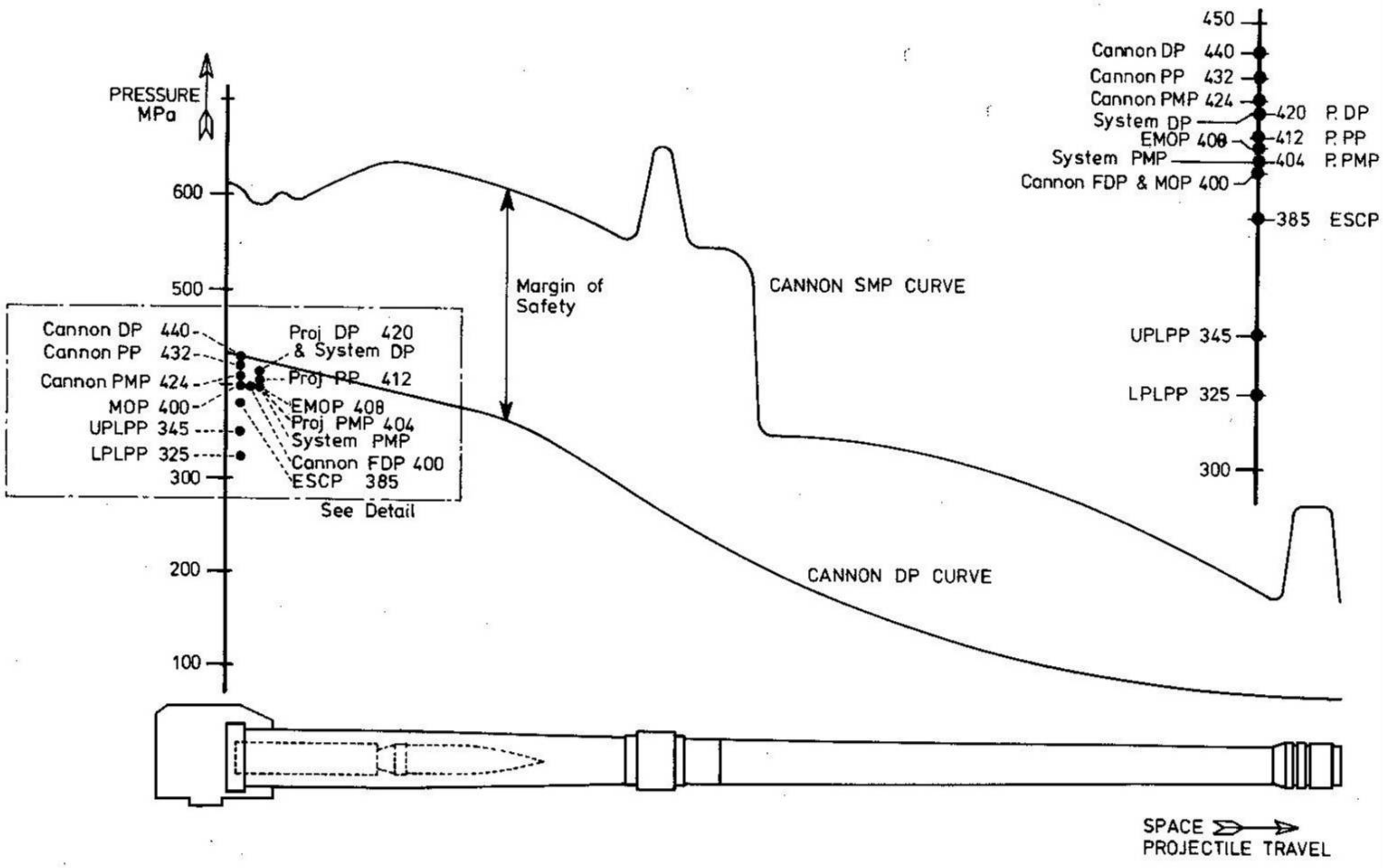
Cannon System Pressure Terms and Relationships

NUMERICAL EXAMPLE OF TYPICAL PRESSURE LEVELS

Serial	Pressure Term	Designation	Value (MPa)	Para. No.	Remarks
1.	Cannon Design Pressure	Cannon DP	440	4.1.1	
2.	Cannon Proof Pressure	Cannon PP Max = Cannon DP Min = Cannon PMP	432 440 424	4.1.6 4.1.1 4.1.5	Tolerance ±0.875sd (Serial 9) too small to permit adjustment of charge hence tolerance increased to ±8MPa.
3.	Projectile Design Pressure	Projectile DP	420	4.2.1	
4.	Projectile Proof Pressure	Projectile PP Max = Projectile DP Min = Projectile PMP	412 420 404	4.2.4 4.2.1 4.2.3	Tolerance ± 0.875sd (Serial 9) too small to permit adjustment of charge hence tolerance increased to ±8MPa.
5.	System Design Pressure	System DP	420	4.3.1	Aligned to Projectile DP. (Serial 3)
6.	System Permissible Maximum Pressure	System PMP	404	4.3.2	Aligned to Projectile PMP. (Serial 4)
7.	Extreme Maximum Operating Pressure	EMOP	408.7	4.4.1	From Serials 9, 10 and 11.
8.	Maximum Operating Pressure	MOP	400	4.4.2	From Serials 9, 10 and 12.
9.	Overall Std. Devtn. $s = \sqrt{\left(s_a^2 + s_b^2 + s_c^2 + s_d^2\right)}$ where sds apply for round to round lot to lot cannon to cannon occasion to occasion	s a b c d	5* 3 1 3 1	Annex A	Method of derivation and calculation should be reported. * First order approximation.
10.	Extreme Service Condition Pressure	ESCP	385	4.3.3	From Serials 13, 14 and 15.
11.	4.75 x Overall Std. Devtn	4.75 x s	23.7	Annex A	From Serial 9.
12.	3 x Overall Std. Devtn	3 x s	15	Annex A	From Serial 9.

Serial	Pressure Term	Designation	Value (MPa)	Para. No.	Remarks
13.	Increase in pressure with charge temperature 21°C to Upper Firing Temperature		35	Annex A	
14.	Effect on pressure of projectile weight		5	Annex A	Difference between highest and lowest weight
15.	Upper Pressure Limit for Propellant Proof	UPLPP	345	4.4.3	
16.	Lower Pressure Limit for Propellant Proof	LPLPP	325	4.4.4	

It should be noted that in this example the Maximum Operating Pressure (MOP) is shown as being 24MPa below the Cannon PMP and 4MPa below the Projectile PMP. Similarly, the Extreme Maximum Operating Pressure (EMOP) is more than 31MPa below Cannon DP and more than 11MPa below Projectile DP. This example reflects typical pressure values found with 155mm systems such as FH70.



Theoretical System – A Numerical Example of the Application of the Pressure Terms as Specified

Notes:

1. The Projectile DP can be the same as the Cannon DP (desirable) but in the illustration used, the pressure has been taken as 20MPa lower.

2. The proof charges used for both Cannon and Projectile testing should embrace not only the pressure requirements specified but also maximum projectile velocity and acceleration likely to be seen in the worst case service environment (normally at the upper firing temperature of either).

3. This numerical example addresses calculations for pressure safety levels applying to the chamber section of a cannon. Additional tests and calculations may be required to ensure that the pressure safety requirements are maintained in the shot travel section of the cannon.

CALCULATION OF SYSTEM RECOIL IMPULSE USING AN EMPIRICAL APPROXIMATION BASED ON THE HUGONIOT THEORY

1. The recoil impulse of a cannon system can be estimated using the following empirical approximation based on the Hugoniot theory and further developed equations, (see References below);

$$I_2 = \left(m_p + \frac{m_c}{2}\right)v_0 + \sqrt{\frac{f - {v_0}^2(\gamma - 1)\left(\frac{m_p}{2\ m_c} + 0.17\right)}{\gamma}}\,m_c\left(1 + \frac{m_c}{12\ m_p}\right)\left(\frac{\gamma + 1}{2}\right)^{\frac{3-\gamma}{2(\gamma-1)}}$$

where $f = P_e \frac{v_b - \alpha m_c}{m_c}$

and I_2 = system recoil impulse [N.s]

m_p = projectile mass [kg]

m_c = propellant mass [kg]

v_0 = projectile exit velocity [m/s]

f = propellant impulse [Nm/kg]

P_e = propellant pressure at exit [N/m^2]

v_b = volume of bore [m^3]

α = propellant covolume [m^3/kg]

γ = ratio of specific heats for propellant gas

References:

1. Hugoniot. Comptes Rendus. Acad. Sci. Paris, Vol. 103 (1886), page 1002.
2. Rateau. Mem. artillerie franc. Acad. Sci. Paris, (1932) page 5.
3. Corner, J. Theory of the Interior Ballistics of Guns, Chapter 9. Wiley, New York, 1950.
4. Oerlikon Pocket Book, Edition 1958.
5. Rheinmetall Pocket Book, Edition 1977.