NATO STANDARD

AEP-70

PROCEDURES TO DETERMINE FIELD ARTILLERY MUZZLE VELOCITY MANAGEMENT, INTERCHANGEABILITY AND PREDICTION

Edition A Version 1

May 2014

NORTH ATLANTIC TREATY ORGANIZATION

ALLIED ENGINEERING PUBLICATION

Published by the
NATO STANDARDIZATION AGENCY (NSA)

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO STANDARDIZATION AGENCY (NSA)

NATO LETTER OF PROMULGATION

28 May 2014

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Director NATO Standardization Agency

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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PROCEDURES TO DETERMINE FIELD ARTILLERY MUZZLE VELOCITY MANAGEMENT, INTERCHANGEABILITY AND PREDICTION.

ANNEXES:

A -	Definitions.
B -	Procedures to calculate, report and exchange muzzle velocity information in the field.
C -	Procedures to calculate and exchange differences in muzzle velocity due to propellant lot variability using National Standard Lots.
D -	Muzzle velocity prediction.
E -	Muzzle velocity management rejection procedures.

RELATED DOCUMENTS:

STANAG 4106 :	PROCEDURES TO DETERMINE THE DEGREE OF BALLISTIC PERFORMANCE SIMILARITY OF NATO INDIRECT FIRE AMMUNITION AND THE APPLICABLE CORRECTIONS TO AIMING DATA.
STANAG 4114 :	MEASUREMENTS OF PROJECTILE VELOCITIES.
STANAG 4119 :	ADOPTION OF A STANDARD CANNON ARTILLERY FIRING TABLE FORMAT.
STANAG 4144 :	PROCEDURES TO DETERMINE THE FIRE CONTROL INPUTS FOR USE IN INDIRECT FIRE CONTROL SYSTEMS.
STANAG 4355 :	THE MODIFIED POINT MASS AND FIVE DEGREES OF FREEDOM TRAJECTORY MODELS.
STANAG 4367 :	THERMODYNAMIC INTERIOR BALLISTIC MODEL WITH GLOBAL PARAMETERS.
STANAG 4425 :	A PROCEDURE TO DETERMINE THE DEGREE OF INTERCHANGEABILITY OF NATO INDIRECT FIRE AMMUNITION.
STANAG 4568 :	PROCEDURES TO DETERMINE THE LEVELS OF PERFORMANCE (MUZZLE VELOCITY, PRESSURE) AND ASSOCIATED QUALITY OF IN-SERVICE LARGE CALIBRE PROPELLING CHARGE LOTS.
AOP-29 :	NATO INDIRECT FIRE AMMUNITION INTERCHANGEABILITY.

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AIM:

1. The aim of this standard is to establish a standardized procedure to calculate, report and exchange muzzle velocity (MV) information between multinational forces and NATO fire control systems.
The procedures cover manual and automated MV prediction techniques and take into consideration future gun systems, such as extended range ordnance, and the use of predicted fire.

2. This standard is not applicable to

   a. Direct fire weapon systems.

   b. Surface to air weapon systems.

DEFINITIONS:

3. The definitions used in this Standard are given in ANNEX A.

DEFINITIONS

Configuration:

A system consisting of the following components:

- Hardware which measures projectile time and/or position at a certain distance from the muzzle.
- Procedures which calculate the projectile muzzle velocity.
- Procedures which determine muzzle velocity management, interchangeability and prediction.

EFC:

The EFC (Equivalent Full Charge) round number is the number of rounds equivalent in erosion effect to that of the primary ammunition fired at (or near) the highest service charge.

Muzzle velocity:

The muzzle velocity (MV) is the projectile´s velocity obtained by extrapolation - back to the muzzle position - after measuring real velocity on the trajectory beyond the intermediate ballistic phase.

The MV in general:

The MV for the projectile is in general expressed as:

$$MV_i = MV_S + \Delta MV_T + \Delta MV_M + \Delta MV_G + \Delta MV_{Lot} + \delta_{MMV} + \delta_{MV,i}$$

where:

- MV_i is the velocity of the i^{th} projectile in a series,
- MV_S is the standard MV under standard conditions taken from the firing tables, STANAG 4144.
- ΔMV_T is the correction for temperatures different from 21°C (standard propellant temperature).
- ΔMV_M is the correction for projectile mass different from the standard mass (weight).
- ΔMV_G is the correction for the gun.
- ΔMV_{Lot} is the correction for the lot.
- δ_{MMV} and $\delta_{MV,i}$ express errors for the inaccuracy in match respectively due to unknown and/or unmeasured variations.

MV precision:
The round-to-round deviation in MV.

MV occasion - to - occasion variability:
Variability of the average MV due to the influences of gun, propellant and sample size.

An occasion:
An occasion is a number of MV-measurements, obtained by firing a number of rounds with the same gun, in the same conditions at a regular firing rate.

MV management:
MV management is organizing, maintaining and putting into standard format muzzle velocity information for use and interchanging.

MV prediction:
MV prediction is a method to estimate the MV of the next round and/or next occasion based upon MV data from the past and/or other sensor data if available.

MV Variation:
MV Variation is the correction to the AMV applied within the Fire Control System (FCS) selected and entered by the User (national criteria).

Predicted fire:
Predicted fire is a firing technique which gives the possibility of effective first round fire for effect.

Extended range:
Defined as firing ranges beyond 20 km for unassisted projectiles and beyond 30 km for assisted projectiles.

Firing table:
Any fire control equipment for surface-to-surface artillery cannon.

Standard MV (MV_s):
The MV_s of a specified gun or howitzer firing a specified projectile/charge combination is the muzzle velocity for which the relevant firing table is compiled, as described in STANAG 4144.

Firing Table Zero Wear MV (FTZ_wMV):
The FTZ_wMV of a specified gun or howitzer firing a specified projectile/charge combination is the average muzzle velocity of all new guns or howitzers from the family (having no wear).
An estimation of this value can be calculated by the regression analysis of muzzle velocity data (reduced to standard condition of projectile weight and charge

temperature) gathered by different guns or howitzers from the same family with known states of wear and firing the same projectile/charge combination.
The response variable is MV and the explanatory variable is wear. The model is written as:

$$FTZ_{w}MV = MV - G_{W}(x)$$

where:

x is the wear, measured at a specified location at or near the origin of rifling ;
$G_W(x)$ is the function found by the regression analysis.

Firing Table Zero EFC MV ($FTZ_{EFC}MV$):

The $FTZ_{EFC}MV$ of a specified gun or howitzer firing a specified projectile/charge combination is the the average muzzle velocity of all new guns or howitzers from the family (having an EFC = 0).
An estimation of this value can be calculated by the regression analysis of muzzle velocity data (reduced to standard conditions of projectile weight and charge temperature) gathered by different guns or howitzers from the same family with known values of EFCs fired and firing the same projectile/charge combination.
The response variable is MV and the explanatory variable is EFC. The model is written as:

$$FTZ_{EFC}MV = MV - G_{EFC}(x)$$

where:

x is the EFCs fired.
$G_{EFC}(x)$ is the function found by the regression analysis.

Adopted MV (AMV):

The AMV of a gun or howitzer firing a specified projectile/charge combination is the muzzle velocity used in the ballistic computation, under standard conditions.

Charge:

The amount and type of propellant required to fire a projectile, round or shell.

Propellant:

That source which provides the energy required for propelling a projectile. Specifically, an explosive charge for propelling a projectile; also a fuel, either solid or liquid, for propelling a rocket or missile.

Ammunition lot:

A quantity of homogeneous ammunition, identified by a unique lot number, which is manufactured, assembled, or renovated by one producer under uniform conditions and which is expected to function in a uniform manner.

Cartridge:

A cylindrical case of metal containing the charge and the primer.

Abbreviation	Definition
AMV	Adopted MV.
δ_{MMV}	Inaccuracy in MV occasion - occasion variability due to unknown and/or unmeasured variations.
$\delta_{MV\,i}$	Inaccuracy in precision due to unknown and/or unmeasured variations.
ΔMV_{EFC}	EFC correction for the influence from EFC’s fired.
ΔMV_{G}	Correction for the influence from the gun.
ΔMV_{Lot}	Lot correction for the influence from the lot of propellant/charge/cartridge.
ΔMV_{M}	Mass correction for projectile mass difference from the standard mass.
ΔMV_{s}	The difference between MVs and a reference lot
ΔMV_{T}	Temperature correction for temperatures difference from 21°C.
ΔMV_{W}	Wear correction for the influence from wear.
FCI	Fire Control Input
FDC	Fire Direction Centre
G_{EFC}	Regressionfunction based on EFC`s fired
FT	Firing Tables
$FTZ_{EFC}MV$	Firing Table Zero EFC MV in standard FT conditions.
$FTZ_{W}MV$	Firing Table Zero wear MV in standard FT conditions.
$G_{W}(x)$	Regressionfunction based on measured wear
MCAL	Manual calculation
MMV_{oc}	Mean MV, occasion
MV_{MVD}	Measured MV
MVD	MV Device
MV_{i}	The velocity of the i^{th} projectile in a series
MV_{S}	Standard MV is the muzzle velocity for which the relevant firing table is compiled.
NA	National Authority
NSL	National Standard Lot
OUAMV	Old Updated Adopted MV
PMV	Predicted MV, used to calculate firing data.
QE	Quadrant Elevation
RMV_{MVD}	Reduced MV: Is the MV_{MVD} reduced to standard conditions.
σ	Standard deviation
s	Estimated standard deviation
SL	Standard Lot
UAMV	Updated Adopted MV

PROCEDURES TO CALCULATE, REPORT AND EXCHANGE MUZZLE VELOCITY INFORMATION IN THE FIELD

MEASUREMENT AND CALCULATION

1. The occasion mean value.
The occasion mean value is the basic quantity used in the field. After n measurements by a muzzle velocity measuring device (MVD) on an occasion the mean MV value (MMV_{oc}) is calculated as

$$MMV_{oc} = \frac{\sum MV_i}{n} = MV_S + \Delta MV_T + \Delta MV_M + \Delta MV_G + \Delta MV_{Lot} + \delta_{MMV} + \frac{\sum \delta_{MV,i}}{n}$$

and the estimated standard deviation (s) of the δ_{MV} is

$$s_{\delta MV} = \sqrt{\frac{\sum (MV_i - MMV_{oc})^2}{n-1}}$$

The estimated standard deviation of the mean value $s_{MMV,oc}$ is a measure of how well a single occasion will estimate the true MMV. It is calculated as

$$s_{MMV,oc} = \frac{s_{\delta MV}}{\sqrt{n}}$$

The influence from the MVD on the measurements is neglected provided that the MVD meets the demands in STANAG 4114.
The main influence on the size of $s_{MMV,oc}$ comes from

- the quality of the charge ($s_{MV,Lot}$) which is expressed by its contribution to
$\delta_{MV,i}$ and

- the limited number of rounds (n) in an occasion.

2. Outliers, see annex E, should be removed from MV occasions, and warmers or conditioning rounds should be handled as outliers.

3. The MMV_{oc} used in the field.

The MMV_{oc} is used in the field in the following two ways

- to update firing data using current measurements of MMV and
- to calculate ΔMV_{Lot} (assuming that the δ_{MMV} and $\delta_{MV,i}$ are negligible) as

$$\Delta MV_{Lot} = MMV_{oc} - (MV_S + \Delta MV_T + \Delta MV_M + \Delta MV_G)$$

or if ΔMV_G is not known

$$\Delta MV_{Lot} + \Delta MV_G = MMV_{oc} - (MV_S + \Delta MV_T + \Delta MV_M)$$

Whether ΔMV_{Lot} or $\Delta MV_{Lot} + \Delta MV_G$ should be calculated depends on the inaccuracy of ΔMV_G.
In order to reduce the effect of δ_{MMV} on the estimate of ΔMV_{Lot} or ΔMV_{Lot} + ΔMV_G more than one occasion should be used by averaging the individual estimates from each occasion if barrel wear has not changed significantly (from occasion to occasion) or has been corrected for.
Whenever a new propellant lot or, a new gun or a change in configuration is introduced the above procedure should be repeated.

FIELD HANDLING PROCEDURES FOR MUZZLE VELOCITIES AND VELOCI-METERS.

4. Principles.
Procedures used in the field for calculating, reporting and exchanging MV information depend upon how units organize the guns, the MVD and the firing data calculating systems (computers using STANAG 4355 or manual calculation (MCAL) using tabular firing tables STANAG 4119) in the fire direction center (FDC).
The guns can be organized in relation to the calculation of firing data, as

- single guns (eg. autonomous guns) equipped with individual MVD`s or

- grouped guns (eg. batteries, battalions, etc.).

The grouped guns are equipped with a MVD on each gun or on one gun in a group. With grouped guns and a single MVD it is preferable to have the possibility to exchange MV information.
Only in emergency (a defective MVD) is it necessary to exchange MV information for single guns.
Table B - 1 summarizes the principles that can be carried out in the field.

GUNS	LOT NO.	NUMBER OF MVD	FIRING DATA CALCULATION SYSTEM	GROUP
Single	Same	One per gun	STANAG 4355	a
			MCAL	b
Grouped	Same	One per group	STANAG 4355	b
			MCAL	b
		One per gun	STANAG 4355	a
			MCAL	b
	Different	One per group	STANAG 4355	b
			MCAL	b
		One per gun	STANAG 4355	a,b
			MCAL	b

Table B - 1

<u>Group a</u>: The measured/calculated MV / MMV_{oc} can be used directly in the firing data calculation for each gun. The gun, the MVD and the FDC computer are in principle an integrated system.
In this group (a) annex C should be taken into consideration ie, ΔMV_{Lot} is now available for fire control solutions to use.

<u>Group b</u>: The ΔMV_{Lot} or $\Delta MV_{Lot} + \Delta MV_G$ should be used to calculate firing data according to national procedures.

(a) The best way of handling MV information is that every gun has its own MVD. The measured MV enables trajectory calculations to be made (STANAG 4355) without considering the complex intermediate ballistic conditions and it is only necessary in emergency to exchange MV information.

(b) With one MVD for a group of guns (battery and/or battalion) and knowledge of ΔMV_G for each gun, the gun with the MVD can calculate ΔMV_{Lot} which again can be used to calculate MMV for each gun using para. 1. The calculation can only be carried out with the same guntype, charge, projectile type and lot.

(c) Very often because of the problem of deciding on a valid value of ΔMV_G, the guns are grouped in classifications with nearly the same value of ΔMV_G. In this situation $\Delta MV_G + \Delta MV_{Lot}$ is calculated from the MVD-gun and used for the other guns in the class.

The same ΔMV_{Lot} can be applied to all projectile types (which are ballisticly similar as described in STANAG 4106) fired.

PROCEDURES TO CALCULATE AND EXCHANGE DIFFERENCES IN MUZZLE VELOCITY DUE TO PROPELLANT LOT VARIABILITY USING NATIONAL STANDARD LOT.

INTRODUCTION.

1. Scope.
This annex describes procedures to calculate, report and exchange predetermined ΔMV_{Lot} (ie, not determined in field) based on a national standard lot amongst multinational forces or NATO fire control systems. Exchange of predetermined ΔMV_{Lot} can only be done among propellant charges mentioned in clear or shaded cells in AOP 29, NATO INDIRECT FIRE AMMUNITION INTERCHANGEABILITY.

2. National standard lot
For each type of propelling charge or for different types of propelling charges according to paragraph 1, ΔMV_{Lot} can be determined by using a National Standard Lot (NSL) as reference STANAG 4568.
To determine the lot to lot deviation this NSL has to be fired simultaneously together with all the lots in question. This method demands only that the storage of the NSL must take place under conditions in accordance with national procedures.

NATIONAL PROCEDURES.

3. Calculation.
In order to be able to exchange ΔMV_{Lot} each country must select a NSL:

- For each type of propelling charge or
- for different types of propelling charges according to paragraph 1.

When a new lot is introduced to the artillery and only if this lot has to be used either among various artillery units or in a multinational/NATO force, the National Authority (NA) should initiate a test firing to measure the MV.
Before the test firing the NA has to make the decision - what charge/charges from this particular lot does the artillery really need to use.
The selected charges must then be fired together with the same charges from the NSL. The measurement of MV and the calculation of the average MV for each selected charge has to be based on national procedures, but it is recommend that there are at least 5-6 valid rounds in each series. Outliers have to be rejected according to ANNEX E. The difference in the average measured MV for each chosen charge (corrected to a standard temperature of 21° C and a standard projectile weight) will then be an estimate of ΔMV_{Lot} for the tested lot. The ΔMV_{Lot} may be applied into the FCS as a MVV manually or via the FCS database.

4. Report.
NA has to build up a data base containing the results from all the test firings. It is recommended that the NA once a year publish to all artillery units a list containing for each type of propellant:
- Lot and
- ΔMV_{lot} for each selected charge.
The artillery units pick out data for actual lot and store them so they can be used directly in case of mobilization, exercises and so on.

EXCHANGE ΔMV_{Lot} AMONG NATO-COUNTRIES.

5. A special report (see fig. 1) has to be used if two NATO-countries want to exchange ΔMV_{Lot}. In order to determine the ΔMV_{Lot} the procedures in paragraph 3 are to be followed. The selected charges (from the other country) must be fired together with the same charge either from the NSL or from another lot mentioned in the list published by NA. These are referred to as the test lot and the reference lot respectively in Figure 1.

6. Use of ΔMV_{Lot} among NATO countries.
The following examples are provided to illustrate the use of the information found in Figure 1. Other possibilities also exist. All calculations assume that the paired comparison test in para. 3, eliminates the gun and occasion effects on ΔMV_{Lot}.

a. Use of ΔMV_{Lot} by the receiving nation.
If the reference lot in Figure 1 is also the NSL of the receiving country, then simply add the ΔMV_{Lot} to the NA data base report of the receiving nation following normal procedures.
If the reference lot in Figure 1 is not the NSL but is in that nations data basereport, then algebraically add the difference in MV between the reference lot and the NSL to the ΔMV_{Lot} in Figure 1 and enter the result in the database.

b. Use of ΔMV_{Lot} by the donor nation.
If the test lot provided by the donor nation is in the donor nations database report, then the donor can add the receiving nations reference lot to its database by algebraically adding the ΔMV_{Lot} from Figure 1 to the difference in MV between the test lot and its NSL (found in its own database report).

c. Use of ΔMV_{Lot} to combine NA database.
If the two nations represented in Figure 1 exchange their data base reports, then they can each add all of the others database values to their own reports by following the general procedure in para. b above. For example, the donor nation can add (algebraically) the difference in MV between any other lot in the receiving nations database and the reference lot in Figure 1 to the ΔMV_{Lot} in Figure 1 to estimate the difference from its own NSL.

FORM TO EXCHANGE ΔMV_{Lot}

Country .... Date: ....

National Authority ....

Propellant type ....

Test lot .... Country: ....

Ref. lot .... Country: ....

Projectile type and weight ....

Gun/Howitzer

- Type ....
- Identification ....
- Firing Table ....

Charge	$\Delta MV_{Lot} = MV_{Test\ lot} - MV_{Ref.\ lot}$ [m/s.]	MV_S [m/s]

Figure 1

MUZZLE VELOCITY PREDICTION

INTRODUCTION

1. **Purpose**. The purpose of Muzzle Velocity (MV) management is to improve the accuracy of predicted fire by reducing the effect of MV variability. The degree of improvement is dependent on the level of sophistication of the management strategy which depends on the

   a. availability and scale of issue of

      (1) Fire control instruments.

      (2) MV measuring Device (MVD).

   b. interfacing between the two.

2. **Adopted MV (AMV)**. The AMV for a projectile/charge combination is the velocity to be used by the fire control instruments for the calculation of the data, under standard conditions, for the next round to be fired (MV_i) or the next occasion (MMV_{OC}).

3. **Interchangeability and MV Prediction**. To be interchangeable MV data must be available for standard firing conditions. Therefore MV prediction is considered in two stages:

   a. The expected MV of the gun when firing a projectile of standard weight at standard charge temperature and,

   b. The correction of expected MV for non-standard projectile weight and charge temperature.

MV PREDICTION

4. **Prediction for Standard Firing Conditions**.

   a. **MVD Not Available**. In order of priority.

      (1) **Wear Data Available**. If wear data is available:

      $AMV = FTZ_W MV + \Delta MV_W$

      where:

      $FTZ_W MV$ is the MV at zero wear.

ΔMV_W is the correction for wear which is calculated for each ammunition combination using the regression function $G_W(x)$. If wear data are not collected for all ammunition combinations $G_W(x)$ may be estimated using the interior ballistic model (STANAG 4367) which has been calibrated by matching known wear data.

(2) **Equivalent Full Charge (EFC) Data Available**. If EFC data are available:

$AMV = FTZ_{EFC}MV + \Delta MV_{EFC}$

where:

$FTZ_{EFC}MV$ is the MV at zero EFCs.

ΔMV_{EFC} is the correction for EFCs fired which is calculated for each ammunition combination using the regression function $G_{EFC}(x)$. If EFC data are not collected for all ammunition combinations $G_{EFC}(x)$ may be estimated using the interior ballistic model (STANAG 4367) which has been calibrated by matching known EFC data.

(3) **Wear/EFC Data Not Available**. If no wear or EFC data are available:

$AMV = MV_S$

where:

MV_S is the standard MV under standard conditions taken from the firing tables, STANAG 4144.

b. **MVD Available**. In order of priority.

(1) **Continuous Updating**. When a MVD is available for each gun the AMV can be updated round by round:

AMV = UAMV

where:

UAMV is the updated AMV which is the output of a MV prediction algorithm the input to which is the Measured MV (MV_{MVD}).

(2) **Periodic Updating**. Provided at least one MVD is available periodic updating is possible.

(a) When the AMV is not updated round by round in the fire control instrument it will be updated periodically when the difference between AMV and the UAMV exceeds a nationally specified threshold.

AMV = UAMV when it is decided to update AMV

(b) When this strategy is adopted national procedures may be used to fully utilise the MV data available on a round to round basis.

Note: The continuously changing difference of the UAMV-AMV may be entered (either manually or automatically) into the FCS using the MVV.

c. **AMV Updates**. AMVs are updated when nationally specified thresholds for the following are exceeded:

(1) Number of rounds fired or,

(2) EFCs or

(3) Measured wear or,

(4) Other national criteria.

5. **Prediction for Non-standard Firing Conditions**.

$PMV = AMV + \Delta MV_M + \Delta MV_T + \Delta MV_{Lot}$

where:

PMV is the predicted MV used to calculate firing data for the next round or next occasion.

ΔMV_M is the correction for projectile mass different from the standard mass (weight).

ΔMV_T is the temperature correction for temperatures different from 21°C (standard propellant temperature).

ΔMV_{Lot} is the correction for the differences in propellant lot performance from MV_S. If ΔMV_{Lot} data are not available for all ammunition combinations, it may be estimated using the interior ballistic model (STANAG 4367) which has been calibrated using known data. If no ΔMV_{Lot} data are avaible, then ΔMV_{Lot} will be included in AMV.

ALGORITHMS FOR PREDICTING AMV

6. MV_{MVD} obtained from the MVD is reduced to standard conditions. This Reduced MV (RMV_{MVD}) is the input to the AMV algorithm. RMV_{MVD} can be calculated for individual rounds or the average of several rounds in an occasion.

$$RMV_{MVD} = MV_{MVD} - \Delta MV_M - \Delta MV_T - \square MV_{Lot}$$

Prediction algorithms are categorised as either static or dynamic. Regardless of the category in use different algorithms may be used for early rounds in a series and subsequent round in the same series.

7. **Static Algorithms**. Static algorithms are the result of the statistical analysis of previously gathered MV data. They do not require the availability of a MVD to be implemented in the field. The resulting AMV is used to calculate PMV in para. 5. Two methods are available.

   a. **MV/Wear Relationship**. The MV/Wear relationship for a projectile/charge combination is the regression of sets of MV data gathered at known conditions of barrel wear. It takes the form:

   $$AMV = FTZ_W MV + G_W\ (Wear)$$

   where:

   G_W is the regression function described in para. 4.a.(1).

   A quadratic wear curve will be used for the Gw function.

   b. **EFCs**. The MV/EFC relationship for a projectile/charge combination is the linear regression of sets of MV data gathered at known EFC values. It takes the form:

   $$AMV = FTZ_{EFC} MV + G_{EFC}\ (EFCs\ fired)$$

   where:

   G_{EFC} is the regression function described in para. 4.a.(2).

8. **Dynamic Algorithms**. Dynamic algorithms require the availability of a MVD. The data collected is used to calculate an UAMV. These algorithms are either simple or complex.

   a. **Simple Dynamic Algorithms**. Simple dynamic algorithms use a running average formula to calculate the UAMV based on the RMV_{MVD} of the last data collected.

$$UAMV = (1 - a) \cdot RMV_{MVD} + a \cdot OUAMV$$

where:

OUAMV is the Old UAMV, ie., the UAMV calculated using the RMV_{MVD} of the penultimate round or occasion and, a is the weighting factor. (If a = 0.5 then equal value is placed on the current MV measurements and on the average of all previous MV measurements. A value greater then this puts greater value on previous performance whereas a value less than this puts greater value on the MV of the last round fired).

In order to maximise the use of data collected for each projectile type, RMV_{MVD} for the various charges can be translated to the reference wear curve for that projectile family using the predetermined relationships between wear curves for the various charges eg.

$$AMV_{\text{Next Round}} = FTZ_W MV_{\text{Next Round}} + G_W(x)_{\text{NextRound}} \left(\frac{AMV_{\text{Last Round}} - FTZ_W MV_{\text{Last Round}}}{G_W(x)_{\text{LastRound}}} \right)$$

where the numerator represents the measured value and the denominator the expected value, and where Next Round could refer to a different family and/or charge than the Last Round.
The last term in the above equation adjusts the MV/wear relationship between the next round and last round to better match the most current wear state of each cannon using the adopted MV data.

Checks to determine if a significant shift in the reference wear curve has occurred can be calculated by testing the null hypothesis $H_0 : |\mu_{UAMV} - \mu_{OUAMV}|$ = 0 m/s against the alternative hypothesis $H_A : |\mu_{UAMV} - \mu_{OUAMV}|$ = 2 m/s using the z statistics for significance level of 10% in α and β by pooling the RMV_{MVD} (translated to the wear curve) from the last N occasions to estimate μ_{UAMV} and N is calculated by solving

$$Var(\overline{MMV_{OC}}) = \frac{Var(MMV_{oc}) + \frac{Var(\delta_{MV})}{n}}{N}$$

and

$$(\mu_{UAMV} - \mu_{OUAMV})^2 = Var(\overline{MMV_{OC}})(z_{\alpha/2} + z_\beta)^2$$

μ_{OUAMV} is estimated by $G_W(x)$. The value of 2 m/s is based on the performance of current systems and the values for $Var(\delta_{MV})$ and $Var(MMV_{OC})$ are functions of the projectile, charge and weapon.

b. **Algorithm Initialisation**. The algorithm is initialised, when required, by either:

(1) Entering the state of the algorithm when the gun last fired or,

(2) By setting

AMV = UAMV = OUAMV

where:

AMV (in priority order) = $FTZ_W MV + \Delta MV_W$ or, $FTZ_{EFC} MV + \Delta MV_{EFC}$ or, MV_S.

c. Simple Dynamic Algorithms (2). Simple dynamic algorithm using running averages and standard propellant lot to estimate the correction for the lot ΔMV_{Lot} and the correction for the gun ΔMV_G from measured occasion mean value MMV_{oc}. The algorithm makes the assumption that one particular propellant lot is defined as standard lot. The standard lot will be used in firings to establish the MV_S, and ΔMV_{Lot} for this lot will therefore be included in MV_S. Thus, ΔMV_{Lot} for the standard lot will per definition be zero.

The algorithm assumes the relation below taken from Annex B where the left side is unknown and needs to be estimated.

$$\Delta MV_{Lot} + \Delta MV_G = MMV_{oc} - (MV_S + \Delta MV_T + \Delta MV_M)$$

The aim is to separate ΔMV_{Lot} and ΔMV_G by using the assumption that ΔMV_{Lot} is zero for the standard lot. Thus, when firing the standard lot one can estimate the correction for the gun since the left side of the above equation only consists of ΔMV_G. A running average separate for each gun is maintained to estimate the correction for the particular gun.

$$U\Delta MV_G = \frac{1}{2}\left[MMV_{oc} - (MV_S + \Delta MV_T + \Delta MV_M) + O\Delta MV_G\right]$$

where $U\Delta MV_G$ is the updated estimate using the current measured occasion mean value, and $O\Delta MV_G$ is the old estimate, i.e. the $U\Delta MV_G$ of the penultimate occasion. The average will only be updated when firing with the standard propellant lot.

Further, when firing other propellant lots than the standard, the $U\Delta MV_G$ for the appropriate gun will be included making ΔMV_{Lot} the only unknown. A similar running average for each propellant lot, other than the standard lot, is maintained to estimate the correction for the particular lot.

$$U\Delta MV_{Lot} = \frac{1}{2}\left[MMV_{oc} - (MV_S + \Delta MV_T + \Delta MV_M) - U\Delta MV_G + O\Delta MV_{Lot}\right]$$

where $U\Delta MV_{Lot}$ is the updated estimate using the current measured occasion mean value, and $O\Delta MV_{Lot}$ is the old estimate, i.e. the $U\Delta MV_{Lot}$ of the penultimate occasion. $U\Delta MV_G$ is the updated correction for the particular gun that was used to fire the occasion.

d. **Complex Dynamic Algorithms**. Complex dynamic algorithms use advanced statistical techniques, eg., Kalmann Filters and Neural Networks, to calculate the UAMV, even for early rounds. They require more computing power than simple algorithms but are more effective.

MV MANAGEMENT REJECTION PROCEDURES.

PLAUSIBILITY CHECKS.

1. When data gathered in the field are used to predict MV on an occasion to occasion or round to round basis it may not be possible/practical to apply rigorous statistical rejection criteria before the data are used. In this event plausibility checks may be used to determine if data should be included or rejected. The criteria used in these checks will be easily applied.

   Example: MV data varying more than 6% from the standard MV with projectile weight and the propellant temperature correction included are rejected.

OUTLIER HANDLING (STATIC).

2. The following outlier tests are recommended:

   a. If the sample size is less than 4, don't test for outliers. Use a plausibility check instead.

   b. If the sample size is greater than or equal to 4 and less than or equal to 7, use the outlier test: Outliers test I.

   This outlier test is applicable if independent estimates of the probable error (standard deviation) in MV are available from previous firings (e.g. firing table data base).
   If not available use outlier test: Outliers test II.

   c. If the sample size is greater than or equal to 7, use the outlier test: Outliers test II.

Outlier test I.

The following outlier test may be used to test a small sample of N muzzle velocities for outliers.

The test requires stable independent estimates of the probable error in MV for the given projectile/propellant/charge combinations. As a rule, the data are available from the firing table data base and stored on a PE_{MV} -table. This independent estimate should include two sources of error, i.e. the round-to-round and the occasion-to-occasion variability.

(1) For the given projectile/propellant/charge combination obtain the probable error in MV from the PE_{MV} -table.

If there is no PE_{MV} available use Outlier test II.

(2) If $N < 4$ then there are not enough data to obtain a reliable estimate. Use a plausibility check instead.
If $N > 7$ then use Outlier test II.

(3) Compute the sample mean MMV :

$$MMV = \frac{MV_1 + MV_2 + ... + MV_N}{N}$$

(4) Find the largest difference $D_k = |MV_k - MMV|$

MV_k represents the largest or smallest observation in the sample.

(5) Test D_k to determine if MV_k is an outlier:

If
$D_k > T \cdot PE_{MV}$ (for critical value (T) see table below)

then MV_k is an outlier.
Remove MV_k from the sample and repeat from step 2 (once only).

Table of Critical Values for T When Independent Estimates of Probable Error are Available

Significance Level (One Sided Test)	5%	2,5%	1%
Sample Size N			
3	2,58	2,90	3,29
4	2,88	3,21	3,60
5	3,08	3,42	3,81
6	3,23	3,57	3,97
7	3,36	3,69	4,09
Sample Size N			
Significance Level (Two Sided Test)	10%	5%	2%

Outlier test II (Grubbs's outlier test) (*).

Given a sample of N data: MV_1 , MV_2 , ..., MV_N

(1) Compute sample mean MMV

$$MMV = \frac{MV_1 + MV_2 + \cdots + MV_N}{N}$$

(2) Compute sample variance $s^2_{\delta MV}$

$$s^2_{\delta MV} = \frac{1}{N-1}\Sigma(MV_i - MMV)^2$$

(3) Find the <u>largest difference</u>

$$D_k = |MV_k - MMV|$$

MV_k represents the largest <u>or</u> smallest observation in the sample.

(4) Calculate $T^* = D_k / s_{\delta\ MV}$

(5) Test T^* to determine if MV_k is an outlier.

If

$T^* > T$ (for critical value T see table below)

then MV_k is an outlier. Remove MV_k from the sample and repeat from step 1 (<u>only once</u>).

Table of Critical Values for T (One-sided Test) When Standard Deviation is Calculated from the Same Sample

Number of Observations n	5% Significance Level	2,5% Significance Level	1% Significance Level
3	1,15	1,15	1,15
4	1,46	1,48	1,49
5	1,67	1,71	1,75
6	1,82	1,89	1,94
7	1,94	2,02	2,10
8	2,03	2,13	2,22
9	2,11	2,21	2,32
10	2,18	2,29	2,41
11	2,23	2,36	2,48
12	2,29	2,41	2,55
13	2,33	2,46	2,61
14	2,37	2,51	2,66
15	2,41	2,55	2,71
16	2,44	2,59	2,75
17	2,47	2,62	2,79
18	2,50	2,65	2,82
19	2,53	2,68	2,85
20	2,56	2,71	2,88
21	2,58	2,73	2,94
22	2,60	2,76	2,94
23	2,62	2,78	2,96
24	2,64	2,80	2,99
25	2,66	2,82	3,01
30	2,75	2,91	
35	2,82	2,98	
40	2,87	3,04	
45	2,92	3,09	
50	2,96	3,13	
60	3,03	3,20	
70	3,09	3,26	
80	3,14	3,31	
90	3,18	3,35	
100	3,21	3,38	

(*) Grubbs, F.E., 1969. Procedures for Detecting Outlying Observations in Samples. Technometrics, Vol. 11, No. 1, pp. 1-21.

OUTLIER HANDLING (DYNAMIC).

3. When using a simple dynamic algorithm (see annex D.8.a.) the following test procedure is
recommended.

$$T^* = \frac{\left|MV_i - MMV_{i-1}\right|}{s_{\delta MV_{i-1}}}$$

MV_i current observation to be tested to determine if it is an outlier
MMV_{i-1} previous mean value (without outlier)
$s_{\delta MV_{i-1}}$ previous s.d. (without outlier)

If T* is greater than the critical value T, then MV_i is considered to be an outlier and not included in the calculation.
Recommended: T = 4 = const.

Recursive calculation of mean MMV and standard deviation $s_{\delta MV}$.

$$MMV_i = MMV_{i-1} + \frac{1}{i}\left(MV_i - MMV_{i-1}\right)$$

$$s^2_{\delta MV_i} = \frac{i-2}{i-1} \cdot s^2_{\delta MV_{i-1}} + \frac{1}{i}\left(MV_i - MMV_{i-1}\right)^2$$

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