Note: The ASCDL/LAB Guidance on Estimation of Measurement Uncertainty – ANNEX B (AL-PD-3064 Ver 1.0) was used as a template when writing this measurement uncertainty report.

Test Method Information

Two analysts perform this test method

- The two analysts used a 48 inch and 12 inch digital ruler both measuring down to .1 inch.
- Fifteen guns were selected from the firearm reference collection consisting of barrel lengths ranging between 7 and 30 inches and overall lengths ranging between 17 to 51 inches.
- The two analysts measured the barrel length and overall length for each gun on different days and different times of day.

Measurement Traceability

The traceability for this measurement process is established through the yearly calibration of the 48 inch and 12 inch rulers.

The external calibration of the 48 inch and 12 inch digital rulers is performed by a calibration laboratory (Alaska Metrology and Calibration Services) that meets Section 3.2.3 of the ASCLD/LAB Policy on Measurement Traceability

Measurement Assurance

The laboratory performs intermediate checks to maintain confidence in the calibration status of the rulers during the interval between external calibrations. These checks are carried out according to a defined schedule and procedure.

Data is available from both an initial study and ongoing quality control that evaluates the variation in the measurement process using a check standard surrogate. Both analysts participate. A random sampling of eight firearms from the fifteen test method are selected and measured. The results are checked for agreement with the test method barrel length and overall length measurements for those eight weapons.

NIST 8-Step Process for Estimating and Reporting Measurement Uncertainty

Step 1: Specify the measurement process

Measurand:

Overall length of a Firearm using a 48 and 12 inch, steel, digital rulers with .1 inch scale markings.

Barrel length of Firearm using a 48 and 12 inch, steel, digital rulers with .1 inch scale markings.

Current test method: The procedure for this measurement process is described in Firearms/Toolmark Work Instructions (FTMWI 2013 R1).

Summary of measurement:

Overall length: A measured line that is parallel to the axis of the bore from a perpendicular tangential line that touches the rearmost point of the butt-plate to the muzzle.

Barrel length: A measure line that is the distance from the breech end of the barrel to the muzzle.

Range of Measurement: up to 51 inches

Expressed by the mathematical equation: $Y = y + b \pm U$

Where:

y is the best estimate of the measurand Y from the test method and is expressed by

$y = f(X_1, X_2, \ldots, X_n)$

y is a function to the components of uncertainty

b = bias; in this example, the calibrated scale error is a systematic bias in the measurement

U = expanded uncertainty

Applicable Statute wording : Rifle or Shotgun overall length must be greater than 26 inches.

Overall length: Rifle or Shotgun overall length must be greater than 26 inches

Barrel length: Rifle barrel must be greater than 16 inches. Shotgun barrel must be greater than 18 inches

Step 2: Identify uncertainty components

Traceability is established for this measurement through a yearly calibration of the ruler used to make the measurement.

Equipment used for the test method: 48 inch and 12 inch digital rulers with .1 inch markings

List of uncertainty components considered:

Measuring equipment

- Length scale readability
- Length scale resolution
- Calibrated scale error
- Proper use, storage and handling

Staff

- Multiple Analysts
- Training
- Experience
- Visual acuity
- Time of day, day of week

Test Method

- The same test method is used to measure the length of all types of firearms
- Analyst must position measuring equipment at the firearm butt and barrel end

Facility

- Lighting
- Space

Step 3: Quantify uncertainty components

Data is available from a study performed to evaluate the variation in the measurement process across all analysts. The study performed during method validation used firearms from the laboratory reference collection. These firearms included shotguns and rifles ranging in lengths between 17 and 51 inches with barrel lengths between 7 and 30 inches. The study attempted to cover a wide variety of firearms, both analysts, different days, different times of day, and normal variations in temperature and lighting.

The laboratory has standard operating procedures for use, storage, handling, and calibration checks for the digital rulers.

The table below lists each uncertainty component considered and how it will be evaluated.

Uncertainty Component	Method of Evaluation
Measuring Equipment: 48” digital ruler – Only one 48” ruler in discipline	
Length scale readability	Type B Evaluation
Length scale resolution	Type B Evaluation
Calibration uncertainty	Type B Evaluation
Calibrated scale error	Type B Evaluation
Proper use, storage and handling	Covered in *Type A Evaluation* of process reproducibility data
Staff	
Multiple analysts	Covered in *Type A Evaluation* of process reproducibility data
Training	Covered in *Type A Evaluation* of process reproducibility data
Experience	Covered in *Type A Evaluation* of process reproducibility data
Visual acuity	Covered in *Type A Evaluation* of process reproducibility data
Time of day, day of week, interruptions, workload	Covered in *Type A Evaluation* of process reproducibility data
Test Method	
Differences in establishing parallel and perpendicular between analysts	Covered in *Type A Evaluation* of process reproducibility data
Analyst positioning of measuring equipment	Covered in *Type A Evaluation* of process reproducibility data
Facility	
Temperature coefficient of expansion for measuring equipment	Type B Evaluation
Lighting	Covered in *Type A Evaluation* of process reproducibility data
Space	Covered in *Type A* Evaluation of process reproducibility data

Type A Evaluation of uncertainty components:

Measurement Process Reproducibility

The number of measurements from the study is greater than 100.

Because the length varied with each firearm measured, the data of interest is not the nominal length, but the variation of each measurement from the mean of the measurements made by all analysts on a single measurand.

The variation data appears to have a normal distribution.

The statistic that will be calculated is the standard deviation. Standard deviation (Sample):

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

The standard deviation of the reproducibility data for overall length is = .049 inches

The standard deviation of the reproducibility data for barrel length is = .034 inches

Type B Evaluation of uncertainty components:

Length scale readability: equals .1 inch

> Readability is defined as the smallest increment that can be detected by the measuring equipment. The measurement procedure requires interpretation at both the “zero” and the muzzle, therefore the uncertainty budget will have two entries using the standard uncertainty.

Length scale resolution: Per laboratory policy, the measurement will be taken to the nearest greater .1 inch scale mark.

Calibration Uncertainty: Scales come with paperwork stating that the measurement has a calibration error of .005 inches per foot.

Calibrated Scale Error: The calibration certificates from the accredited external calibration laboratory indicate that “the ratio of the expanded uncertainty of all Standard Applied/Readings to the Specifications the Customer’s equipment is calibrates is greater than or equal to 4:1”. This would equate to .00125 inches per foot. This error rate will not impact a reported measurement, so it is insignificant.

Step 4: Convert quantities to standard uncertainties

Type A evaluations of components:

Reproducibility data: Expressed as one standard deviation.

The standard deviation of the reproducibility data for overall length is = .049 inches

The standard deviation of the reproducibility data for barrel length is = .034 inches

Type B evaluations of components:

Length scale readability;

This component is evaluated as a rectangular distribution.

For a rectangular distribution, the standard uncertainty is calculated as:

$a/\sqrt{3}$

Where a= measuring equipment readability= .1 inches

The standard uncertainty = .1 / $\sqrt{3}$ = .05774 inches

The measurement procedure has to interpret both the zero and the muzzle; therefore, the uncertainty calculation will have two entries using this standard uncertainty.

Calibration uncertainty:

The measurement has a calibration error of .005 inches per foot. The total error for 5 feet would be: .005 * 5 = .025 inches total error. This is not an expanded error.

The calibration uncertainty = .025 inches

Step 5: Calculate the combined standard uncertainty

The Root Sum of the Squares formula will be used to calculate the combined uncertainty.

$$\text{Combined Standard Uncertainty} = \sqrt{S^2\text{process} + \text{Read}_{\text{zero}}^2 + \text{Read}_{\text{end}}^2 + \text{Cal}^2}$$

$$\text{Combined Standard Uncertainty for Overall Length} = \sqrt{.0493 + .0577 + .0577 + .025}$$
$$\text{Combined Standard Uncertainty for Overall Length} = \pm\ 0.099 \text{ inches}$$

$$\text{Combined Standard Uncertainty for Barrel Length} = \sqrt{.034 + .0577 + .0577 + .025}$$
$$\text{Combined Standard Uncertainty for Barrel Length} = \pm\ 0.092 \text{ inches}$$

Step 5: Calculate the combined uncertainty continued – evaluation of bias

Any possible bias is measured as component of the Process Reproducibility evaluation which evaluates the differences between the analysts performing the measurement.

Step 6: Expand the combined standard uncertainty by coverage factor (k)

95% Coverage:

The combined standard uncertainty can be expanded to a 95% coverage probability (coverage factor k = 2):

Overall Length Expanded Combined Standard Uncertainty (k=2) = 2 *.099 = ± 0.197

Barrel Length Expanded Combined Standard Uncertainty (k=2) = 2 *.092 = ± 0.184

Both 0.197 inches and 0.184 inches can be rounded up to 0.2 inches to match the .1 inch readability of the rulers.

99% Coverage:

The combined standard uncertainty can be expanded to a 99% coverage probability (coverage factor k = 3):

Overall Length Expanded Combined Standard Uncertainty (k=3) = 3 *.099 = ± 0.296

Barrel Length Expanded Combined Standard Uncertainty (k=3) = 3 *.092 = ± 0.276

Both 0.296 inches and 0.276 inches can be rounded up to 0.3 inches to match the .1 inch readability of the rulers.

Step 7: Evaluate the expanded uncertainty

The distribution of data from the check standards and calibrated mass reference standards confirm that the mean ± 0.2 inches approximates 95% of measurements made for Overall Length and Barrel Length.

AND

The mean ± 0.3 inches approximates 99% of measurements made for Overall Length and Barrel Length.

Step 8: Report the uncertainty

The expanded combined standard uncertainty rounded to 1 significant figure is:

Expanded Combined Standard Uncertainty = ± 0.2 inches or ± 0.3 inches for Overall Length and Barrel Length.

The measurement result and the expanded uncertainty will be reported in the same units. The coverage probability used to expand the uncertainty will also be reported.

Report wording example:

The overall length of Item 1 was found to be 20.1 inches ± 0.3 inches at a coverage probability of 99.73%.