Language and Systems of Measurement

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Language and Systems of Measurement

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How Big?

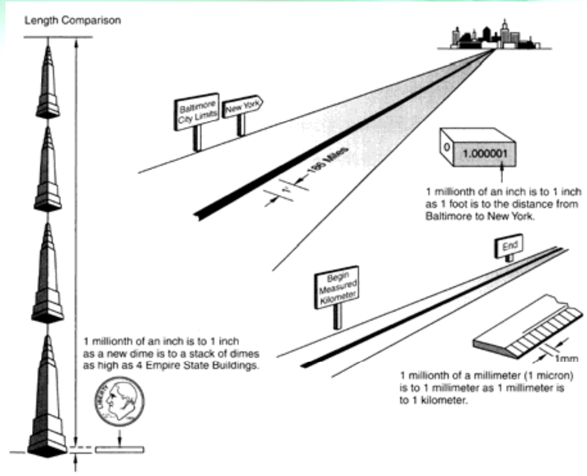


FIGURE 2–2 One millionth is to 1inch as 1 inch is to 16 miles. Or in the metric system 1 micrometer is to 1 meter as 1 meter is to 1,000 kilometers. These examples show what that means in actual practice.

How Far Apart?

Multiplier	Unit of length
6	inches
30	seconds
4	miles

The 6, 30, and 4 are cardinal numbers.

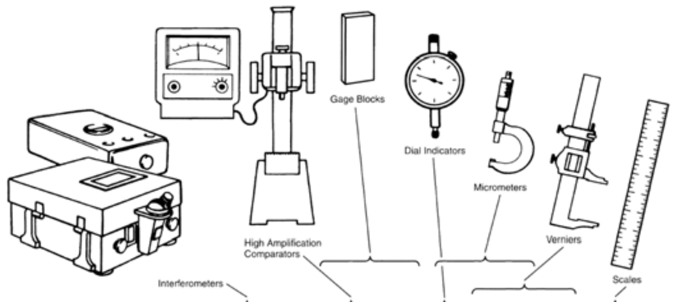
Multipliers smaller than one are expressed by fractions or decimal multipliers:

6 inches	½ foot	0.5 foot
(cardinal)	(fractional)	(decimal)

Very large or small multipliers are more conveniently expressed as exponents:

$$0.3 = 3 \times 0.1 = 3 \times 10^{-1}$$
$$300 = 3 \times 100 = 3 \times 10^{2}$$
$$3{,}000{,}000{,}000 = 3 \times 1{,}000{,}000{,}000 = 3 \times 10^{9}$$

How Far Apart?



Inch	10^{-7}	10^{-6}	10^{-5}	10^{-4}	0.001	0.01	0.1	1	10	100
One Thousandth Inch (Mil)	10^{-4}	0.001	0.01	0.1	1	10	100	1000	10^{4}	10^{5}
One Millionth Inch	0.1	1	10	100	1000	10^{4}	10^{5}	10^{6}	10^{7}	10^{8}
One Hundredth Meter (Centimeter)	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	0.001	0.01	0.1	1	10
One Thousandth Meter (Millimeter)	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	0.001	0.01	0.1	1	10
One Millionths Meter (Micrometer)	10^{-5}	10^{-4}	0.001	0.01	0.1	1	10	100	1000	10^{4}
One Billionth Meter (Millimicron)	0.01	0.1	1	10	100	1000	10^{4}	10^{5}	10^{6}	10^{7}

Coatings, Films — Sheets — Plates

FIGURE 2–4 Exponential multipliers simplify the expression of very small and very large measurements.

How Far Apart?

Dimensions, Features, and Measurements

A. The designer's concept for a perfect part determined the DIMENSION.

B. The toolmaker's machining resulted in the FEATURE of the part.

C. The inspector's MEASUREMENT verified the toolmaker's work to the designer's concept.

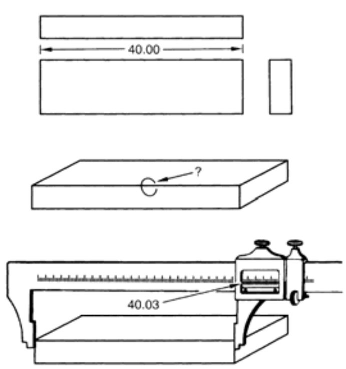


FIGURE 2–5 Measurement verifies the designer's dimension to the feature of the actual part. This happens even when the designer, the machinist, and the inspector are all the same person, as is often the case.

The Act of Measurement

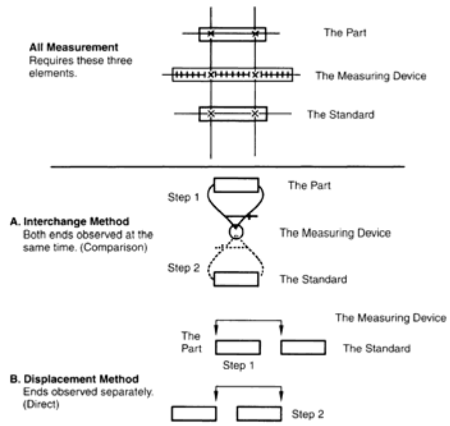


FIGURE 2–6 All measurements consist of the comparison of the unknown with a known. The methods for comparison vary but fall into one of two groups: interchange or displacement.

Accuracy, Precision, and Reliability

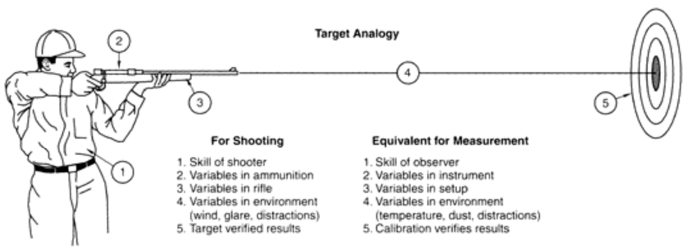


FIGURE 2–7 Measurement is influenced by variables similar to those that affect the score when target shooting. This comparison shows the difference in the meaning of familiar terms.

Accuracy, Precision, and Reliability

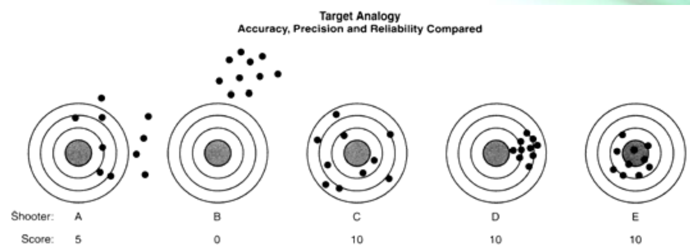


FIGURE 2–8 Which of these targets represents accurate shooting? Precise shooting? Reliable shooting?

Accuracy, Precision, and Reliability

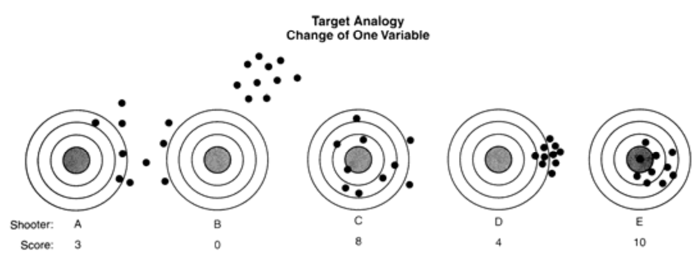


FIGURE 2–9 A change in one variable, such as wind, alters the results as shown. Does this show which shooting was most reliable?

Accuracy, Precision, and Reliability

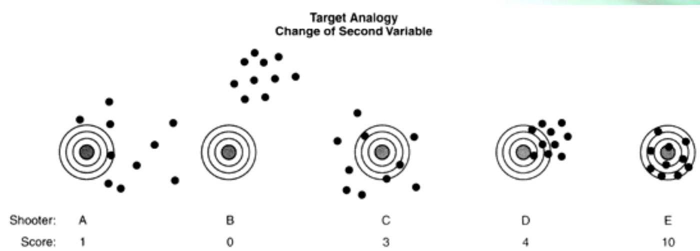
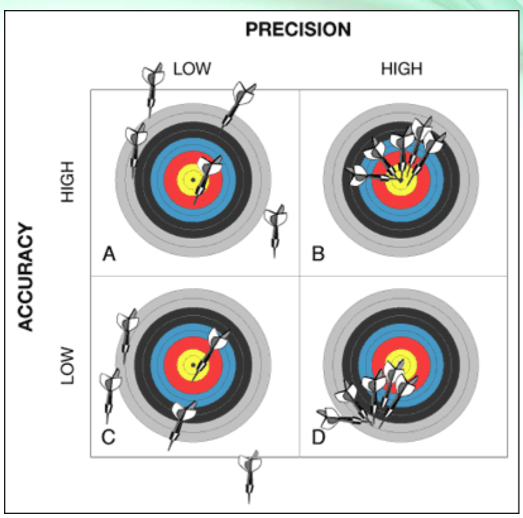


FIGURE 2–10 Reducing the target size by one-half shows that the accuracy requirement may dictate the precision requirement.

Accuracy versus Precision



Accuracy versus Precision

	Precision	Accuracy	Reliability
General Meanings:	Exactness Degree of exactitude	Desirability	Probability of achieving desired results
Measures:	Fineness of readings	Ratio of correct to incorrect readings	Reliability of correct readings
Method of stating:	Within a 3 circle Plus or minus one thousandths inch	5 out of 10 50 percent of full scale	90 percent reliable
Specific meaning:	The lower the standard deviation of measurement, the higher the precision	The number of measurements within a specified standard as compared with those outside	The probability of performing without failure a specific function under given conditions for a specified period of time

FIGURE 2–11 These definitions fit most measurements, but many exceptions can be found. A good rule is to use the most precise term that the listener can understand easily. (Courtesy of Juran, J. M., *Quality Control Handbook*, 5th ed., McGraw-Hill Book Co., 1999)

Evolution of Standards

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second

Origin of the Metric System

SI prefixes

1000^m	10^n	Prefix	Symbol	Since[1]	Short scale	Long scale	Decimal
1000^8	10^{24}	yotta	Y	1991	Septillion	Quadrillion	1 000 000 000 000 000 000 000 000
1000^7	10^{21}	zetta	Z	1991	Sextillion	Trilliard	1 000 000 000 000 000 000 000
1000^6	10^{18}	exa	E	1975	Quintillion	Trillion	1 000 000 000 000 000 000
1000^5	10^{15}	peta	P	1975	Quadrillion	Billiard	1 000 000 000 000 000
1000^4	10^{12}	tera	T	1960	Trillion	Billion	1 000 000 000 000
1000^3	10^9	giga	G	1960	Billion	Milliard	1 000 000 000
1000^2	10^6	mega	M	1960	Million		1 000 000
1000^1	10^3	kilo	k	1795	Thousand		1 000
$1000^{2/3}$	10^2	hecto	h	1795	Hundred		100
$1000^{1/3}$	10^1	deca	da	1795	Ten		10
1000^0	10^0	(none)	(none)	NA	One		1
$1000^{-1/3}$	10^{-1}	deci	d	1795	Tenth		0.1
$1000^{-2/3}$	10^{-2}	centi	c	1795	Hundredth		0.01
1000^{-1}	10^{-3}	milli	m	1795	Thousandth		0.001
1000^{-2}	10^{-6}	micro	μ	1960[2]	Millionth		0.000 001
1000^{-3}	10^{-9}	nano	n	1960	Billionth	Milliardth	0.000 000 001
1000^{-4}	10^{-12}	pico	p	1960	Trillionth	Billionth	0.000 000 000 001
1000^{-5}	10^{-15}	femto	f	1964	Quadrillionth	Billiardth	0.000 000 000 000 001
1000^{-6}	10^{-18}	atto	a	1964	Quintillionth	Trillionth	0.000 000 000 000 000 001
1000^{-7}	10^{-21}	zepto	z	1991	Sextillionth	Trilliardth	0.000 000 000 000 000 000 001
1000^{-8}	10^{-24}	yocto	y	1991	Septillionth	Quadrillionth	0.000 000 000 000 000 000 000 001

1. The metric system was introduced in 1795 with six prefixes. The other dates relate to recognition by a resolution of the CGPM.
2. The 1948 recognition of the micron by the CGPM was abrogated in 1967.

Legality of the Metric System in the United States

- In 1988, Congress passed the Omnibus Trade and Competitiveness Act, which designates "the metric system of measurement as the preferred system of weights and measures for United States trade and commerce." Among many other things, the act requires federal agencies to use metric measurements in nearly all of their activities, although there are still exceptions allowing traditional units to be used in documents intended for consumers.
- The U.S. adopted the metric system in 1866. What the U.S. has failed to do is to restrict or prohibit the use of traditional units in areas touching the ordinary citizen: construction, real estate transactions, retail trade, and education. The U.S. has not made the crucial transition from "soft metric" to "hard metric", so that "1 pint (473 mL)" becomes "500 mL (1.057 pint)", with the traditional equivalent fading into smaller type sizes and finally disappearing.

http://www.unc.edu/~rowlett/units/usmetric.html

The International Inch

Inch, unit of measure

- An inch (plural: inches; symbol or abbreviation: in) is the name of a unit of length in a number of different systems, including English units, Imperial units, and United States customary units. Its size can vary from system to system. There are 36 inches in a yard and 12 inches in a foot. A corresponding unit of area is the square inch and a corresponding unit of volume is the cubic inch. The inch is the virtually universal unit of measurement in the United States, and is very commonly used in Canada and the United Kingdom. In the US and the UK, personal heights are expressed in feet and inches by people of all ages. In 1958 the United States and countries of the Commonwealth of Nations defined the length of the international yard to be precisely 0.9144 metres. Consequently, the international inch is defined to be equal to 25.4 millimetres. The English word inch comes from Latin uncia meaning "one twelfth part" (in this case, one twelfth of a foot); the word ounce (one twelfth of a troy pound) has the same origin.

http://www.unitconversion.org/length/inch-conversion.html

Fundamental Criteria for the Evaluation of Possible Measurement Systems

- Naturalness of the Systems
- Economic Considerations
- Either/or reasoning

The Best System

The “best” system of measurement depends on what is being measured, what use the measurement has, whether scientific, commercial, or cultural, and the audience who must understand the results of the measurement process. We must use the measurement system that helps other people understand the goals that we are trying to accomplish—the goals that created the need to measure in the first place.

Practical Criteria

To determine the best system of measurement, we use three factors:

1. Metrological factor—which act of measurement will yield usable results
2. Computational factor—which system yields figures that we can use mathematically
3. Communicative factor—which system makes it easiest for us to share the measurement with other people

In turn, each of these factors must be evaluated by four subcriteria, whether the systems provide:

1. Maximum measurement potential
2. Minimum time required
3. Minimum error potential
4. Minimum cost incurred

Practical Criteria

METRIC AND INCH-POUND SYSTEMS COMPARED

Separate factors to be compared:	Basis for comparing each factor:
1. Metrological	1. Maximum measuring ability
2. Computational	2. Minimum errors
3. Communicative	3. Minimum time to measure
	4. Minimum cost

Factors	Metric	Inch-Pound
Metrological		
Science	Excellent	Poor
Industry	Fair	Good
Domestic	Poor	Fair
Computational		
Science	Excellent	Poor
Industry	Good	Poor
Domestic	Good	Poor
Communicative		
Science	Good	Poor
Industry	Good	Poor

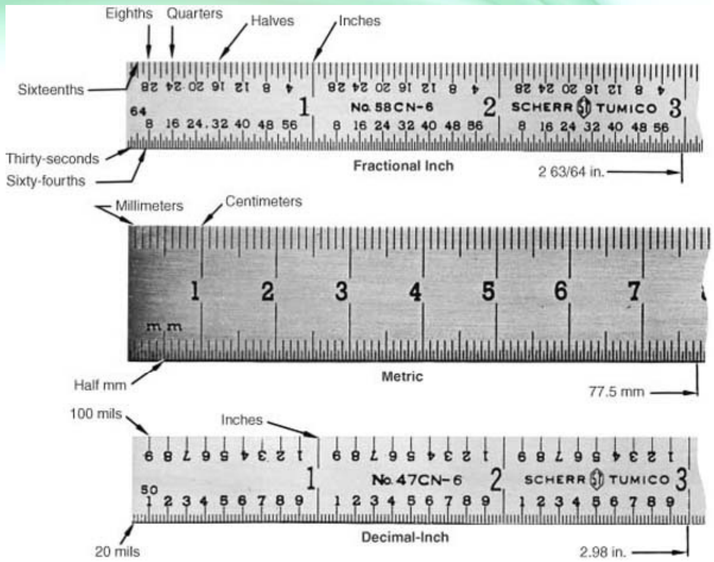
FIGURE 2–15 When the two systems are critically analyzed, neither is all good nor all bad.

The Decimal-Inch System

In order to try to eliminate some of the computational problems with the inch system, the decimal-inch system was created. It is not such a new idea because the decimal foot was used in surveying in the United States before 1856. In fact, until the Civil War, 1/64 in. was the smallest standard measurement used in practical work; thousandths of an inch were nothing more than theories.

The decimal-inch system made its first major breakthrough into popular use when, in 1930, the Ford Motor Company adopted it, followed quickly by the aircraft industry. The Society of Automotive Engineers (SAE) published a complete decimal-inch dimensioning manual in 1946. Thirteen years later, the American Standards Association (ASA) and the Society of Manufacturing Engineers (SME) chose to jointly urge greater use of the decimal-inch, proposing an American standard for its definition and use.

Metrological Considerations



Communications Considerations

LINEAR MEASUREMENT UNITS IN THE INCH-POUND AND METRIC SYSTEMS COMPARED

Linear Measure	Microinch (.000001y) µin.	Ten Thousandths (.0001y)	Thousandths (.001y)	Inch (y) or (z/12) in.	Foot (12y) or (z) ft.	Yard (3z) yd.	Mile (5280z) mi.
Nanometer nm (.000000001x)	0.0394 **25.4**						
Micrometer* µ (.000001x)	39.37 **0.0254**	0.3937 **2.54**	**25.4**				
Millimeter mm (.001x)		393.7	39.37 **0.0254**	0.0394 **25.4**	**304.8**		
Centimeter cm (.01x)		3937.	393.7	0.3937 **2.54**	0.0328 **30.48**	**91.44**	
Meter m (x)				39.37 **0.0254**	3.2808 **0.3048**	1.0936 **0.9144**	**1609.3**
Kilometer km (1000x)					3280.8	1093.6	0.6214 **1.6093**

*Micrometer is the official name but micron is widely used.

FIGURE 2–17 To use the English/metric conversions tables: enter a horizontal or vertical column; combine either the lightface or boldface units or numbers; and read its corresponding value in terms of one unit of the opposing scale. For example: 1.0936 yards = 1 meter.

Communications Considerations

Examples of Decimal-Inch Terminology

Write: For type-set material	Write: On Drawings	Say (Preferred form is first)	Number of Syllables (to compare brevity)
0.002" or 2 mil	.002	two mil	2
0.012" or 12 mil	.012	twelve mil	2
0.02" or 20 mil	.02	twenty mil point zero two inch	3 5
0.2"	.20	point two inch	3
2.005"	2.005	two inch five mil two point zero zero five inch	4 8
2.00"	2.00	two inch	2
0.000005" or 5×10^{-6}" or 5	.000005 or 5	five micro inch	2
0.00002" or 20	.00002 or 20	twenty micro inch	3
0.0002	.0002	point two mil point zero zero zero two inch two tenths*	3 9 2
0.0025"	.0025	two point five mil point zero zero two five inch	4 8
2.000005"	2.000005	two inches and five micro inch	4
2.0005"	2.005	two inch point five mil two point zero zero zero five inch	5 10

*Colloquialism — not recommended

Computational Considerations

Computation Comparison

System	Addition	Addition	Subtraction	Subtraction	Subtraction
Fractional System	1-1/64 9/32 1-31/32 2-3/4	1-1/64 18/64 1-62/64 2-48/64 4-129/64 6- 1/64	1-5/8 -9/32 -27/64	1-40/64 -18/64 -27/64	104/64 -45/64 59/64
Exact Decimal Equivalents	1.015625 .28125 1.96875 2.75 6.015625		1.625 - .28125 - .421875		1.625000 -.703125 .921875
Two-Place Decimal System	1.02 0.28 1.97 2.75 6.02		1.62 -.28 -.42		1.62 -.70 .92

FIGURE 2–19 The computational advantage of the decimal-inch system is evident from this comparison of an addition problem and a subtraction problem, both solved by the three methods.

Successive Halving

1	1.	
1/2	0.5	1 place
1/4	0.25	2 places
1/8	0.125	3 places
1/16	0.0625	4 places
1/32	0.03125	5 places
1/64	0.015625	6 places

FIGURE 2–20 Successive halving of one (1) in order to form the common fractions results in the 64ths having six decimal places.

Rounding-Off Numerical Values

GENERAL RULES FOR ROUNDING OFF

When a value is to be reduced in number of decimal places, one of the following three rules is followed:

1. When the digit to be dropped is less than 5, there is no change in the preceding figures.
   Examples:
   0.280423 to 0.28042 to 0.2804 to 0.280 to 0.28
2. When the digit to be dropped is greater than 5, the preceding digit is increased by 1.
   Examples:
   0.046857 to 0.04686 to 0.0469 to 0.047 to 0.05
3. **When the digit to be dropped is exactly 5, round off to the nearest even number.**
   Examples:
   0.09375 to 0.0938 but 0.09385 to 0.0938

FIGURE 2–25 Whenever possible, carry the calculation two places beyond the desired value, then round off the last two significant figures.

Rounding-Off Numerical Values

ROUNDING UP VS ROUNDING DOWN

	Calculated Volume	Rounded Up	Rounded Down
	1400.375	1400.38	1400.37
	1400.376	**1400.38**	**1400.38**
	1399.995	1400.00	1399.99
	1400.395	1400.40	1400.39
	1399.991	**1399.99**	**1399.99**
Totals	7001.132	7001.15	7001.12
Differences		over by 0.02	under by 0.01
Average T/5	1400.226 (true)	1400.230 (high)	1400.224 (low)

FIGURE 2–22 In this group of five values the rounded up column yielded high values, the rounded down, low values. The more items involved, the greater the total error and average error.

Summary

- Because it is necessary to understand each other, some terms must have specific meanings. Linear measurement expresses distance between points. It permits distances to be reproduced. A measurement consists of a unit of length and a multiplier. Each measurement begins at a reference point and terminates at a measured point. It lies along a line of measurement, which must have a known relationship to the feature being measured.
- A feature is a measurable characteristic. It is bounded by edges, usually but not always, formed by the intersection of planes. The dimension of the feature is the designer's concept of perfection. Features of actual parts are not perfect.
- Measurement shows the deviation from perfection. The measured conformity to the dimension is the accuracy. The refinement with which this can be known is the precision. The effect of accuracy and precision on attaining the desired results is reliability. Precision is essential for reliability but alone cannot produce it. Increased reliability requires increased accuracy and that requires increased precision.
- Therefore, the general term used to denote progress in measurement is precision.

Summary

- There is no insurmountable difficulty involved in a total change from the inch-pound system to the metric system, nor is there any convincing proof that such a change is needed or desirable.
- The metric system is unquestionably superior in ease of computation. Popular use of the metric system in science clearly advocates its continued use. The units of the metric system were selected theoretically. It is not surprising that they bear little natural relation to most things in the real world, including the resolving power of the human eye.
- The inch-pound system is handicapped by an apparently disorderly assortment of units. This slows computation and sometimes clogs communication. However, its basic units are of such convenience that it finds wide use even in places in which the metric system is the legal system. While design engineers often use metric dimensions, the inch system is still the primary measurement system used in tool rooms within the United States.
- Each system has merit and has roles in which it is fully accepted. It is even possible to borrow good points from one system to enhance the other; an example of this is the decimal-inch. Furthermore, in this computer age the system of annotation is relatively unimportant and should not be an issue. Our efforts are needed far more for the application of sound principles and the perfection of our reference standards.

References

http://ts.nist.gov/WeightsAndMeasures/Publications/appxc.cfm
http://www.convert-me.com/en/
http://www.unc.edu/~rowlett/units/
http://www.measurement.com/
http://www.historyworld.net/wrldhis/PlainTextHistories.asp?historyid=ac07