TC for Metrology in Length:
Highlights and Challenges

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PTB, Germany

10th General Assembly

Oslo, Norway
23-27 June 2016

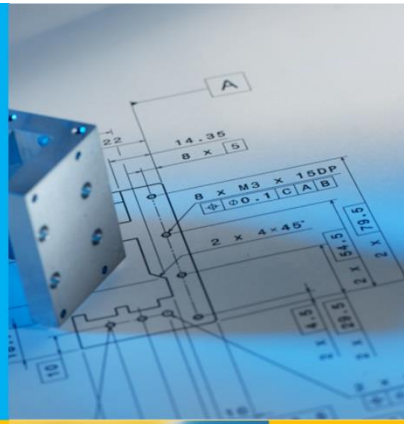
G10.08.15

Length

Length metrology - Areas of Impact

EURAMET

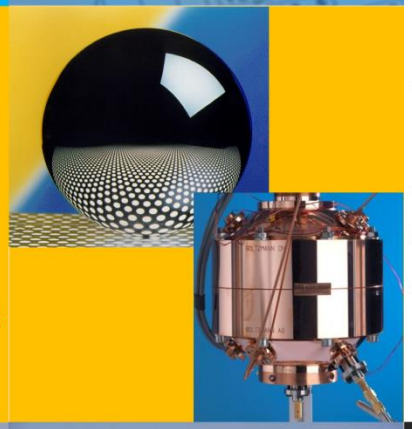
Traceability in dimensional measurements underpins all manufacturing, engineering and assembly industry worldwide, ensuring compatibility & interchangeability of parts.



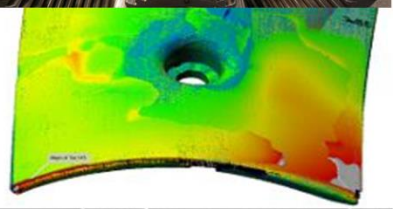
CCL Strategy Document
with input from **EURAMET TC-L members of WG-S**

Topics are dealt with in **four TC-L Roadmaps**

Precision engineering and dimensional metrology are key to 3 SI re-definitions based on fundamental constants: form & dimension of Avogadro spheres and Boltzmann resonators, Planck balance interferometry

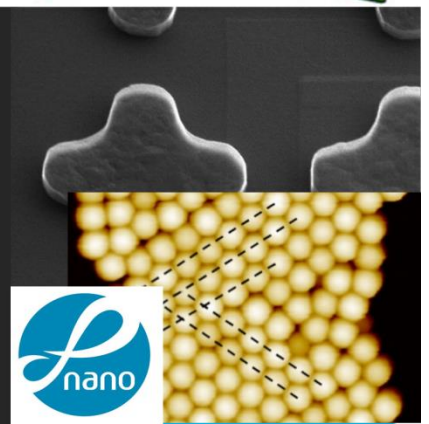


For new science (particle accelerators), energy generation (wind, civil nuclear), better accuracy & *in situ* calibration are speeding up manufacturing and enabling better efficiency, longer lifetimes. Solving gearbox problems is key to wind energy.



In aerospace, improving accuracy in aircraft assembly is reducing weight, reducing fuel burn (lower environmental impact, better energy efficiency). Key needs are accuracy and traceability for parts up to 40 m size.

Surface form and texture are critical to many nano-scale devices, particularly for *in-vivo* applications for health. Traceability infrastructure for 3D surface texture and simple dimensions on nano particles



OUTLINE

- EMRP project results from Calls 2012 (about to be finished)
- Nanoscale 2016
- eu**spen** 2017

Surveying, SIB60, Call 2012

Metrology for long distance Metrology

Main Challenge:

- Traceable measurement of long distances in surveying

Approach:

- Optical refractivity-compensation
- Isolated study of GNSS uncertainty contributions

Main Results:

- Primary standards with measurement uncertainty of $10^{-7}\ l$ for distances up to 1 km
- Best practice for low uncertainty GNSS-based distance metrology

Details

LUMINAR, IND53, Call 2012

Large-volume Unified Metrology for Industry, Novel Applications & Research

Main Challenge: In situ, traceable, 3D shop-floor (industrial) metrology, to 10s of µm

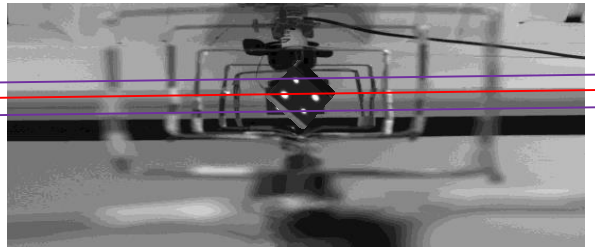
Approach:

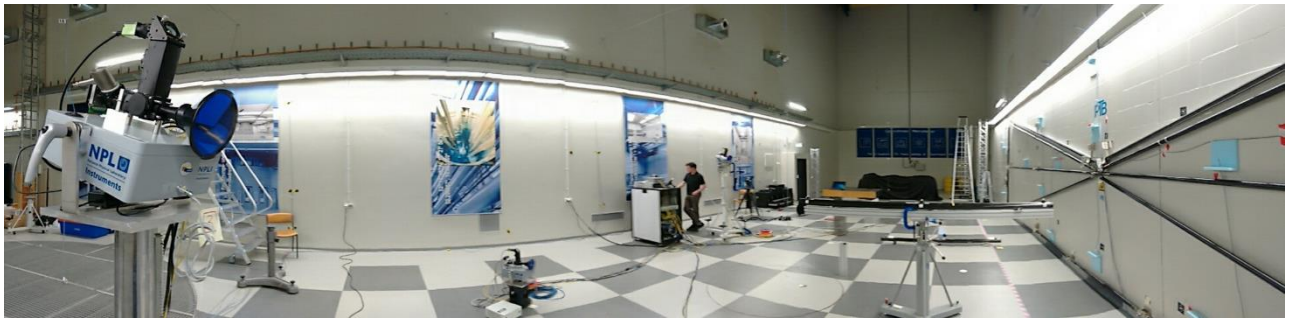
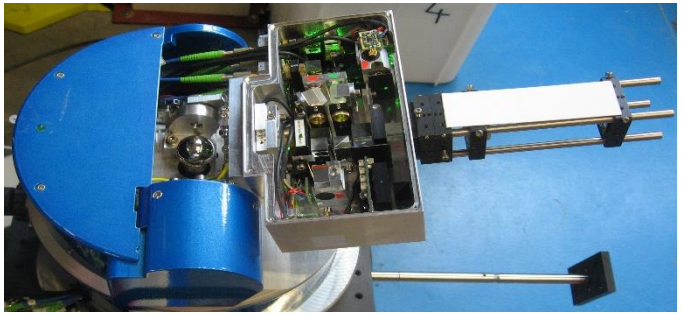
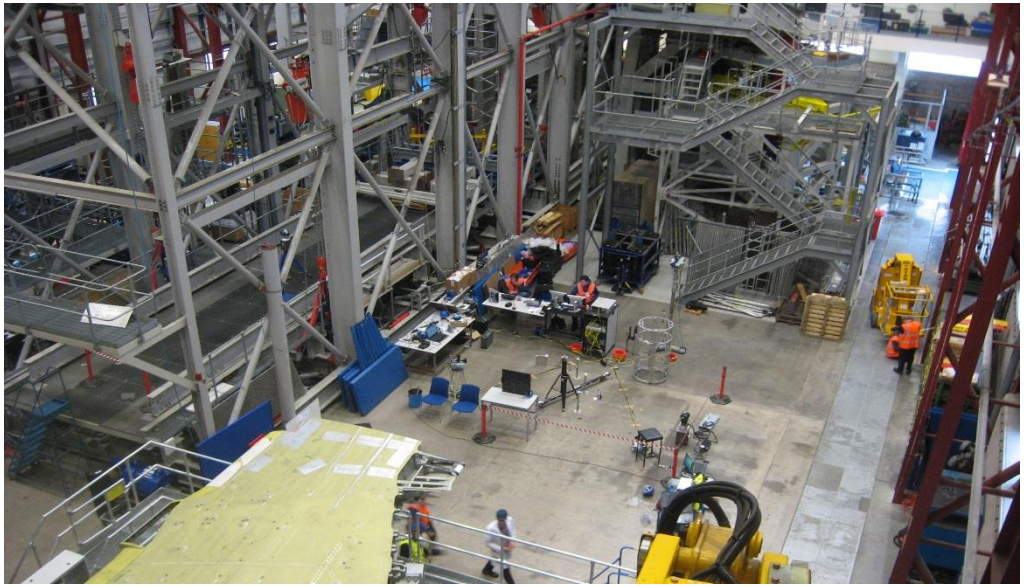
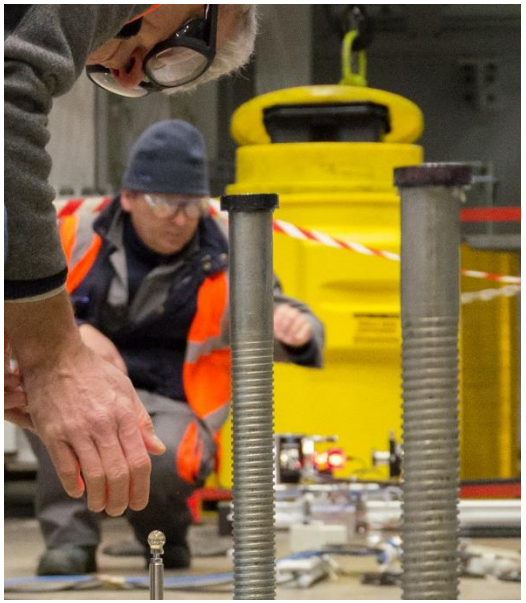
- Refractive index compensated telemeter and laser tracer
- Simulated environment (50 m) & reference probes/interferometer
- Hybrid thermal/dimensional modelling
- Refraction detection/compensation using photogrammetry
- *InPlanT* (separated planes)
- 3D divergent beam Frequency Scanning Interferometry (FSI)

Main Results:

- New h/w & s/w available: telemeter, tracer, *InPlant*, FSI, Photogrammetry, models
- Along beam ref index to 10^{-7} , 3D coordinates to 30 µm
- Commercialization of 2 JRP outputs (PTB tracer, NPL FSI)
- 5 patents, 4 future collaborations, equipment requests from Airbus, CERN, …
- 27 conference presentations (incl. invitations from CERN, euspen)
- 8 publications, 8 training events (incl. secondment from CERN)

Details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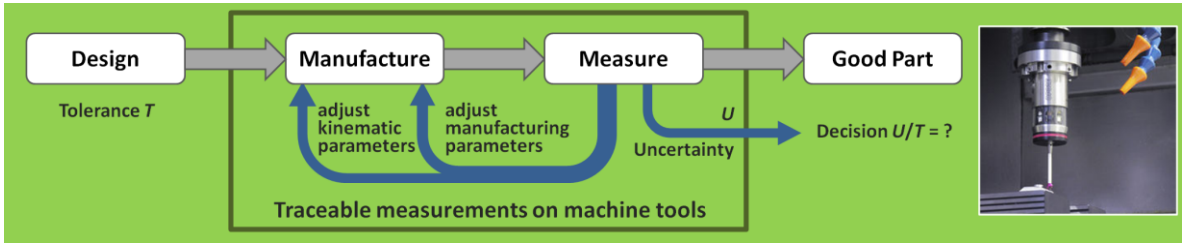
TIM, IND62, Call 2012



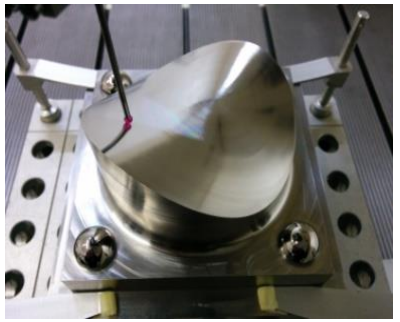
Traceable in-process dimensional measurement

Main Challenge:

- Accuracy enhancement of machine tools in rough env. by in-process metrology

Approach:

- Provide defined thermal environment for machine tests: 15 … 45 deg.
- Develop thermally stable work-piece like reference artefacts
- Develop thermo-mechanical models



Portable simulation chamber

Main Results:

- Reduction of systematic machine tool deviations of up to 80% at diff. temp. by characterization and compensation
- Five Good Practice Guides for different machine tools

Details

6DoF, IND58, Call 2012

Metrology for movement and positioning in six degrees of freedom

Main Challenges:

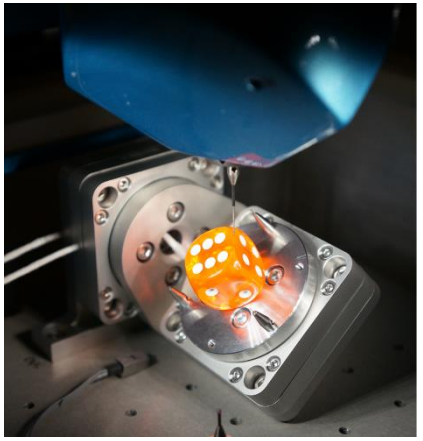
- Traceability for positioning systems with large angular motion
- In process measurement of straightness
- Improvement of measurement speed of metrological AFM

Approach:

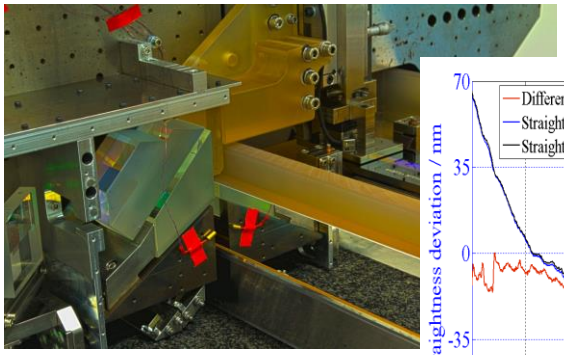
- Sequential calibration of three reference points by CMM
- Deflectometry by multi beam interferometers
- Non equidistant AFM scanning
- 6DoF characterization of nanopositioners

Main Results:

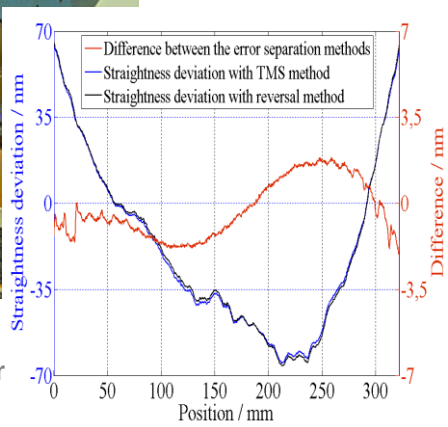
- MU for deflectometric straightness < 5 nm
- Procedure for calibration of 6DoF stages by CMM
- Gwyddeon library for non equidistant scanning
- Correction of hysteresis of a video rate AFM



Characterisation of an two axis angular table at the METAS µCMM



PTB length comparator with 3 parallel Interferometer beams for Deflectometry



[Details]

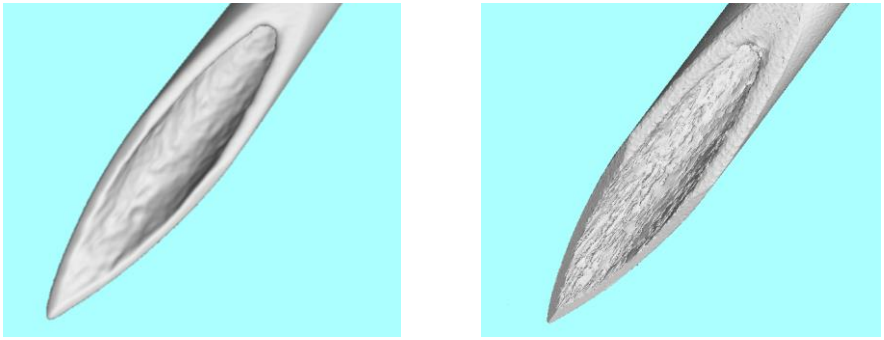
Microparts, IND59, Call 2012

Multi-sensor metrology for microparts in innovative industrial products

Main Challenges:

- Small tactile probes (≤ ∅50 µm) needed to measure complex microparts
- Measurements of microparts with optical sensors and CT systems are mostly not traceable

CT-scans of an insulin injection needle (∅250 µm)
left: Industrial CT, right: Synchrotron CT

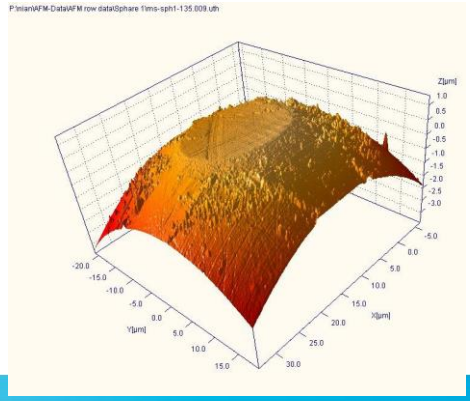


Approach:

- Realization of small microprobes
- Development of calibrated workpiece-like reference standards

Main Results:

- Size, form and wear of tactile microprobes (∅50 µm) characterized
- 4 workpiece-like reference standards realized



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METROSION, IND61, Call 2012

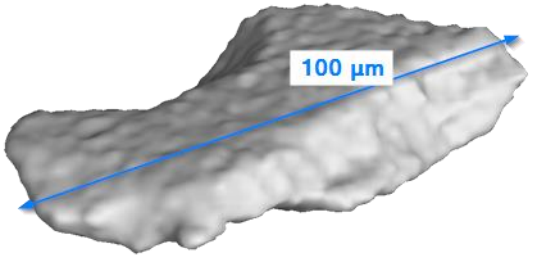
Metrology to enable high temperature erosion testing

Main Challenge:

- Erosion by particles (30-150 µm) degrade performance of e.g. turbines (high costs and danger for life)
- Understanding of erosion process as a function of temperature, and velocity, size and shape of particles by simulation and experiment

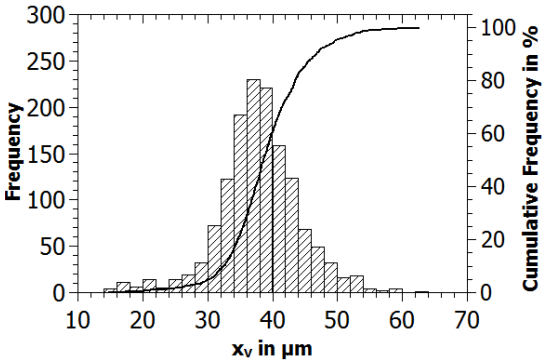
Approach:

- Characterization of microparticles by XCT
- Development of test rigs for v ~ 300 ms^{-1}, T ~ 900 ° C



Main Results:

- 3D-shape of particles determined
- Volume-equivalent diameter, x_V, with 2.5% and particle volume with 7.5% uncertainty determined



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Angles, SIB58, Call 2012

Angle Metrology

Main Challenge:

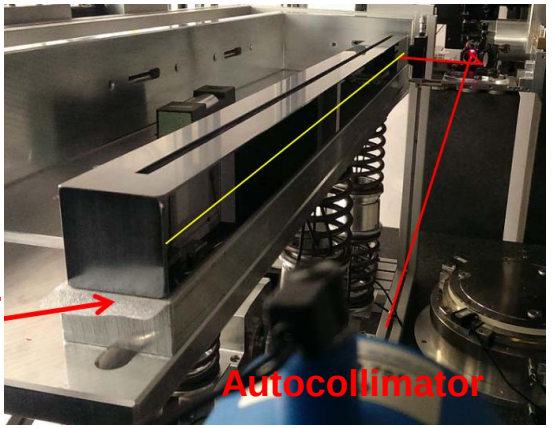
- Traceable angle measurements targeting at nanoradian uncertainty for stringent demands

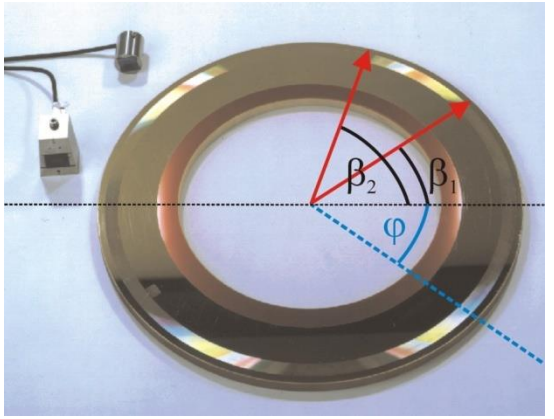
Approach:

- Investigations for reaching fundamental metrological limits in the autocollimator-based form measurement of curved optics (e.g. X-ray optics)
- Development of new devices - methods for enhancement of autocollimators, angle encoders and small angle generator applications

Main Results:

- Milestone: first spatial (2D) autocollimator calibration
- Improvements in application of angle measurement devices with uncertainties of a few nrad





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Crystal, SIB61, Call 2012

Crystalline surfaces, self assembled structures, and nano-origami as length standard in (nano)metrology

Main Challenge: surface and nanometrology

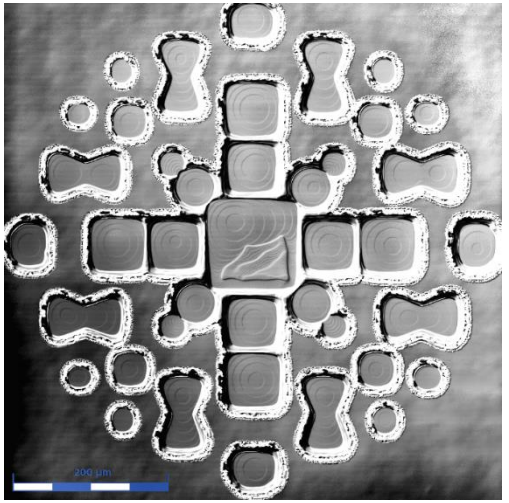
- Gap in traceability for step height (0.5 ... 6 nm) and lateral standards (5 … 50 nm)

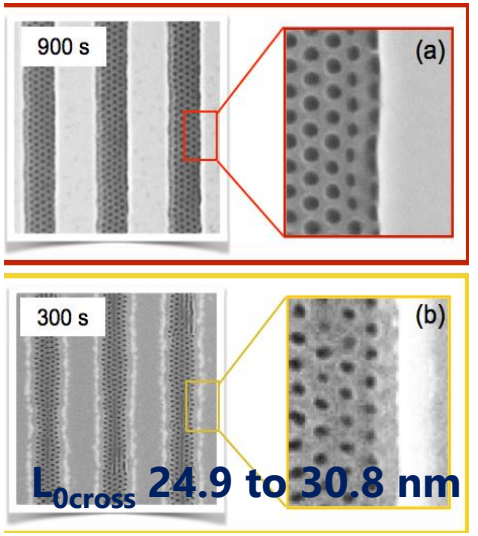
Approach:

- Preparation of crystalline surfaces: larger flat areas and use of atomic steps; Dev. of metrology UHV-STM
- Use of DNA-Origami and self-organization processes for realization of lateral standards

Main Results:

- Si-surface: flat >100 µm; step: h = 0.3114 ± 0.006 nm
- Lateral standards: self-organized di-block copolymers





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Nanoscale 2016 Conference

- Organised by TU Wroclaw, GUM and PTB in co-operation with EURAMET TC-L and CCL WG-N

- March 9th to 11th, 2016
- TU Wroclaw, Poland

- > 80 participants

euspen 2017 Conference in Hannover: May 29 – June 2, 2017; keynote talks

- **Prof. Joachim Ullrich,**
  President of the Consultative Committee for Units of the CIPM and President of the PTB:
  - Title: **„Linking the International System of Units to Fundamental Constants"**

- **Prof. Karsten Danzmann**, Director of Albert-Einstein-Institute Hannover, MPI Gravitational Physics and Institute for Gravitational Physics of Leibniz University in Hannover:
  - Title: **„Gravitational Wave Astronomy: Listening to the Dark Universe"**

- **Dr. Harald Sinn**, European X-FEL, Hamburg, Group Leader X-ray Optics & Beam Transport:
  - Prov. title: **„European X-FEL: Metrology and Alignment issues …"**

Thank you
for your attention!

TC-L Oct. 2015, CEM Spain

=> Next TC-L Meeting:
17-19 Oct. 2016, VSL, NL

Length