The NIST MEL: Assisting Aerospace Manufacturing through Measurements and Standards

David C. Stieren
National Institute of Standards and Technology
100 Bureau Drive Stop 8202
Gaithersburg, MD 20899-8202
301-975-3197
david.stieren@nist.gov

Abstract—The research, measurement and standards activities of the Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) are summarized, especially as they relate to aerospace manufacturing. NIST is a non-regulatory agency of the U.S. Department of Commerce's Technology Administration that was established in 1901 as the National Bureau of Standards.

MEL is one of seven NIST measurement and standards laboratories. MEL works with the American manufacturing sector to develop and apply technology, measurements, and standards. MEL provides industry-needed engineering tools, interface standards, systems architectures, and traceability. Through its research and services, MEL helps U.S. industry successfully compete in the global marketplace. Manufacturers employ MEL research results, test methods, software conformance tests, calibration services, and measurement tools.

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Additional information about MEL and the programs summarized in this paper can be found at the MEL website, located at www.mel.nist.gov.

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1. INTRODUCTION

The National Institute of Standards and Technology (NIST) is a non-regulatory agency of the U.S. Department of Commerce’s Technology Administration. Established in 1901 as the National Bureau of Standards, NIST strengthens the U.S. economy and improves the quality of life by working with industry to develop and apply technology, measurements, and standards. Global technology and market changes are demanding U.S. shifts in federal research and development (R&D) strategies, and NIST plays an important role in making investments for long-term economic growth. NIST focuses on tasks vital to the country's technology infrastructure that neither industry nor the government can do separately. NIST conducts a portfolio of four major programs:[1]

- Measurements and Standards Laboratories, which provide technical leadership for the nation's measurement and standards infrastructure and assure the availability of needed measurement capability to promote the U.S. economy and public welfare. Efforts of the NIST Labs are planned and implemented in cooperation with industry and focused on infrastructural technologies, such as measurements, standards, evaluated data, and test methods. The benefits from such enabling technologies typically spread across entire industries, and individual companies cannot recover the investments needed to produce them. The Manufacturing Engineering Laboratory (MEL) is one of the seven NIST Laboratories.

1 U.S. Government work not protected by U.S. copyright.
- Advanced Technology Program (ATP), which provides cost-shared funding awards to industry to develop high-risk, enabling technologies that promise significant commercial pay-offs and widespread benefits for the economy. The ATP provides funding to individual companies and to industry-led joint ventures. The program seeks to build bridges between basic research and product development. It accelerates technologies that otherwise are unlikely to be developed in time to compete in rapidly changing markets without such a partnership of industry and government.

- Manufacturing Extension Partnership (MEP), which is a grassroots effort to improve the competitiveness of smaller manufacturers by offering access to the business and technology information and expertise that allow them to improve their operations. These smaller companies are assisted through MEP's nationwide network of affiliated manufacturing extension centers run by local, state, and non-profit groups.

- Baldrige National Quality Award Program, which recognizes and promotes performance excellence by U.S. manufacturers, service companies, educational organizations, and health care providers. The Malcolm Baldrige National Quality Award has become both the U.S. standard of quality achievement in industry and a comprehensive guide to quality improvement.

The remainder of this paper focuses on the activities of the NIST MEL. After describing MEL, the paper summarizes examples of the type of work being conducted within MEL that is relevant to the U.S. aerospace manufacturing industry.

MEL Background

The mission of MEL is to satisfy the measurements and standards needs of the U.S. discrete-parts manufacturers in mechanical and dimensional metrology and in advanced manufacturing technology by conducting research & development, providing services and participating in standards activities.[2]

MEL is organized into four technical divisions and one support division. Additionally, MEL includes an office that is responsible for program management and for identifying, negotiating, and developing strategic relationships between MEL and organizations from industry, other government agencies, and academia. MEL's divisions are listed below:

- The Precision Engineering Division (PED) conducts research and development in precision-engineered, length-metrology-intensive systems in both measuring and production machines. PED delivers to industry important length-related measurements, standards, and technology services that support U.S. manufacturing's products and processes.

- The Manufacturing Metrology Division conducts research and development in realizing and disseminating Systeme Internationale d'Unites (SI) mechanical units; develops methods, models, sensors, and data to improve metrology, machines, and processes; provides services in mechanical metrology, machine metrology, process metrology, and sensor integration; and leads in the development of national and international standards.

- The Intelligent Systems Division (ISD) works with industry, universities, and other government agencies in the development of new measurement techniques and standards for intelligent machine systems, robots, and automated manufacturing systems. ISD's focus is to provide a theoretical framework for the development of interface standards and performance measures for intelligent systems, and to develop engineering guidelines for the design and implementation of intelligent control systems for a wide variety of applications.

- The Manufacturing Systems Integration Division promotes developing technologies and standards that lead to the implementation of information-intensive manufacturing systems. Such systems can be integrated into a national network of enterprises working together to make U.S. industry more productive.

- The Fabrication Technology Division provides fabrication services for instruments and devices required by researchers from MEL and other NIST laboratories.

Through its research and services, MEL sustains a solid record of helping U.S. industry successfully compete in the global marketplace. Manufacturers employ MEL research results, test methods, software conformance tests, calibration services, and measurement tools. Manufacturers collaborate with MEL on technical projects, standards development, and testbed-based research, both on an individual basis and as members of industrial consortia. In addition, MEL plays a key role in fostering inter-company cooperation and industrial adoption of strategically important manufacturing and computing hardware, equipment, and software standards.

MEL research and services particularly benefit the discrete-parts manufacturing sector. For example, MEL's work on characterizing and controlling machining processes enables this sector to improve dramatically its tools, processes, and products. Efforts in the area of intelligent machines and systems are accelerating the trend toward open systems architecture and intelligent manufacturing.
MEL Customers and the Aerospace Industry

MEL has three types of customers: customers that receive direct assistance, sponsors outside of NIST who fund MEL work, and oversight bodies who assess or evaluate the impact of MEL work. These customers represent industry, government, academia, standards organizations, consortia, technical societies, and the public. They include users of MEL services and products, and participants in MEL programs.

The management of MEL is constantly faced with establishing priorities for which customers MEL should serve. Questions of where and how MEL should invest and apply its resources and focus its programs are growing in importance in today’s environment of flat NIST budgets.

To help answer these questions, members of MEL’s management team recently solicited the assistance of professionals from the NIST Economic Assessment Office. An exercise was conducted to identify and quantify the Standard Industrial Classification (SIC) codes and characteristics of those specific manufacturing sectors that fall into what is considered to be “discrete part manufacturing industries.” [2] This exercise revealed that two SIC manufacturing sectors stand out both in size and the extent to which they contribute to the U.S. gross domestic product. These two sectors are the automobile and aerospace manufacturing sectors.

The results of this exercise have proven valuable to MEL for a number of reasons, a few of which are provided below.

- MEL has conducted programs for many years in partnership with, and that are relevant to the automobile and the aerospace sector.
- MEL programs are beginning to more closely focus on contributing to the production of outcomes that are broadly based across industry. As such, MEL is beginning to more intensively apply its resources to the automobile and aerospace manufacturing sectors, since these are the sectors within discrete part manufacturing that have the greatest impact on the U.S. economy.

With recent improvements of the global economy and increases in world air traffic, the U.S. aerospace industry has found itself challenged by growth to seek ways to improve processes and production time. The NIST MEL conducts a number of technical programs that offer a variety of technical assistance to U.S. aerospace firms to enhance their competitiveness in the global marketplace.

The next sections of this paper describe various MEL technical areas and programs that directly relate to aerospace manufacturing and/or are being conducted in partnership with the aerospace industry.

2. MECHANICAL AND DIMENSIONAL MEASUREMENTS

The manufacture of airplanes and other aerospace vehicles and platforms requires thousands of different measurements to be made and repeated. This requirement spans the lifecycle from initial design to retirement from service. MEL researchers offer measurement standards and calibrations, and perform research that assist in addressing measurement problems and ultimately in assuring and assessing the quality of aerospace parts and materials. The following MEL programs relate to mechanical and dimensional measurements.

Engineering Metrology

This program (1) provides dimensional measurement services, (2) develops new dimensional measuring techniques to address changing industry needs, (3) disseminates metrology knowledge, and (4) participates in national and international standards activities. The program includes a variety of length and geometric measurements of objects with characteristic dimensions that range from a fraction of millimeter to more than a meter.

This program supports national and international manufacturers, research and calibration facilities, standards writing organizations, and academia. The program strives to address, efficiently and effectively, the needs of its customers, which includes several aerospace manufacturers. These customer needs fall into three categories: (1) traceable measurements and standard reference materials with the lowest attainable uncertainty, (2) development of new techniques to improve and extend measurement capabilities, and (3) the latest, most accurate technical guidance on measurement related issues.

Large Scale Metrology

This program provides dimensional measurements and measurement research on the scale of one meter or larger. These efforts are primarily focused in three areas: coordinate metrology with linear axis coordinate measuring machines, coordinate metrology using frameless coordinate measuring systems (theodolite systems, tracking laser interferometer systems, or laser ranging systems), and machine tool metrology for emerging technologies such as parallel actuated machining systems. The initial development of laser tracker technology occurred at NIST in conjunction with activities of the predecessor to the current Large-Scale Metrology Program.

Large-scale coordinate metrology problems are addressed on two major fronts in this program: (1) developing national, international, and Department of Defense (DOD) standard specifications for these coordinate metrology instruments; and (2) conducting research into performance issues and subsequent artifact development in support of these.
standardization efforts. NIST staff members working this program are actively involved on both the American National Standards Institute (ANSI) and the ISO standards developing bodies in the area of performance assessment of large-scale coordinate metrology instruments.

Mechanical Metrology
This program provides U.S. industry, federal, state, and local governments, and the scientific community with best-in-the-world class measurement services and access to the top of the traceability chain for the mechanical quantities of mass, force, sound pressure, acceleration, shock, and ultrasonic power.

The program realizes and/or maintains the national standards for mechanical quantities and continuously seeks to improve its facilities. These facilities include a world-class clean room mass laboratory with tight environmental controls, a world-class force laboratory with six deadweight machines that generate discrete forces over a range of 44 N to 4.448 MN, a 450 m² anechoic chamber, and other specialized laboratories and equipment. The program strives to provide timely and accurate physical measurement services, and it performs short-term development to meet customer and standards needs.

Shop Floor as a National Measurement Institute (NMI)
This program develops the means to allow U.S. manufacturing firms to meet the global-market requirement for "new traceability" by making task-specific measurements effectively and economically on the shop floor that:

- realize the international standard of length without dependence upon calibrations made by NIST or any other NMI
- use measurement uncertainty to describe the expected variability in the measurement result
- approach the highest level of accuracy technologically attainable, without development by NIST of the task-specific measurement services or capabilities themselves.

The program aims to develop, validate, and propose for standardization an array of non-task-specific techniques. These would allow task-specific dimensional measurement on parts in the manufacturing shop floor environment of a demonstrable uncertainty and traceability to the SI unit of length without recourse to, or dependence on:

1. provision by NIST of a task-specific measurement service, or
2. development by NIST of a task-specific measurement capability, or
3. development for testing by NIST of a task-specific measurement methods.

3. Manufacturing Processes
There are thousands of processes involved in the manufacture of a machine as complex as an aircraft. MEL research is helping in several areas to make these processes more accurate and more efficient.

Predictive Process Engineering
This program develops the measurements and standards needed to characterize and specify manufacturing processes sufficiently well to ensure first part good part. To explain, one of the powerful visions espoused in current manufacturing roadmaps can be summarized as "first part, good part." Achieving this vision requires making the next logical step in a series of paradigm shifts in manufacturing product realization.

The 'golden era' of US manufacturing (pre-1975) was defined by a linear process. Part designs were developed and then "lobbed over the wall" to manufacturing, which developed a process plan (implicit or explicit). After the part was made it was inspected - and likely rejected. Several iterations resulted in a process producing geometrically acceptable parts, sometimes.

Another control loop addressed functional criteria such as residual stresses and paint adhesion. The mid-1980s saw a new paradigm, the idea of in-process geometric measurement with feedback. In general, the measurements were process intermittent, and subsequent functional inspection resulted in some reject rate and some feedback to improve the process. At NIST, this paradigm was embodied in, and driven by, the Quality in Automation program.

"First part, good part" demands a different approach in many areas of manufacturing engineering. This program proposes a new paradigm in predictive manufacturing - "process characterization" leading to proactive quality assurance. The new paradigm is a shift from classical feedback quality assurance or optimization to model-based feed forward process design and quality control. Part design assumes knowledge of process specifications and generates, seamlessly, a process designed to produce the right part first time; there will be no prototyping. Feedback from process metrology improves the process model, the process specification, and the manufacturing process itself.

Metrology and Smart Systems for Manufacturing Equipment
This program provides methods, standards, and smart sensor systems to characterize, monitor, and improve the performance and health of equipment for the manufacture of discrete parts, with a focus on machine tools for material removal. The vision of this program is manufacturing equipment whose performance is known and assured through real-time self-characterization, self-diagnosis, and self-improvement to achieve zero unscheduled downtime.
and error-free execution of manufacturing operations. The program is also revolutionizing the connectivity and utilization of sensors in metrology, manufacturing, and conditioned-based maintenance to enhance industrial capability and manufactured quality.

The program addresses the needs of U.S. manufacturers as they are faced with the challenge of intense global competition while moving toward more complex parts, closer tolerances, smaller batch sizes, shorter time-to-market, just-in-time production, more general-purpose equipment, and manufacturing that occurs on a more globally distributed basis.

Success in this environment requires accurate and reliable manufacturing equipment whose performance is known and guaranteed for a large variety of tasks and operating conditions. The ability of an enterprise and its suppliers to meet these requirements largely determines the range and features of products that can be produced, the capability in which the first and every subsequent part meets specifications, and the efficiency and agility of the manufacturing process.

Assisting and often leading the development of national and international standards in these technical areas is a large facet of this program. This includes participation and provision of secretariat services by program staff on several standards committees, including the Institute of Electrical and Electronics Engineers (IEEE) 1451 Standard for a Smart Transducer Interface for Sensors.

4. SYSTEMS INTEGRATION AND INTEROPERABILITY

Computer controlled manufacturing processes and systems need to speak the same language. Computer-aided design (CAD) systems must be able to receive and transmit product data accurately between and within shops. The following MEL work focuses on interfaces, architectures, and representation formats in an effort to improve the integration and interoperability of manufacturing systems. The results of this work can mean that aerospace manufacturers spend less time solving integration and interoperability issues and more time building planes.

Intelligent Open Architecture Control of Manufacturing Systems

This program provides measurements and standards needed to support a competitive market in intelligent control technology for U.S. discrete parts manufacturers. Specifically, the program participates in industry efforts to standardize open architecture control for the machine tool, robot, and automated metrology equipment sectors. Each of these sectors produces equipment that is typically used in the manufacture of aerospace vehicles and platforms.

When possible, MEL identifies standardization efforts at their beginning, by working with industry and government agencies to identify and develop new manufacturing applications of intelligent control. The program continues by participating with industry groups to develop suitable architectures on which to base standardization. Program activities focus on validation, performance measures, standardization, and conformance tests.

Initially, testbeds are established for developing performance measurement techniques and validating architecture and interface standards. Standards validation work proceeds in collaboration with industry groups, during a lengthy period of interaction with members. This results in the publishing and dissemination of the architecture and interface specifications. Program participation culminates in the provision of conformance tests that can be applied by vendors, users, and third parties to maximize interoperability.

Product Engineering

This program develops information protocols for interoperability of computer-aided design and product engineering systems. The program seeks to provide a basis for future standards in areas with high industry impact, focusing on the key issues that are emerging from the new collaborative product development paradigm. Specifically, the primary needs for the next generation of CAD-related software systems are interoperability among software tools, collaboration among distributed designers and design teams, integration of data and knowledge across the product development cycle (from design, to analysis, to manufacturing and beyond), as well as knowledge capture, exchange and reuse.

The R&D efforts of this program, ranging from specification and standards development to technology development and prototype implementation, strive to provide the foundation that will support the creation of next-generation product development tools, thereby increasing the efficiency, effectiveness, capability and productivity of U. S. industry.

Information Technology Metrology for Manufacturing

This program develops and provides formal methods, reference artifacts, and testing services that US industry needs for the continuous improvement of manufacturing software interoperability and information reliability. MEL is pursing fundamental research efforts focused on test methods, testability, and quantified references. These will provide industry the resources it needs to develop quality standards and measure implementations.

This program works to identify the elements common to individual measurement issues, to synthesize these common elements into the principles underlying rigorous testing approaches, and to codify these principles into a set of
formal methods that can be applied over a wide spectrum of manufacturing problem domains.

As part of the program, MEL identifies and enumerates types of software testing relevant to systems integration, including identifying how those testing mechanisms relate to one another. The program is also developing a lexicon of testing terminologies, investigating the methodologies and metrics relevant to systems integration testing and software behavior characterization, and developing best-in-class approaches. Program staff perform the research necessary to create a measurement infrastructure for manufacturing information technology.

MEL is establishing a formal basis for the testing and analysis of standards-based software implementations. This program provides reference data for measuring software performance and accuracy, and it defines metrics and dimensional units for software measurement.

The Standard for the Exchange of Product Model Data (STEP)

MEL has been active for several decades in the development of STEP. STEP is a standard recognized by the International Organization for Standardization (ISO) that is used widely in the aerospace industry for the computer-interpretable representation and exchange of product data. The objective of STEP is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent from any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

MEL currently provides the secretariat function for Technical Committee 184 / Subcommittee 4, “Industrial Data,” of the ISO 10303 STEP Standard.[3]

5. SUMMARY

The NIST MEL conducts an array of leading-edge technical programs that are relevant to the U.S. aerospace manufacturing industry. Most of the work summarized in this paper is actually conducted in partnership with the aerospace industry. MEL programs typically perform research, provide measurement services, and/or accelerate the development of standards. Additional details about MEL’s technical programs and MEL’s relationships with the aerospace industry can be found at the MEL website, located at www.mel.nist.gov.

While MEL serves those U.S. manufacturing sectors that are considered to be within the scope of discrete-part manufacturing, it also places priorities on how and where it can best leverage its resources and produce significant outcomes for the U.S. society and economy. As such, MEL attempts to focus particular attention on working with, anticipating the needs of, and providing quality solutions to the problems of the U.S. aerospace and automobile manufacturing sectors. These are two discrete manufacturing sectors that represent a large impact on the U.S. economy. MEL programs that are directly relevant to and being worked in partnership with the U.S. aerospace manufacturing sector focus on:

- mechanical and dimensional measurements
- characterizing and enhancing the performance of manufacturing processes
- improving the integration and interoperability of manufacturing systems

6. REFERENCES


7. AUTHOR BIOGRAPHY

David C. Stieren is the Strategic Relations Manager for the NIST MEL. He is responsible for identifying, developing, and implementing strategic and business partnerships with other government agencies, U.S. industry, and academia. Prior to his current duties, Mr. Stieren served as the Program Manager of the NIST National Advanced Manufacturing Testbed (NAMT). In this capacity he was responsible for the daily management, development, and representation of this leading edge collaboratory for manufacturing research and measurement services.

Mr. Stieren has been employed at NIST since 1988 and he has worked closely with several U.S. manufacturing sectors, including automobile, aerospace, and shipbuilding. His manufacturing expertise includes in-depth knowledge of flexible computer-integrate-manufacturing processes, technologies, and system, and he has an extensive research and measurement service background in the area of manufacturing metrology.

Mr. Stieren has a Bachelor of Mechanical Engineering degree from the Catholic University of America, a Master of Science in Technology Management degree from the University of Maryland, and he is currently performing his dissertation research for a Doctor of Science in Engineering Management degree from the George Washington University.