

# Mechanical Metrology

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Program Funding:	\$2.3 M
FTEs:	9.3

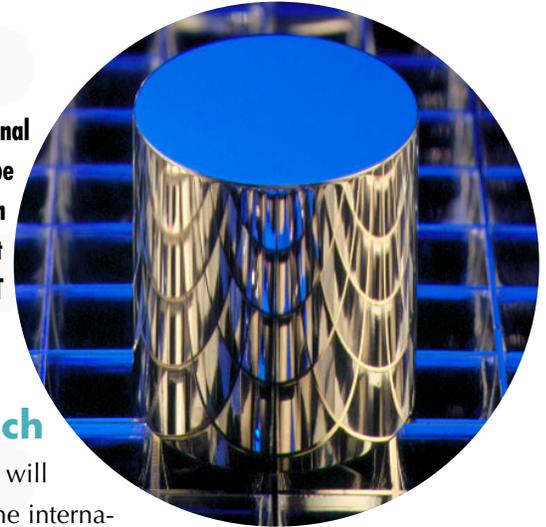
## Program Goal

Develop and deliver timely measurements and standards to address identified critical U.S. industry needs for traceable mechanical metrology in the areas of acoustics, force, mass, and vibration, particularly for the support of trade and innovation, process-control, and quality in manufacturing.

## Problem

The Mechanical Metrology Program maintains, realizes, and disseminate the SI units of sound pressure, force, mass, and acceleration to a broad customer base that covers numerous industries and impacts nearly every sector of the U.S. economy. The program staff must maintain and continuously enhance the high-quality, state-of-the-art measurement capabilities, and develop new research areas and measurement services to advance the state-of-the-art in mechanical metrology, provide new opportunities, and boost the competitiveness of the U.S. industry.

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Kilogram  
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## Approach

The program will draw upon the internationally recognized skills and expertise of MEL staff in the mechanical metrology areas to develop new and improved measurement capabilities, provide high-quality measurement services, and guarantee open worldwide markets to U.S. industry by participation in international comparisons and standards committees. By increasing the emphasis on Research and Development (R&D), the program will respond to the customer needs for future measurement capabilities and increase the interactions with mechanical metrology R&D organizations and the “end-users” of devices and artifacts calibrated by MEL measurement services.

## Typical Customers and Collaborators

Aerospace industry, automotive industry, construction industry, nuclear power industry, pharmaceutical industry, instrument manufacturers, university research labs, state weights and measures labs, federal agencies (Departments of Agriculture, Commerce, Defense, Energy, Labor, Veterans Affairs, and Justice, and the Food and Drug Administration).

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**Program Manager:**  
Zeina J. Jabbour

**Total FTEs:**  
9.3

**Annual Program Funds:**  
\$2.327 M

## Customer Need & Intended Impact

**M**echanical metrology plays a critical role in nearly all sectors of the U.S. economy and in everyday life. The mechanical metrology program provides the research and development infrastructure for responding to and anticipating the needs of the U.S. government and industry in the areas of acoustics, force, mass, and vibration measurements. In addition, the program realizes, maintains, and disseminates the basic SI (System of International Units) unit of mass, and the quantities of acoustics, force, and vibration to a broad customer base covering the nuclear, aerospace, electronics, electric power, pharmaceutical, biotechnology, materials, chemical, construction, and automotive industries, state governments, as well as the U.S. departments of defense, labor, energy, transportation, veteran's affairs, and agriculture.

To insure the competitiveness of the U.S. industry in world markets, the mechanical metrology program maintains active participation in the CIPM (Comité International des Poids et Mesures) consultative committees on Mass and related quantities (CCM – Consultative Committee on Mass and Related Quantities) and Acoustics, Ultrasound, and Vibration (CCAUV – Consultative Committee on Acoustics, Ultrasound, and Vibration), the Interamerican Metrology System (SIM), participation in the Mutual Recognition Arrangement (MRA) and associated international key comparison. A crucial aspect of the mechanical metrology program is the transfer of NIST-developed measurement and uncertainty evaluation techniques to the U.S. industry and other government agencies. This is accomplished through participation and/or leading of standards activities (ISO, IEC - International Electrotechnical Commission, OIML - International Organization of Legal Metrology, ASTM – American Society for Testing and Materials) and other direct outreach activities that serve the dual purpose of assessing immediate and anticipated needs of the metrology and research and development (R&D) community as well as transferring the current resident knowledge and expertise at NIST.

The R&D needs include short-term and current needs that are the focus of the existing activities. It is the intention of this program to increase the emphasis on long-term anticipated needs. This will be accomplished over time in an evolutionary manner, beginning with forming high-level contacts with the R&D community to assess the impact of the current measurement services provided and to establish a roadmap for the long-term future of mechanical metrology.

Areas such as stable mass artifacts, traceable vacuum mass measurements, optical detection of forces, MEMS (Micro Electro-Mechanical Systems) load cells, shock metrology, traceable phase measurements for accelerometers, next-generation measurement techniques for new microphones, and angular accelerometers are areas of known interest for industry and public-sector customers would result in significant anticipated impacts cutting across most sectors of the U.S. economy. The short-term/current needs are evidenced by the large demand for the measurement services provided and the continuous requests to improve and upgrade, existing services, and/or develop new ones. Such additional needs include the development of low-frequency vibration capabilities, improved density measurements, torque, dynamic force, and dynamic torque measurements.

## Technical Approach & Program Objectives

The program goal will be met through prioritization of activities and allocation of resources to address the key elements of each mechanical metrology service area. For each service area, the activities of R&D for new and improved measurement capabilities, provision of services to customers, participation in international comparisons to eliminate barriers to trade, and standardization of measurement methods and protocols are integral to the overall success of the program. These aspects form the basis for the program objectives and each objective interacts strongly with the others. The program will draw upon the internationally recognized skills and expertise of MEL staff in the mechanical metrology areas to achieve the program objectives. Funding will be leveraged from multiple sources as much as possible to enable appropriate allocation of resources. As indicated above, the program intends to increase the emphasis on R&D to respond to customer needs for future measurement capabilities and to increase the interactions with mechanical metrology R&D organizations and the “end-users” of devices and artifacts calibrated by MEL measurement services.

### Objective #1: Research and Development Activities

By FY2009, conduct research and development activities to anticipate the long-term, short-term, and current needs of fundamental SI metrology, government, and industry, and drive future advancements in the areas of mass, acoustics, force, and vibrations.

**Deliverables for FY2009:**

Foundation for “future mass metrology” built by designing, building, and testing a prototype magnetic levitation vacuum balance, and developing stable mass artifacts to provide the foundation for the first directly-traceable vacuum measurements, eliminate the time-variance of the mass artifacts and the definition of the Kilogram and enables the realization of the alternative definitions of the artifact mass definition.

**Milestones:**

- For 2005, preliminary design of balance including weighing mechanism, vacuum/air interface chamber, and magnetic levitation and shielding mechanisms.
- For 2007, the magnetic rigid link system and report on the operation of the balance in air and in vacuum.
- For 2007, mechanisms for in-situ measurements of surface and material properties.
- For 2007, methods for manufacturing stable mass artifacts and evaluation of platinum-iridium and stainless steel samples.
- For 2008, the first set of stable mass standards and report on surface and material properties monitoring.

- For 2009, full implementation of first prototype magnetic levitation balance; first vacuum/air mass measurement with direct traceability to one of the U.S. national prototype Kilograms; and a report of operation uncertainty sources, and requirements for building the next-generation balance to realize measurements with  $1 \times 10^{-10}$  relative precision.

**Deliverables for FY2006:**

Robotic mass and solid density measurement facility built in the Advanced Measurement Laboratory (AML) to eliminate errors caused by human interface and optimize measurement process. This facility will cover the mass range from 1 mg to 64 kg and solid density of artifacts in the range from 10 g to 1 kg and will be used to improve the measurements efficiency and uncertainty of NIST reference standards used in R&D and those used in delivery of measurement services. This facility will be adapted for the provision of the mass calibrations in the ranges specified and all procedures and uncertainties documented.

**Milestones:**

- For 2005, implementation of mass and density robotic systems in AML. and measurement procedures for robotic systems.
- For 2006, robotic systems for the provision of mass and solid density measurement services and procedures documented.

**Deliverables for 2005:**

The automation and upgrade of hardware and software controls of the 27 kN (6.1 klbf) force deadweight machine completed to allow hysteresis measurements, enhance efficiency and improve the consistency of the measurement process and document all operation procedures, hardware, software, and testing results in NISTIR.

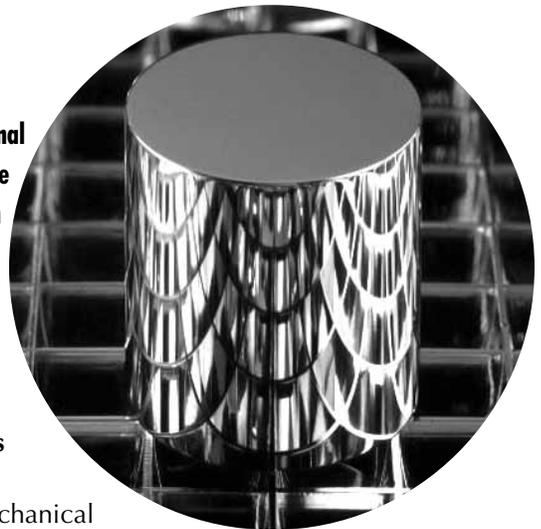
**Deliverables for 2005:**

The extended low-frequency sinusoidal accelerometer calibration system with improved accuracy and extended frequency range to satisfy the requirements of the automotive, aerospace, construction, nuclear power, manufacturing industries, and Department of Defense (DoD) for traceability of vibration transducers in the frequency range extending at least an order of magnitude below 1 Hz; documentation of developed procedures and uncertainty analysis necessary for establishing a new NIST SP250 calibration service; and vibration measurement services implemented in new laboratory in AML.

**Objective #2: Customer Interactions**

By 2008, establish and/or maintain contacts with customers from various sectors of the U.S. industry, government agencies and departments, and academia to evaluate and assess the future research and development needs in the areas of mechanical metrology.

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**Deliverables for 2005:**

- Major mechanical metrology customers identified and contacts initiated with assistance from MEL strategic manager.
- Site visits to selected customers to identify the current impact of the mechanical metrology services and identify the future needs; and a summary report of findings.

**Deliverables for 2006:**

Multiplws workshops to formally assess and identify the industry needs in the acoustics, force, mass, and vibration and reports on workshops results and findings.

**Deliverables for 2008:**

Consensus technology roadmaps developed with industry contacts, that to plan and prioritize development of future mechanical metrology capabilities based on identified industry needs and workshop results in mass, acoustics, force, and vibration.

**Objective #3: Measurement Services**

Provide measurement services in conformance with an ISO 17025 compliant quality system to meet the needs of the U.S. government and industry in the areas of acoustics, force, mass, and vibrations.

Activities associated with this objective are ongoing with annual deliverables.

**Annual Deliverables:**

1. Provided SP250 calibration services and special tests to broad customer base in the areas of acoustics, force, mass, and vibration with uncertainties equal to or better than those specified in publication NIST SP 250; and 90% or better on-time delivery of reports of calibrations and special tests to all customers.
2. Compliance with ISO 17025 quality systems for all SP250 measurement services from all administrative and technical aspects including regular calibration of NIST reference and working standards, calibration of all equipment and/or instrumentation associated with calibration systems with direct traceability to NIST, and maintaining control charts. Report on status to Measurement Services Advisory Group (MSAG).
3. All calibration fees reviewed and revised as necessary to insure full cost recovery for all calibration services in accordance with NIST policies.

**Objective #4: International Key Comparisons**

By 2008, conduct international key comparisons to insure U.S. compliance with the MRA and insure competitiveness of the U.S. industry in world markets.

**Deliverables for 2008:**

Participate and/or pilot, perform measurements, and generate reports for the CIPM and SIM key comparisons in acoustics:

**Milestones:**

- For 2005, participation in the CCAUV comparison of laboratory standard microphones at 31.5 Hz to 25 kHz; analysis and comments on Draft A results.
- For 2006, participation in the CCAUV comparison of free field sound pressure in air in the range of 2 kHz to 40 kHz (if enough other National Measurement Institutes (NMIs) are ready),
- For 2006, participation in the CCAUV comparison of laboratory standard microphones at low frequencies in the range of 2 Hz to 125 Hz.
- For 2008, participation in the SIM comparison of laboratory standard microphones in the range of 125 Hz to 8 kHz.

**Deliverables for 2008:**

Participate and/or pilot, perform measurements, and generate reports for the CIPM and SIM key comparisons in force:

**Milestones**

- For 2005, pilot lab for the CCM 2 MN and 4 MN comparisons.
- For 2006, participation in the CCM 10 kN comparison.
- For 2007, participation in the CCM 100 kN comparison.
- For 2008, participation in the CCM 1 MN comparison.

**Deliverables for 2008:**

Participate and/or pilot, perform measurements, and generate reports for the CIPM and SIM key comparisons in mass:

**Milestones**

- For 2005, co-pilot lab for the CCM comparison of 1 kg stainless steel artifacts.
- For 2006, participation in the CCM comparison of solid density.
- For 2006, participation in the CCM comparison of 50 kg mass standards.
- For 2008, participation in the CCM comparison of multiples and submultiples of 1 kg standards.

**Deliverable:**

Participate and/or pilot, perform measurements, and generate reports for the CIPM and SIM key comparisons in vibration:

**Milestones**

- For 2005, pilot lab for the SIM comparison in the range of 50 Hz to 5 kHz.
- For 2006, participation in the SIM low frequency vibration comparison.

**Objective #5: Standards Activities**

Provide high-level technical expertise through participation in standards activities in the areas of acoustics, force, mass, and vibration to ensure traceability and comparability of U.S. physical and documentary standards in mechanical metrology to those of other nations and to represent and protect the interests of the U.S. industry in global markets. A complete list and roles of mechanical metrology program staff in standards committees is listed under the “standards participation” section. Activities associated with this objective are ongoing with annual deliverables.

**Deliverables:**

NIST interests represented and defended contribution to future planning activities, and status reports on technical developments and MRA related activities at the meetings of the CCM and associated working groups on mass, force, and density in the years 2005, 2006, 2008, and 2009, CCAUV in the years 2006 and 2008, SIM and its associated working groups on mass and related quantities, and acoustics, ultrasonics, and vibrations as needed.

**Annual Deliverables:**

As Technical Advisor to the USNC (ANSI’s United States National Committee)/IEC for Technical Committee (TC) 29, recommendation USNC/IEC position and contribution to the development of acoustics standards (annual deliverables):

- IEC 61094-6 “Measurement microphones – Part 6: Electrostatic actuators for determination of frequency response,”

- IEC 61094-7 “Measurement microphones – Part 7: Values for the difference between free-field and pressure sensitivity levels of laboratory standard microphones,”
- IEC 61672-3 “Electroacoustics – Sound level meters – Part 3: Periodic tests,”
- Drafts/proposals for new ANSI standard S1.15 Measurement Microphones – Part 2: Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique, for other parts of the S1.15 series, and for new ANSI standards on sound calibrators, on sound level meters.

**Deliverables for 2005:**

- Publication of ANSI S2.1 on Vibration and Shock Terminology.
- Publications of ISO 16063-15 on Primary Angular Vibration Calibration by Laser Interferometry and ISO 16063-22 on Shock Calibration by Comparison to a Reference Transducer.

**Deliverables for 2008:**

Publications of ISO 18431-1 on a General Introduction to Mechanical Vibration and Shock Signal Processing in 2007 and ISO 18431-4 on Shock Response Spectrum Analysis in 2008.

**Deliverables for 2009:**

Revision of ISO 2041 (TC108 WG1) on Vibration and Shock Terminology and integration of ANSI S2.1 into it.

**Deliverables:**

- For 2005, technical contributions to resolve transducers stability criteria in ASTM E74-02 “Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines” and revised standard.
- Annual review the ASTM Force Standards E74-02 and E4-03 “Standard Practices for Force Verification of Testing Machines” and participation in bi-annual committees / sub-committees meetings as needed.

**Deliverable**

Technical contributions to OIML R111 and ASTM E617-97 standards on weights, their classifications, technical requirements, and measurement procedures as needed.

## Major Accomplishments

### ISO 17025 compliant quality system implementation and assessment for international recognition of services and participation in the MRA

- Development, documentation, implementation, and assessment of the MEL Manufacturing Metrology Division (MMD) quality system for measurement services in Acoustics, Force, Mass and Vibration completed.
- Quality system assessed both internally by MMD and by NIST at large and found to be in conformance with the NIST quality system by the NIST Assessment Review Board and the NIST Measurement Services Advisory Group.
- Electronic copy of quality manual and report on quality system submitted to SIM Quality System Task Force for approval during November 2004 Regional Board meeting. This quality system supports the NIST Calibration and Measurement Capabilities claimed for Acoustics, Force, Mass and Vibration in Appendix C of the Mutual Recognition Arrangement.

### Strong support for MRA through international and regional intercomparisons to eliminate trade barriers for customers

- Hosted meeting of SIM Metrology Working Group 9 on Acoustics, Ultrasound & Vibration.
- Draft A of the report on CCAUV.A-K3 prepared & circulated among the participating labs.
- Piloted Force 4 MN key comparison, CCM.F-K4; status report submitted for March meeting of CCM Working Group on Force.
- Final reports of results of key comparisons in mass, CCM.M-K1 and CCM.M-K2 published in Appendix B of the BIPM (Bureau International des Poids et Mesures) key comparison data base.

### High quality NIST SP 250 measurement services

- In 2004, 442 calibrations, special tests, and NTEP (National Type Evaluation Program) tests were performed for 98 distinct customers in the industrial, governmental, and educational sectors.

### Crucial role in development and publication of documentary standards to support measurement methodology and their implementation in calibration procedures

- ISO standard on secondary calibration of vibration and shock transducers by comparison published.
- ISO standard on time domain windows for Fourier transform analysis submitted for publication.
- IEC/TS 62370 on electromagnetic and electrostatic compatibility requirements and test procedures for sound-intensity measuring instruments published in May 2004.

- Four national standards published: ANSI S1.11-2004 on octave-band and fractional octave-band analog and digital filters, ANSI S1.17-2004/Part1 on measurements and specification of insertion loss of microphone windscreens, ANSI S3.6-2004 on specifications for audiometers, and ANSI S3.21-2004 on methods for manual pure-tone threshold audiometry.

## **FY2005 Projects**

### **Mass Metrology of the Future (Objective #1)**

Develop preliminary design of a vacuum balance that directly links the vacuum unit of mass to the current realization in air and begin manufacturing and/or procuring parts. Implement robotic mass facility in AML for mass and solid density metrology.

### **Upgrades and Expansion of Mechanical Metrology Measurement Services (Objective #1)**

Expand the vibration measurement services in the low-frequency range. Implement new vibration labs in AML. Automate the 27 kN (6.1 klbf) deadweight machine to improve operation and realization of the unit of force.

### **Outreach (Objective #2)**

Identify major mechanical metrology customers and initiate contacts with assistance from MEL strategic manager. Organize and conduct site visits to selected customers to identify the current impact of the mechanical metrology services and identify the future needs. Generate a summary report of findings.

### **Mechanical Metrology Measurement Services (Objective #3)**

Provide measurement services in the areas of acoustics, force, mass, and vibration in accordance with the NIST quality system. Maintain the quality manual in compliance with ISO 17025 and NIST QMI (Quality Manual I). Update manual as needed. Issue quarterly reports to the MSAG on the status of the quality system for the areas in mechanical metrology.

### **International Key Comparisons and Standards Activities (Objectives #4 & #5)**

Complete measurements and analyze results of the 4 MN key comparisons piloted by NIST in collaboration with the NIST Statistical Engineering Division. Write and submit first draft report to the CCM working group on Force. Pilot SIM key comparison in vibration; conduct measurements, analyze results, and issue preliminary report. Co-pilot 1 kg mass standards key comparison with BIPM. Participate in CCAUV key comparison in acoustics. Represent NIST at the CCM meeting and the meetings of the Working Groups on Mass and Density. Represent NIST and the U.S. in meetings of the ASTM, ISO, IEC, OIML, and other standards organizations as needed.

## Typical Customers and Collaborators

Aerospace industry, automotive industry, construction industry, nuclear power industry, pharmaceutical industry, instrument manufacturers, university research labs, state weights and measures labs, federal agencies (Departments of Agriculture, Commerce, Defense, Energy, Labor, Veterans Affairs, Justice, and the Food and Drug Administration).

## FY2005 Standards Participation

### ANSI S1 Acoustics:

Organizational Member; S1/WG1 Standard Microphones and their Calibration: Chair; S1/WG21 Electromagnetic Susceptibility of Acoustical Instruments: Member

### ANSI S2 Mechanical Vibration and Shock:

Vice Chair and Organizational Member; S2/WG2 Terminology: Chair; S2/WG3 Signal Processing Methods: Member; S2/WG5 Use and Calibration of Vibration and Shock Measuring Instruments: Chair

### ASACOS (Acoustical Society of America on Standards):

Member

### ASTM E7 Nondestructive Testing:

Member; E7.04 Acoustic Emission: Member; E7.06 Ultrasonics: Member.

### ASTM E28 Mechanical Testing:

Member; E28.01 Calibration of Mechanical Testing Machines and Apparatus: Member; E28.05 Residual Stress: Member; E28.13 Dynamic Modulus Measurements: Member.

### ASTM E41.06 Weighing Devices:

Member

### CIPM:

Consultative Committee on Acoustics, Ultrasound and Vibration (CCAUV): Delegate; Consultative Committee on Mass and Related Quantities (including force) (CCM): Delegate; CCM WG on Mass: Member; CCM WG on Density: Member; CCM WG on Force: Member.

### SIM:

MWG7 Mass & Related Quantities, MWG9 Acoustics and Vibration: Member.

### IEC TC29 Electroacoustics:

Chair U.S. Delegation; USNC/IEC for TC29: Technical Advisor; TC29/WG5 Measurement Microphones: Member.

### ISO TC108 Mechanical Vibration and Shock:

Chair U.S. Delegation; TC108 U.S. TAG: Chair; TC108/WG1 Terminology: Member; TC108/WG26 Signal Processing Methods for the Analysis of Mechanical Vibration and Shock: Convener; TC108/SC3 Use and Calibration of Vibration and Shock Instrumentation: Chair U.S. Delegation; TC108/SC 3 U.S. TAG (Technical Advisory Group): Chair; TC108/SC3/WG6 Calibration of Vibration and Shock Transducers: Expert Member; TC108/SC3/WG10 Vibration Condition Monitoring Transducers and Instrumentation: Member.

### ISO TC135 Nondestructive Testing:

Alternate Chair U.S. Delegation; ISO TC135/SC3 Acoustic Methods: Chair; ISO TC135/SC3: liaison to IEC TC87 Ultrasonics.

**OIML TC9 Instruments for Measuring Mass and Density:**

Technical Advisor to U.S. Voting Member; OIML TC9/SC3 Weights: Technical Advisor to U.S. Voting Member; USNWG/OIML TC9/WG1 Load Cells: Member.

**OIML TC13 Measuring Instruments for Acoustics and Vibration:**

Technical Advisor to U.S. Voting Member

**Research Facilities:**

Provide tests and measurements on an as-needed basis in special NIST Research Facilities such as the NIST Acoustic Anechoic Chamber.

**Testing:**

Load Cell Evaluation - Provide evaluations of prototype load cells in accordance with both national (NTEP) and international (OIML R60) standards.

**FY2005 Measurement Services**

**Calibrations and Special Tests:**

Provide calibrations and special tests as described under Mass Standards, Force Measurements, Vibration Measurements, Acoustic Measurements, and Ultrasonic Measurements in the NIST Calibration Services Users Guide, SP 250.



**Army helicopter loudspeaker unit setup for testing in the acoustic anechoic chamber research facility**

# Mechanical Metrology

