NBSIR 75-926

# The National Measurement System for Length and Related Dimensional Measurements, Part I

J. W. Lazar
R. L. Bach

Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

Final

March 1976

Issued August 1976

DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS ★



U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NBSIR 75-926

# THE NATIONAL MEASUREMENT SYSTEM FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS, PART I

J. W. Lazar
R. L. Bach

Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

Final

March 1976

Issued August 1976

U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
Edward O. Vetter, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

CONTENTS

LIST OF FIGURES

LIST OF TABLES

# THE NATIONAL MEASUREMENT SYSTEM FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS

## PART I

J. W. Lazar and R. L. Bach*

Mechanics Division

### EXECUTIVE SUMMARY

The determination of length and related dimensional measurements constitute the largest group of measurements made in science, manufacturing, and technology. It has been estimated that 80% of all measurements made in industry are of length and displacement. Figures developed from our recent study of the National Measurement System shows that an average of $9.4 billion is expended annually by the manufacturing sector alone to perform dimensional measurements in our economy.

Length and related dimensional measurements have impact upon many areas of the economy. The largest area is in manufacturing and within manufacturing the first-order impact areas are air frames and aircraft equipment, ball and roller bearings, car accessories, domestic appliances, electronic equipment, gears, general engineering, geodetic investigations, integrated circuit industry, photogrammetry, research and development, screwthread industry, scientific instruments, and watches. In many of these areas dimensional measurements are made to satisfy functionality requirements and little else. For example, the parts of an automobile engine would not fit properly if they were measured with different micrometers which were not accurately calibrated.

In the course of our National Measurement System study in Length and Related Dimensional Measurements, we have established over one hundred and fifty contacts with individuals within governmental agencies; industry; professional societies and organizations; scientific and trade journals; and universities and colleges around the nation. Many of these people contacted were surprised that we were willing to listen to their problems in dimensional measurements. In almost all cases, the organizations contacted expressed a keen desire to continue the dialogue established between the Bureau and their personnel.

The primary industrial contact was within Standard Industrial Classification 3548, Machine Tool Accessories and Measuring Devices. This industry was expanded into further prouct codes such as 35452, Precision Measuring Tools; 3545211, Comparators; 354221, Gage Blocks; etc. In many cases the contacts expressed no pressing need for any greater accuracy in standards for dimensional measurements. For example, the accuracy inherent in various dimensional artifacts (gage blocks, etc.) and instrumentation (laser interferometers, etc.) *far outpaces* the ability of many to transfer displacements obtained from these devices to other objects. (This is verified by viewing the results of some recent surveys contained in our report illustrating inconsistencies of 0.00177mm to 0.00254mm-70 to 100 microinches-in the measurement of internal diameters of finely finished ring gages.)

The primary users of the National Bureau of Standards' most accurate dimensional measurements are the Department of Defense Primary Standard Laboratories, the various gage and measurement instrument manufacturers, and the private standards laboratories including those who only service the parent organization.

Another major user category of NBS services is the machine tool industry. In the recent *U.S. Industrial Outlook 1973*, the machine tool industry ranked first in percentage increase in value of shipments from 1972 to 1973 (27 percent increase from $0.825 billion to $1.050 billion). An increasing percentage of manufacturing is being done under numerical control (NC). NC machine tool shipments are growing three times as fast as conventional machines and it is estimated that 15-20% of U.S. metalworking machine tool shipments are currently NC. There are pressing needs to develop standards and algorithms to characterize the accuracy of these machines. The reason for accurate calibration of NC machines is that the accuracy of parts produced is totally dependent on the inherent positioning accuracy and geometry of the machine tool.

The areas of surveying and geodetic investigations are frequent users of NBS calibration facilities (tapes). In recent years calibrations have been steadily declining and the 1974 NBS calibrations in this area were only approximately 20% of the same services in 1971. We have found that with the recent

---

* A major portion of the original research work for this study was performed by a former NBS employee, B. Nelson Norden, now with Monsanto Chemical Company of Pensacola, Florida.

advent of relatively inexpensive electronic distance measuring devices, many companies and individuals are now able to afford these devices.

We had initiated steps to interact with the machine tool industry to a greater extent even to the point of obtaining complimentary exhibit space in the International Machine Tool Show (IMTS) in September 1974 in Chicago. The specific purpose of our exhibit was to listen to and view first-hand some of the measurement problems within this important area. Four hundred and sixty-one people requested 1300 copies of the various dimensional technology and optics and micrometrology reports. The majority of these reports are the "how we do it" type.

Space has already been reserved for another NBS exhibit at the next IMTS in September 1976.

One fact has been repeatedly borne out from all contacts - the need for more awareness of the work being done at NBS and the need for more publications at multilevels discussing how to make accurate and precise measurements.

The results of the recent NCSL audit package measurements show the need for dimenional artifacts to verify the accuracy and precision of industry's gages and measurement system other than the standard set of gage blocks, angle blocks, plug and ring gages, spheres, etc. NBS should develop these standards and make them available to the various laboratories for their use to determine the accuracy and precision of their measurement system. In addition NBS should develop, in conjunction with industry, a three dimensional artifact to be used to determine the accuracy of their three dimensional measuring machines as well as their complex NC machining centers.

# 1. INTRODUCTION

This microstudy has been divided into two parts, static and dynamic linear measurements. Part I examines all the aspects of linear measurements of stationary objects such as gage blocks, line scales, angle blocks, etc. Part II is concerned with the measurement of linear motion versus time such as the measurement of displacement and amplitude of an object being subjected to a vibration or shock.

Quality Control, an elusive concept, usually determines if a product which fulfills a need returns a profit or a loss to the producing company. It applies to all steps in the production of an item to the form, shape, or size of the unique parts that constitute a final product. In other words, does the geometry of the machines that manufacture these parts (accuracy of lead screws, orthogonality of spindle and table and flatness of surfaces) meet the functional requirements? Do the individual parts fabricated on these machines meet the requirements of the drawings for these parts as to form, shape, or size so that they will be compatible with other parts made in other places on other machines? If the National Measurement System is alive and working and if all industries truly are part of it and periodically calibrate their machines and gages to the artifacts at NBS, perhaps three or four places down the calibration chain through commercial standards laboratories, then these parts will fit and function as specified. It is the function of the Quality Control or Quality Assurance Departments of all industry to see that this does indeed happen.

## 1.1 Importance of Dimensional Measurements

Phenomenal progress has been achieved during the past decades in areas of product design, manufacturing and quality control. In 1800, a precision of 0.25mm was adequate for length measurements; in 1900, the need for 0.01mm was felt; in 1950, precision needs were 0.25μm, and currently some industrial applications need 12nm. Figure 1-2 illustrates the rapid progression of industry's demand for precision. We see that whereas mechanical assembly was formerly accomplished by individual adjustment of the components, once mass production became possible, the demand for precision soared.

The need for increased precision resulted primarily from:

(1) Component dimensioning closer to the theoretical size limits to achieve material and cost savings.

(2) Trends toward miniaturization which have resulted in reduced tolerances for various components.

(3) Increased life and reliability for products such as gears and bearings which require tighter tolerances on size and form.

(4) General interchangeability and uniform accuracy of parts to improve the maintainability of assemblies on a world-wide system.

(5) Automatic assembly, often occurring at tremendous speed, requires that the various components must be manufactured and assembled consistently and must be able to perform within small margins of error.

There is no universally accepted classification of the regions comprising the spectrum of dimensional (length) measurements but for clarity we have roughly grouped the regions into five groups as shown in figure 1-1.

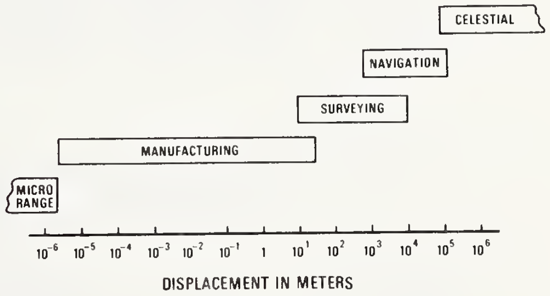



Figure 1-1. Regions of distance measurements.

Since most of the spectrum for dimensional measurements is covered by the manufacturing and surveying regions and many of the devices and methods for measurement spill over to the other regions, our main area of focus for this study will concentrate in these two regions.

The determination of lengths constitutes the largest group of measurements made in science, industry, and technology. It has been estimated (43rd ANZAAS Congress 1971) that 80% of all measurements made in industry are of displacement [1].[1] Some reliable estimates that we have found during our data acquisition are that investments in measuring all facets of length constitute approximately 1% of the annual value of shipments of industry. In the area of construction, ratios derived from experience in land and engineering surveys show that 10% of new construction requires precise control and 1% of new construction costs are charged to survey activity which directly involve length measurements. Thus, we can develop

[1] Figures in brackets indicate references listed at the end of this paper.

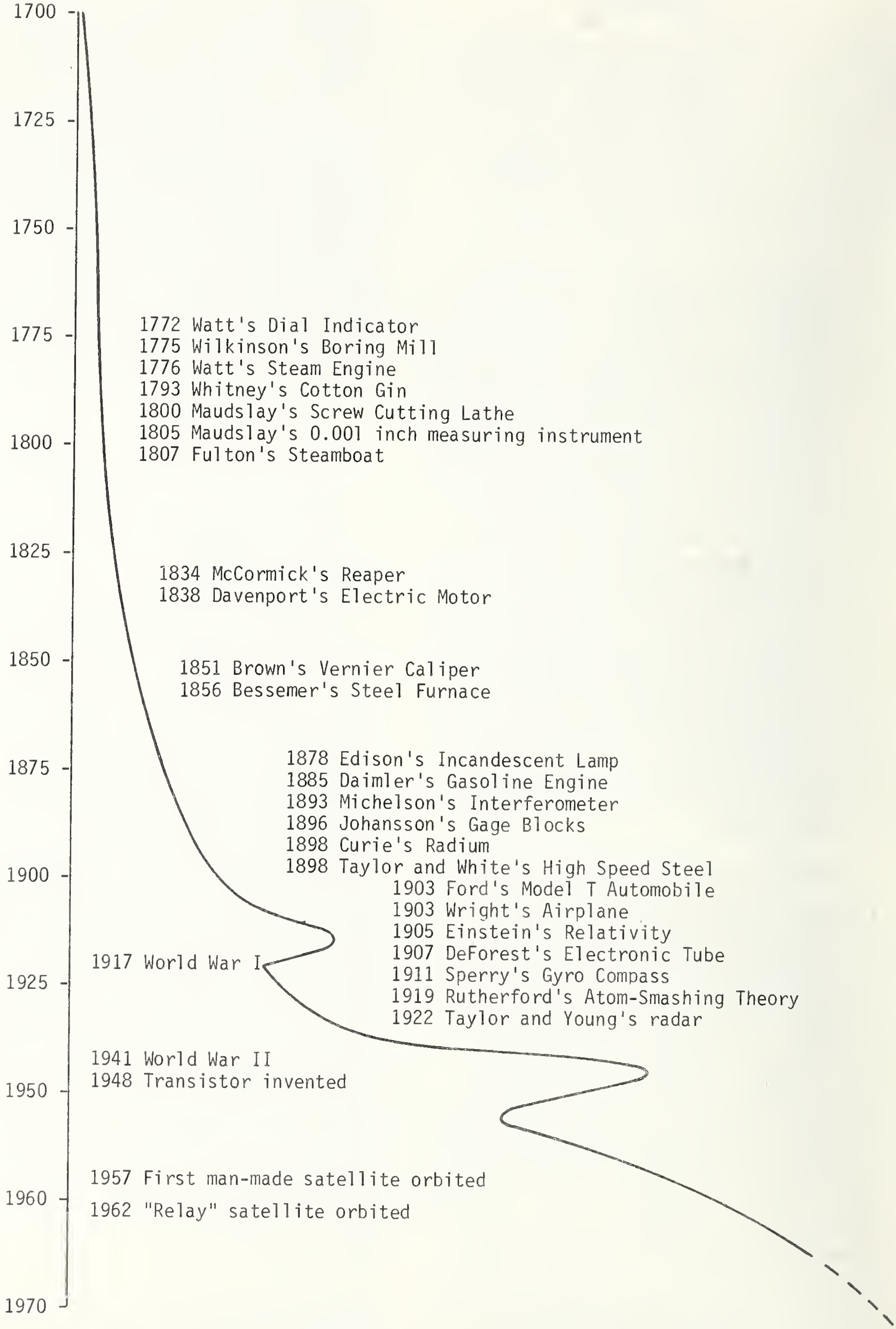



Figure 1-2. Accelerating rise in precision.

figures (table 1-1) for the measurement intensive nature of manufacturing and construction using Department of Commerce 1973 figures for the values of this area of the economy. In the area of manufacturing we see the cost of dimensional measurements ranges from estimates of \$3.9 to \$13.4 billion, the values of \$3.9, \$10, and \$13.4 billion (avg. of \$9.4 billion) agreeing quite well considering they were derived from independent sources. The point is *dimensional measurements comprise a substantial part of this nation's economy.*

The exact numbers are not of critical importance, but it *is* important to recognize that modern production depends on interchangeability and uniformity of parts. The only way to provide this interchangeability is through accurate and precise dimensional measurements.

## 1.2 Purpose of Study

To understand the complexities of technology and the ramifications of NBS work, the concept of a National Measurement System was proposed. The purpose of the system is to provide a foundation for interchangeability and decisions which affect commerce, science, and the economy. An analysis of the National Measurement System would serve as a focal point for discussions concerning problems within the system. This study will identify and examine the areas of dimensional measurement.

Our contacts with industry have shown that there is widespread interest in studies such as this one and that they should be made available to the public. This study of the National Measurement System for Length is organized along the following topics:

Table 1-1. Analysis of dimensional measurement-intensive factors in the economy.

| SIC Code* | Description | 1973 Value (\$ billions) | Cost of Measurement (\$ billions) | Cost of Dimensional Measurements (\$ billions) | | |
|---|---|---|---|---|---|---|
| 20 - 39 | Manufacturing | 485.03[a] | 16.8[b] | 3.97[c] | 10.0[d] | 13.4[e] |
| 15 - 17 | Construction | 150.0[a] | | | 1.5[f] | |

a - From Department of Commerce 1973 Outlook Appendix A.

b - Percentage based on figures by Shirleigh Silverman, Associate Director, NBS, 1969.

c - From recent industry canvass by author. Percentage is based on companies' investments in dimensional measurements vs. value of shipments.

d - From recent industry canvass by author. Estimate of all companies' investments in length measurements from respected personal sources.

e - Estimate that 80% of all measurements made in industry are of displacement. 43rd ANZAAS Congress, 1971.

f - One percent of construction is spent on survey work. NOAA, "The North American Datum," October 1973 (see Appendix G).

Note: 1973 GNP \$1.27 trillion. September 1973 Survey of Current Business, Vol 53. #9.

*Standard Industrial Classification - two digit code.

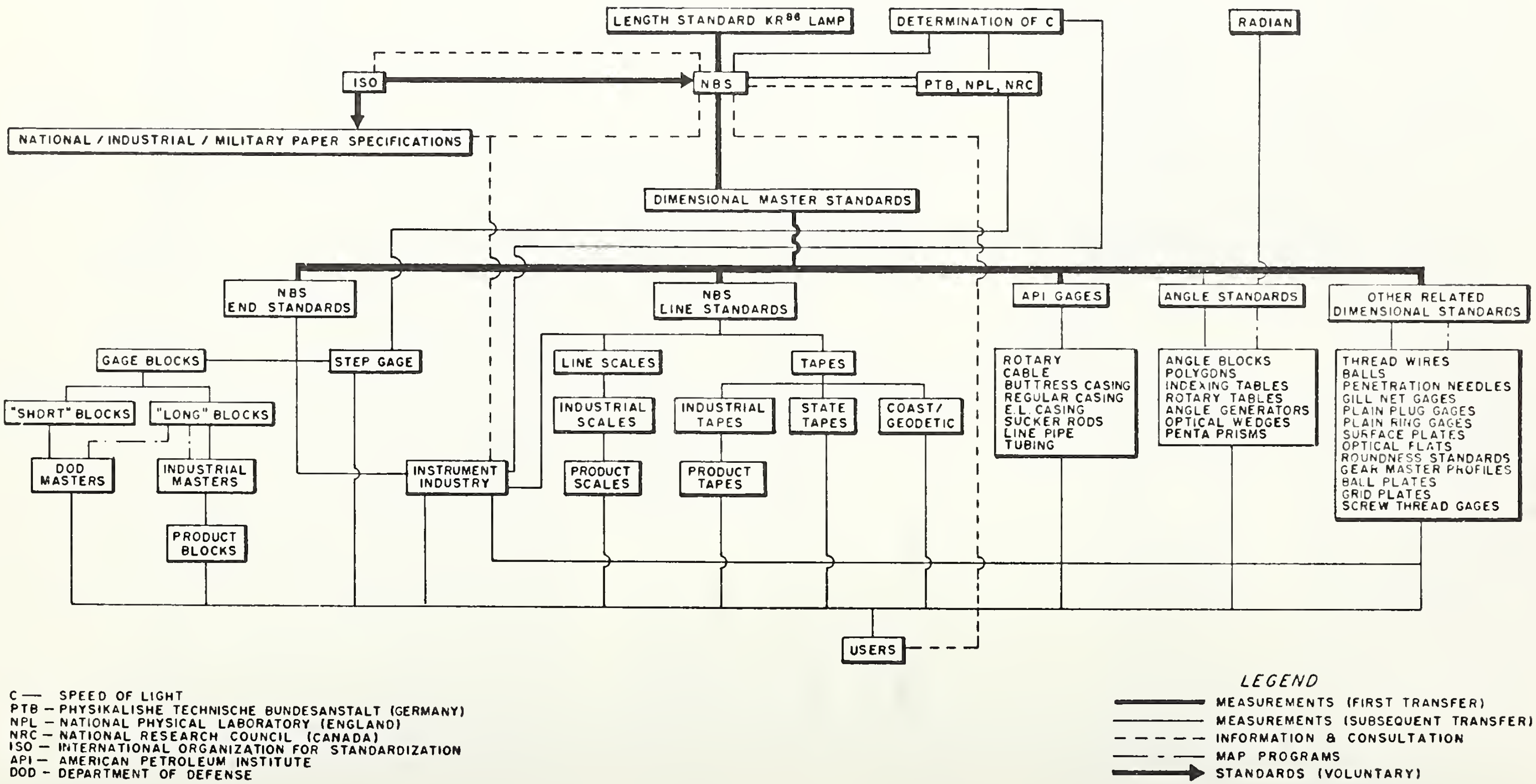



Figure 2-1. Infrastructure of the national measurement system for length.

(1) Defining the assessment task.
(2) Describing the relevant technologies which support the primary technology.
(3) Developing non-technological factors which influence the relevant technologies.
(4) Identifying impact areas.
(5) Making preliminary impact analyses.
(6) Identifying possible action options.
(7) Completing the impact analyses.

In applying this methodology we began by defining the assessment task in terms of the following questions:
(1) What is the present state of the NBS measurement capability?
(2) How are the measurement services of NBS used? By which firms, industries, technologies and agencies? What is the most effective interface with industry, government agencies, state and local authorities, and professional associations?
(3) What are the methods and instruments by which practical length measurements are made? What is the transfer chain from NBS to the final product? What are the most important present and future deficiencies in the area of dimensional measurements?
(4) Are there any services in length which NBS should commence, delete, or improve upon?

## 2. STRUCTURE OF THE MEASUREMENT SYSTEM FOR LENGTH

A unit may be defined as the magnitude of a quantity in terms of which magnitudes of other quantities of the same kind are expressed, e.g. a millimeter is a unit of length which is 1/1000 of a meter, a centimeter is a unit of length which is 10 millimeters or 1/100 of a meter, a decimeter is a unit of length which is 100 millimeters or 10 centimeters or 1/10 of a meter. A standard can be defined as "something that is set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality". In terms of these definitions, dimensional measurements are conducted for the determination of point to point relationships by the assignment of a number of arbitrary units which indicate lengths.

The units of measurement under consideration in this document are related to the standard of length, the meter. The meter is defined as 1,650,763.73 vacuum wavelengths of light resulting from the atomic energy level transition $2p_{10}$-$5d_5$ of the isotope of krypton ($^{86}Kr$).

To facilitate better overall comprehension of the National Measurement System for length, we have developed a model of the system. This model is comprised of the following categories:
(1) Scientific and Technological Base for Length: This includes the definition of the unit under consideration and the international agreement upon which this is based.
(2) "Recognized" advocates of standards: This category includes the national laboratories and all pertinent writers of standards and/or specifications.
(3) Documentary Standards: The category of "paper" standards includes a listing of the pertinent specifications which are set up for industry with specific emphasis on dimensional measurements.
(4) Artifacts used in Transfer/Control: This includes "hardware standards" which are used for either the transfer of the unit of length or for a controlling process which involves the unit, except in some electronic cases, an artifact can be thought of as having no moving parts, e.g. a gage block.
(5) Instrumentation used in Transfer/Control: This subgroup contains an analysis of the instrumentation used within the National Measurement System for transfer and/or control of the unit of length.
(6) Users of the unit of length: This category is by far the largest and includes industries which need dimensional measurements.

Figure 2-1 depicts the infrastructure of the National Measurement System for the unit of length and dimensional measurements.

To illustrate how complex one specific area of users can become we have depicted a detailed infrastructure of the machine tool and gage manufacturers (fig. 2-2).

### 2.1 Conceptual System

In 1875, an international treaty, the "Treaty of the Meter" was established to set up defined standards for length and mass. The General Conference of Weights and Measures, which is the meeting at the diplomatic and political level of the signatories to the treaty, meets periodically to recommend improvements to the system of standards.

In 1960, the Eleventh General Conference on Weights and Measures defined the new International Standard of Length as 1,650,763.73 vacuum wavelength of light resulting from the unperturbed atomic energy level transition $2p_{10}$-$5d_5$ of the krypton isotope having an atomic weight of 86. This orange-red radiation was chosen over other wavelengths because its wavelength was the best defined one known at the time. One inch is defined as 2.54 centimeters exactly.

One of the most important fundamental constants of nature is the speed of electromagnetic radiation, the speed of light (c). It is used quite extensively in ranging because very accurate delay times can be measured and the appropriate conversion from time to distance can be made by using the speed of

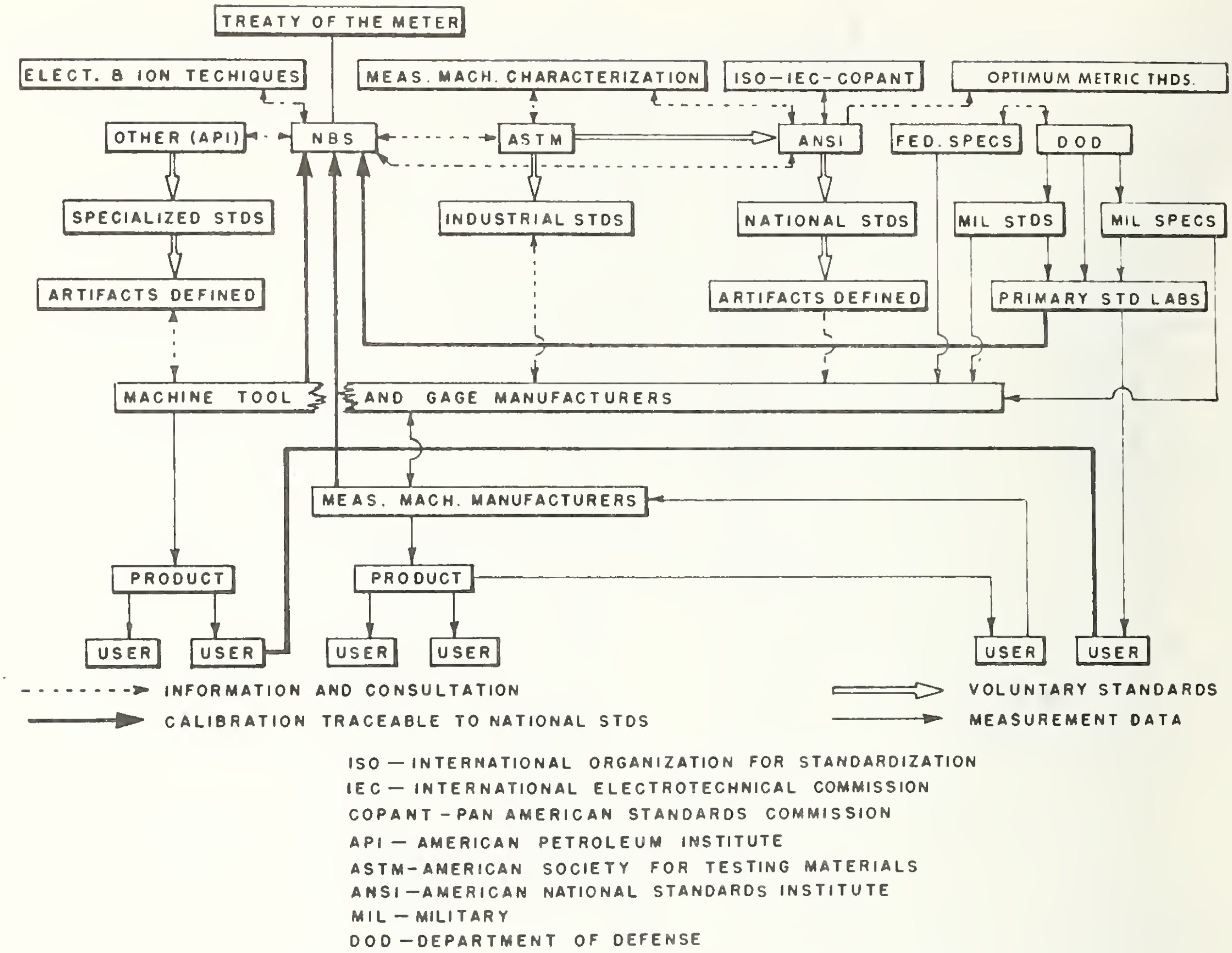



Figure 2-2. Infrastructure example of user-machine tool and gage manufacturers.

light.

Since the advent of reproducible and stable lasers it is now possible to measure optical lengths more precisely than the definition of the meter allows. The methane-stabilized He-Ne laser frequency is reproducible to 3 parts in $10^{12}$ and further work is likely to improve upon this. The definable usefulness of the current krypton 86 length standard is approximately 3 to 5 parts in $10^9$.

## 2.2 Basic Technical Infrastructure

### 2.2.1 Documentary Specification System

#### 2.2.1.1 Documentary Standards - General

Organizations concerned with industrial and commercial standards are found at the international, national, and even lower levels such as states, counties, municipalities and throughout industry. With few exceptions these organizations in the U.S. are non-governmental and the standards published are used voluntarily by industry and government.

The main international body in the area of industrial and commercial standards is the International Organization for Standardization (ISO) whose main function is to develop international cooperation in standardization activities. ISO is comprised of national standard bodies from 69 countries. Its prime objective is to promote the development of world-wide standards with a view of facilitating international exchange of goods and services. From the work of thousands of technical experts around the world emerge the ISO Recommendations, which serve to promote freer international trade by helping to reduce the differences between various national standards.

At the national level, the United States has a single standards organization that coordinates the development and publication of industrial and commercial standards adopted by industrial associations. This organization is known as the American National Standards Institute (ANSI). Its principal function is to act as a clearinghouse to coordinate the work of standards development in the private sector, which is currently being carried on by four hundred different organizations. Through its procedures, timely development of standards is made possible, duplication and overlap are minimized and a neutral forum is provided to consider and identify the need for standards. Through its recognition by international non-treaty standardization bodies as the National Standards body of the USA, ANSI serves as the focal point for organizing USA participation in international standardization. Every industry is affected by and benefits from ANSI since they rely on many of the 4000 American National Standards in the course of operation. The use of American National Standards reduces the time spent by engineers in designing; improves the dependability of parts used in production; reduces the amount of inspection and quality control needed; reduces inventory costs as a result of being able to operate with a smaller inventory, because of the ease and speed with which standardized parts can be obtained.

Listed below are a few of the American National Standards that are applicable to the machine tool and gage industry.

(1) B1.1 Unified Screw Threads
(2) B1.2 Gages and Gaging for Unified Screw Threads
(3) B3.4 Gaging Practices for Ball and Roller Bearing
(4) B3.10 Instrument Precision Ball Bearings
(5) B5.16 Accuracy of Engine and Toolroom Lathes
(6) B6.1 Tooth Proportions for Coarse-Pitch Involute Spur Gears.

In addition to these, there are several hundred other standards that are directly applicable to the materials used in the construction of machine tools and gages such as G25.4 - Gray Iron Castings and H9.20 - Specification for Steel Backed Metal Powder Bearings and Bushing Alloys.

A comprehensive set of standards on dimensional measurements is being developed by a Sectional Committee of the ANSI. Committee B89 is concerned with dimensional metrology and currently has representatives from thirteen technical societies and organizations, including NBS, and representatives from more than thirty-six independent compaines.

The Federal Government is also a major contributor of standards and specifications. These specifications for purchasing are only mandatory for the government, but many, such as military specs, are adapted for non military use. The Department of Defense's (DoD) "Defense Standardization Program" provides uniform definitions of the technical requirements for parts, equipment and systems in which the various elements of the DoD have a common interest. Standardization has long been an important element of military logistics and design, research, and engineering. Although military specifications and standards are considered voluntary standards in the civilian sector, the machine tool and gage manufacturer must comply with them if any of his products are to be sold to DoD or be used by a DoD contractor.

Another branch of the Federal Government which issues Federal Specifications and Standards is the General Services Administration. These Federal Specs fill a need for a statement of policy for the development and use of items in common use in the Federal Government. The most widely distributed document for precise control of measurements which are dependent upon gage blocks is specification GGG-G-15a on gage blocks and accessories. A summary of this specification is included in Appendix B.

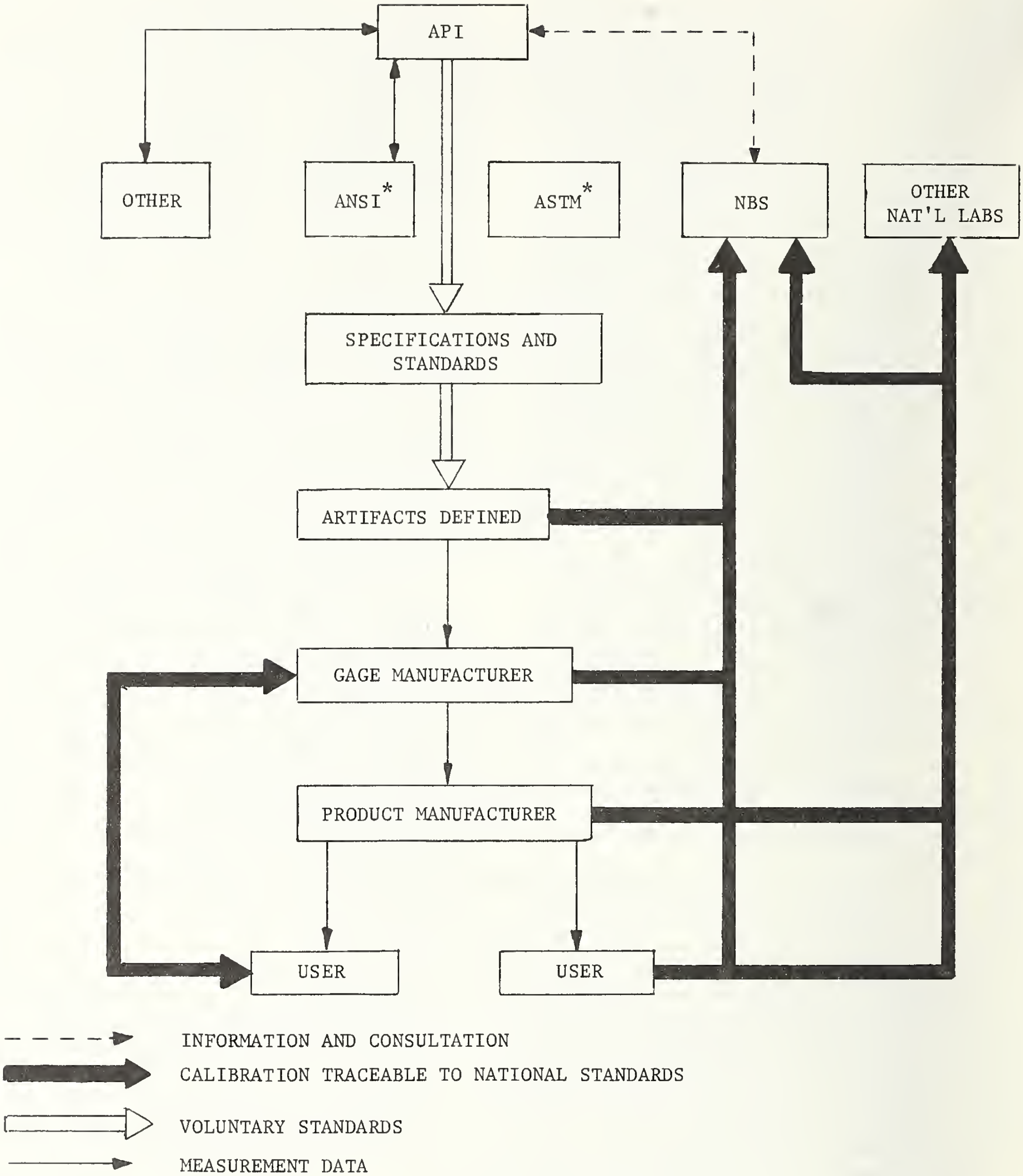
Standards for materials, which are the province of American Society of Testing and Materials (ASTM), are the language for the dialogue between buyer and seller. Nearly every ASTM standard is either a specification or a test method. Many of the standards are directly applicable to the manufacture of machine tools and gages since they specify the exact composition of the iron and steel used in the tool and gage as well as the test methods to determine if they meet all the requirements of the specification. A few of such standards are listed below.

(1) ASTM A295 - Carbon-Chromium Ball and Roller Bearing Steel
(2) ASTM A436 - Austenitic Ductile Iron Castings
(3) ASTM A600 - High Speed Tool Steel
(4) ASTM A307 - Carbon Steel Externally and Internally Threaded Standard Fasteners.

In addition to the ASTM voluntary standards, the majority of all machine tool and gage manufacturers have proprietary standards that they have developed through years of experience. Most of these are closely guarded industrial secrets regarding the heat treatment and methods of finishing various steel and iron alloys that are used in their tools and gages.

#### 2.2.1.2 API Standards

The foremost example of American industry standards becoming international standards are those of the American Petroleum Institute (API). The principal activities of this Institute are simplification, standardization and improvement of equipment and methods used




*ANSI - American National Standards Institute

*ASTM - American Society for Testing and Materials

Figure 2-3. Infrastructure of API standards.

by the petroleum industry. The fundamental purpose of this activity is to prepare and maintain standards and methods acceptable to the industry and the manufacturers of the equipment. This purpose is accomplished through participation and cooperation of users and manufacturers in the development and keeping up to date of such standards and methods.

The standardization committees of the Institute have formal representation or informal liaison with numerous societies and associations including ANSI, ASTM and NBS. The Institute grants to manufacturers, upon application and submission of a statement of qualifications, the right to affix its official monogram on material made in accordance with API standards. Application of the monogram constitutes a warranty by the manufacturer that he has complied with all of the conditions and specifications set forth in the publication covering material so marked.

Prior to development of these standards, all items of oil equipment for drilling, pumping, and piping were unique for each manufacturer and could not be interchanged. With the acceptance of API standards, replacement parts produced by many different foreign manufacturers could be purchased in all oil producing countries with no worry about interchangeability.

Figure 2-3 shows the API Standards Infrastructure. With the assistance of such other standards associations within the U.S. as ANSI, ASTM, American Association of Oil Well Drilling Contractors, American Gas Association and many others, the standardization committees of the API Division of Production issue and keep up to date specifications and standards for all production components used in the oil industry. NBS is concerned with only the screw threads of such components as are used in drilling and piping, and through its membership on the API Gaging Committee informally participates in any additions, deletions or corrections in screw threads for drill stem and pipe.

As shown, API issues voluntary standards which completely define the component or artifact. The prototype is fabricated and is used as the Grand Master Gage. The set of API Grand Master Gages is maintained at NBS and to them all other gages in the world are certified. The gage manufacturer, if he desires to use the API monogram, must fabricate his gages to the requirement of the standard. In addition, the gage must be calibrated and certified by NBS or one of the other National Standard Laboratories before the monogram can be applied. The gage is then sold to a manufacturer of pipe, couplings, valves, etc., who uses this gage, called a Reference Master Gage, to check his working gages. Working gages are used to check the production items.

Since these working gages are used very frequently, they are checked against the producer's Reference Master Gage as soon as they show signs of wear. If they are found out-of-tolerance, they are returned to the gage manufacturer to be reworked. If they cannot be reworked to be within the tolerances specified by the API Standard, they are discarded.

Periodically, the product manufacturer's Reference Master Gages are returned to NBS to be calibrated against the Grand Master Gages. Foreign product manufacturers usually return their gages to the nearest National Standards Laboratory for recertification against the Regional Master Gages. The National Standards Laboratories do not have a complete set of master gages for all sizes so it is not uncommon for a gage to be shipped halfway around the world to be recertified at NBS.

The user of these products also has a set of gages which is used in the field to determine if the screw threads of the pipes, valves, etc. have been damaged during shipment or handling. These gages are periodically returned to the gage manufacturers for rechecking and reworking if it is found necessary.

### 2.2.2 Instrumentation System

It has been pointed out that the current standard of length, the $^{86}$Kr lamp, has a useful accuracy of approximately 5 parts in $10^9$. But experience demonstrates our inability to transfer the wavelength standard to a material artifact to better than 8 parts in $10^7$. Figure 2-4 shows the approximate state-of-the-art for the transfer process now at NBS.

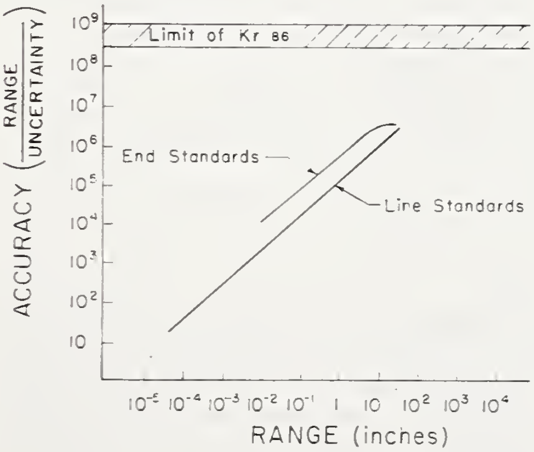



Figure 2-4. Capability of NBS in first transfer to length standards.

The reasons for this lie in the uncertainty in the correction for the refractive index of air (or if vacuum is used, imperfect knowledge of the compression of the artifact as it is returned to atmospheric conditions), phase shifts, "wringing" films, etc.

The total measurement process can be thought of as a system consisting of the operator, environment, measuring algorithm, and the measuring instrument which comprise this process. It is a mistaken impression held by many that the instrument alone determines the final accuracy and precision which flows from a measurement. In many cases this is not true. However, before we can talk about this aspect of the National Measurement System, we must have a feel for the instrumentation currently on the market.

It is helpful to look at the manufacturers of various artifacts used in transfer and/or control of dimensional measurements. Appendix C lists some of the manufacturers of optical flats, gage balls, gage blocks, optical polygons, measuring tapes and rules, squares, and screw thread measuring wires [2].

### 2.2.2.1 Measurement Tools and Techniques

#### 2.2.2.1.1 Artifact Standards

Material artifacts which are used as standards in the transfer and/or control of dimensional measurements can be roughly classified into five major groups:

(1) End standards - Examples are gage blocks which more than any other device form the basis of interchangeability in this country.

(2) Line standards - Examples are linear scales for master length reference, linear scales for feedback control systems, master tapes used by many industries (see fig. 2.5).

(3) API Gages (American Petroleum Institute)- These Grand Master Gages can be considered international artifact standards since all Master API Gages throughout the world are referenced to them.

(4) Angle standards - Examples are angle blocks, polygons, and indexing tables used by various organizations for angular measurements.

(5) Related dimensional standards - This group includes artifacts such as thread measuring wires, master balls, optical flats, etc.

End Standards: As mentioned previously, it might be theoretically conceivable that all gages used in manufacturing and quality control should be checked against basic standards, but in practice it would not be practical or even desirable. The obvious solution is to use primary standards to calibrate secondary standards and to disseminate the latter throughout the system.

In the late 1800's Carl Johansson of Sweden was concerned with the idea of developing a small set of gages which could be used in various combinations to eliminate the need for thousands of fixed gages. He conceived the idea of gage blocks - blocks of durable material (steel) with one pair of plane, parallel measuring surfaces. These gage blocks are one means by which the standard of length is given physical form and made available for practical measurement use.

Use of gage blocks by industry is not universal because many industries such as foundry work, blacksmithing, carpentry, etc., do not require the degree of accuracy that gage blocks can supply. But the production of firearms, automotive parts, typewriters, computers, and mechanical and electrical instruments requires close tolerances so the gage block has an extremely important role in such instances.

The essential function of gage blocks is to make available end standards of specific lengths by temporarily combining several blocks into a single gaging bar. This combination of blocks results in a bar of reasonable cohesion whose actual dimension truly represents the nominal dimension sought.

To accomplish this result we must establish certain specifications:

(1) The individual elements must be available in dimensions to achieve all combinations of sizes within a desired range;

(2) the accuracy of the individual blocks must be within accepted tolerance requirements;

(3) the individual blocks must be attached so closely to each other in the built-up configuration that the resulting bar will be equal to the added sizes of the individual blocks; and

(4) the attachment of the individual blocks to each other must be firm enough for handling but when "decoupled" the blocks should be reusable with very little change in their original size.

Gage blocks are calibrated at NBS for the manufacturers of gage blocks who then use these "master" calibrated blocks to calibrate working blocks which are in turn used to calibrate production blocks. Other customers of NBS gage block calibration services are the high technology industries.

Application of Gage Blocks: Applications of gage blocks are so numerous that only a representative sampling can be discussed. Some of the principal uses are:

(1) Calibration of other gage blocks and the calibration of sensitive measuring instruments. If one set of blocks has been measured then it is a simple matter to calibrate another set from the previous set of

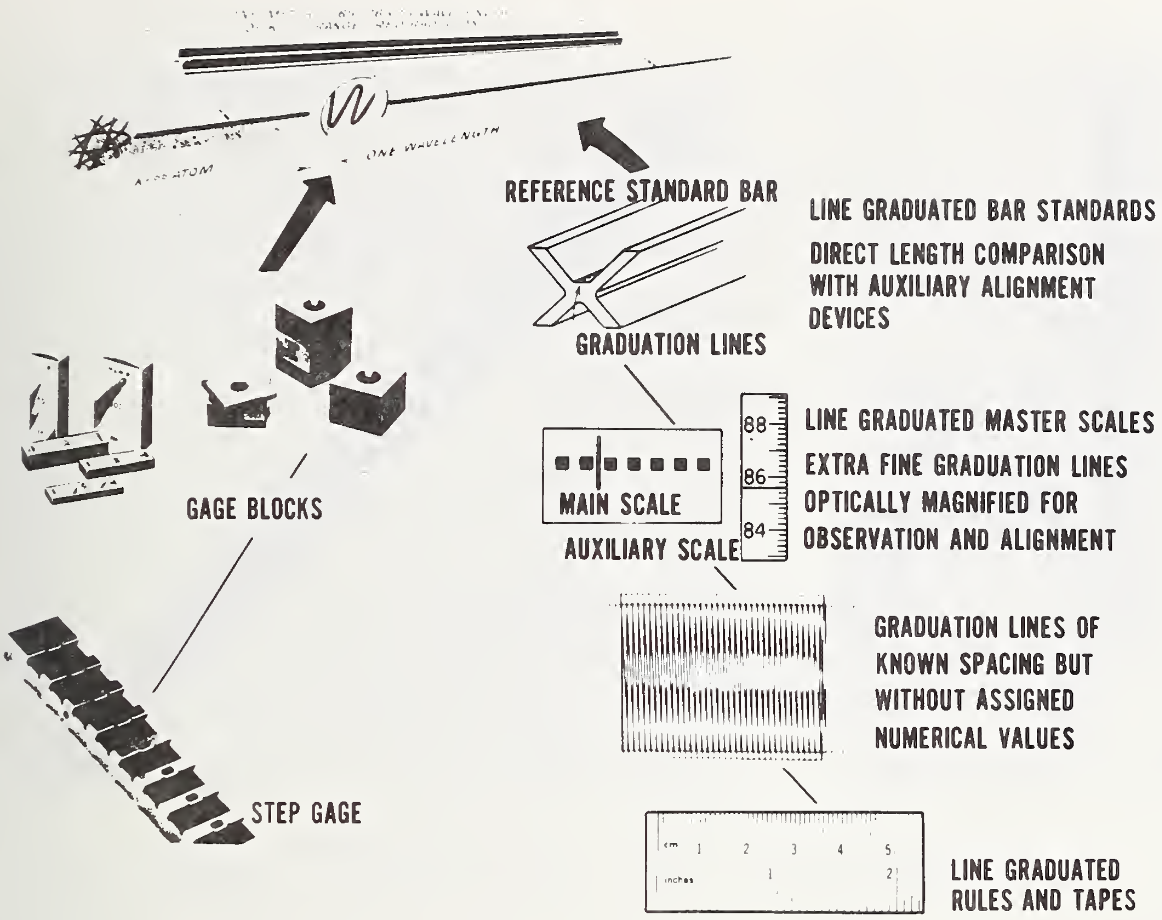



Figure 2-5. Examples of end and line standards.

blocks. The accuracy and linearity of measuring may be checked by reference gage blocks.
(2) Setting of comparators and indicator instruments. The average gage of this type measures the variation from the master in one or more dimensions and is easier to use than gage blocks. Micrometers can be checked for linearity by gage blocks.
(3) Direct measurement of distances between surfaces.
(4) Checking accuracy of tools and fixtures. It is very important that tools used in the manufacture of parts be checked carefully, so the checking of dies, jigs, and fixtures is one of the basic applications of gage blocks.
(5) Checking parts in process of manufacturing. Gage blocks are frequently used in process inspection because their accuracy enables the inspector to follow the size of the part as it approaches the limits of the tolerance.

Other End Standards: The function of an end standard whose gaging surfaces represent the ends of a specific distance is not limited to gage blocks. Although gage blocks are the most versatile, there are instances where other artifact forms are better suited for a particular purpose.

The "measuring rod" is useful when datum planes have to be transferred beyond the measuring range of micrometer screws. An example is the case of measuring tables of optical instruments whose micrometer screws cover a measuring range of one inch only, while the useful table movement is larger than this dimension.

The "step block" or "step gage" consists of either a series of gage blocks arranged in a staggered manner to provide steps at various intervals, or is made of a single bar of steel. One example of the step block is in surface plate work where the desired height levels for dimension transfer can quickly and precisely be established with instruments having a stepped bar for a master (fig. 2-6). The step gage is used in certain types of cir-

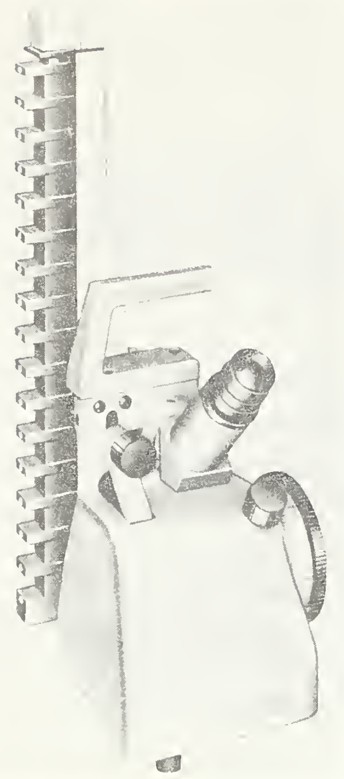


Figure 2-6. Optical height gage.

Figure 2-7. 18-Inch gage (end standard).

cumstances to check the lead screw accuracy of measuring machines. Figure 2-7 shows that the step gage enables one-inch steps to be contained in a single bar and because it is an end standard great precision can be achieved with its usage.

Other end standards such as step bars and gages are calibrated by NBS for industries who use them to check their manufacturing and/or measuring machines.

Line Standards: The line standard is one whose length is defined by the separation of lines engraved on a piece of stable material. These standards continue to be of great importance in spite of the general availability of the wavelength standard for length. An important purpose which reference line standards are intended to serve is the calibration of line graduated inspection tools and of line graduated master scales of measuring instruments.

Line Graduated Reference Bars: One form of line standard is the International Meter Bar which for many years served as the basis for precise length measurements. This is a platinum-iridium bar with a Tresca cross-section with fine lines engraved normal to the longitudinal axis of the bar on the plane of the neutral axis. See figure 2-5 for a view of a reference standard bar. Metrology laboratories serving scientific and industrial institutions have applications for reference bars.

A highly specialized ruling engine is used for engraving the lines on the bar. Graduations are engraved with a sharp cutting tool with the view of making these lines as fine as possible to facilitate using high magnification for readout, to achieve the maximum accuracy possible from the standard.

NBS has facilities for the calibration of line standards. This facility is also suitable for the calibrations of subintervals on these bars. The instrument is shown in figure 2-8. In a comparison of 1-meter bars the error analysis yielded an uncertainty in the reported values of 0.2 micrometer.

Line Graduated Inspection Bar: The major function of an inspection bar is to check the accuracy of common line graduated measuring rules, such as used by toolmakers and mechanics. During the measurement process, the inspection bar and the rule to be calibrated must rest on a smooth surface to avoid major deflections which will cause error.

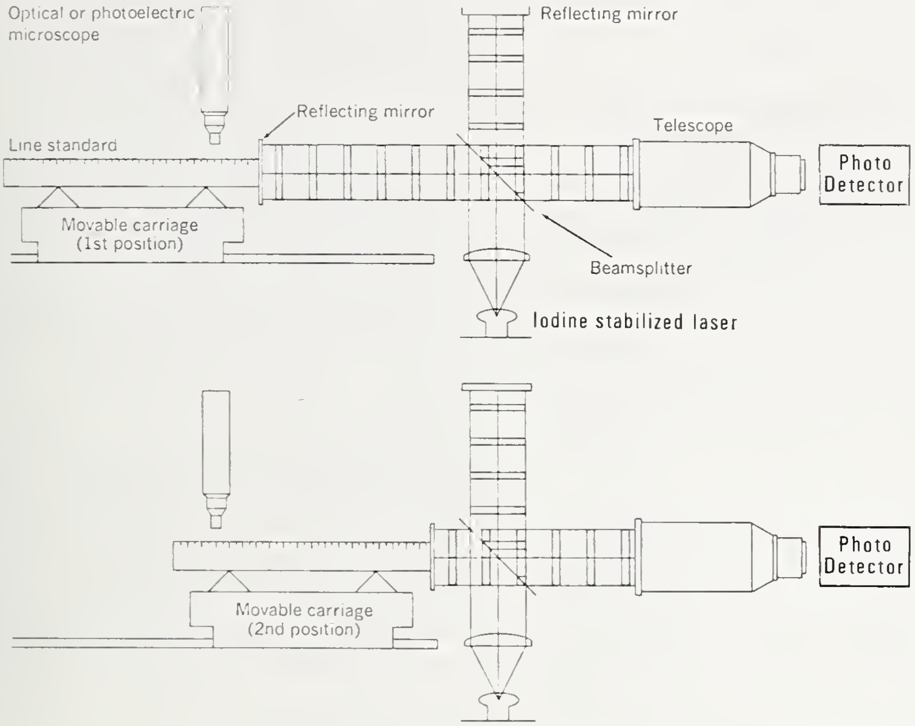



Figure 2-8. Calibration of a line standard with interferometry.

Working Rules: These rules serve as references when transferring length dimensions or for direct measurements in which the edge of the rule is in contact with the object being measured. Most models of the industrial type graduated rules have more than a single graduation with the most frequently used graduations in 32nds and 64ths of an inch.

Classes of Line Standards:
(1) Reference - suitable as reference standards for makers of precision apparatus and for use in the most exact scientific work.
(2) Working - suitable for all ordinary precision work and for the needs of college labs, manufacturers of better grades of scientific equipment, state weight and measures superintendents.
(3) Commercial - suitable for drafting, machine work, etc.

Line Scales: Another form of line standard commonly in use is the line scale. This can be in the form of ruled scale, Ronchi ruling, or grid ruling. Line scale applications include master length reference, feedback control systems, and master grids for electronic micro circuits. The operation of some optical instruments for absolute length measurements is based on precise line graduated master scales.

Many master line scales are now manufactured on numerically controlled ruling engines. The movements are controlled by a feedback system whose sensors are two Michelson interferometers. The entire system is housed in a cell whose average air temperature does not fluctuate more than 0.01°C. Some typical scale ruling capabilities for linear scales are:
(1) Maximum line frequency: 2500/inch(200/mm)
(2) Line widths: .0001 to .05 inch (2.5μm to 1mm)
(3) Accuracies: Reference scales $(4+L)\times10^{-6}$ inches, Inspection scales (.0001+.000005L) inches, Commercial scales (.0005+.0002L)inches where the formulae apply from any line to any other line on the scale L inches away.

Master grids can be ruled from 0.0016 square inches (.01mm$^2$) to 24 square inches (155cm$^2$) with line widths ranging from .0001 inches (.0025mm) to .05 inches (1.27mm). Precision grids are useful in completely defining accuracy simultaneously in two coordinates. Typical capabilities now are:
(1) Line straightness: $<\pm$.003 inches (0.075mm) over any ten-inch section
(2) Line parallelism: <0.05 seconds
(3) Line spacing: Maximum error in spacing

between one line and a second line at distance L from the first line

$$(10+1.5L) \times 10^{-6} \text{inches}$$

$$(250+1.5L) \times 10^{-6} \text{mm}.$$

Ronchi rulings are multiple line rulings having parallel lines, equally spaced with the width of the line equal to the width of the space between the lines. Ronchi rulings are used in readout and feedback control systems. One of the current specifications on rulings available from industry is shown in Appendix D. Two superimposed rulings with slightly inclined lines will produce interference fringes, with the location dependent on the relative position of the two. The operation of certain length measuring machines is based on the optical observation of the fringe variations.

Steel Tapes: Until recently, the most widely used artifacts for measuring lengths extending over several meters were measuring tapes. With the advent of electronic distance measuring devices (EDM's) steel tapes have been losing popularity but since they are used to check reference baselines which are in turn used to check EDM's, a discussion of tapes is in order.

The industrial steel tape is made from special tape strips in which the steel has been heat-treated and tempered to insure the same dimensional stability as is required of other measuring tools. Industrial measuring tapes are currently made in 25, 50, 75, and 100-foot lengths and pocket tapes are usually 6 to 8 feet long. The graduations are made every 1/8 inch on most industrial tapes and every 1/16 inch on pocket tapes. There are many types of measuring tapes because there are many users and each profession has devised a tape with a specific application and accuracy in mind. The users of tapes will be discussed in detail in section 2.2.

The National Bureau of Standards has a temperature controlled laboratory with a 200-foot steel bench that is used for calibrating tapes. These calibrated tapes can then be used in general surveying and engineering or as bench standards by the manufacturers of measuring tapes. There is also a special bench for the calibration of the 50-meter invar base-line tapes used by the U.S. Coast and Geodetic Survey.

API Gages: NBS is the custodian of the grand master thread gages of the American Petroleum Institute (API) to which regional master gages and reference master gages must be periodically calibrated. The majority of the reference master gages are measured by NBS before acceptance by users throughout the world. Several national standards laboratories who maintain regional master gages participate in the program. The American Petroleum Institute requirement that all master thread gages carrying their monogram be calibrated to the set of grand master gages at NBS can be considered mandatory on the gage manufacturer since a pipe manufacturer would not buy a master gage if it did not carry the API monogram. All master API gages throughout the world are referenced to these grand master gages and through them to the U.S. National Measurement System. The gages measured at NBS are sold to a manufacturer of pipe, couplings, etc., who uses these gages to check his working gages which in turn are used to check production items.

Angle Standards: Angular standards are normally referred back to the 360° circle. Angular standards include angle blocks, polygons, indexing tables, rotary tables, angle generators, optical wedges, and pentaprisms.

NBS calibrates master angle block sets for industry and also the working sets sent in by high technology industries. The "typical NBS working accuracies" for these various artifacts are listed in table 2-7, section 2.3, and they are more than sufficient for all known requirements.

Related Dimensional Standards: There are many other artifacts used throughout industry and by governmental agencies in the measurement or control of various dimensions. These include screw thread wires, steel balls, plain plug and ring gages, surface plates, optical flats, roundness standards, gear master profiles, ball plates, grid plates, penetration needles, polariscope tubes, gill net gages, etc.

NBS maintains various of the above that are periodically used in the measurement of industrial artifacts. The chain from the meter to all types of these related dimensional standards (except optical flats) is krypton $<$ NBS master gage blocks $<$ measuring instrument.

Screw Thread and Gear Wires: Two sets of wires (hardened steel cylinders of various diameters, approximately .1 to 25.4 mm (.004 to 1.000 inches)) are normally used in industry, thread measuring wires and gear measuring wires. These are used for tests in the production, testing and buying of bolts, screws, pipes, and connectors, gears, etc. NBS calibrates master wires sent by manufacturers and other industries. Typical measurement uncertainty at NBS is 0.12 μm (5 microinches).

Steel Balls: Master Ball sets are used by the ball bearing industry and by other high technology industries such as makers of gyro components to size production parts. NBS calibrates such master ball sets and reports a diameter with a measurement uncertainty of 0.1 micrometer (4.0 microinches).

Plug and Ring Gages: A plug gage is a cylindrical standard and a ring gage is a "hole" standard. These are used throughout industry to check types of gaging systems which in turn are used to perform quality control on production items. NBS normally measures the diameter of these items with a measurement uncertainty of 0.1 micrometer (4.0 microinches).

Optical Flats: An optical flat is used to check on the flatness of components through optical interference phenomena. They are also used for the control of other products such as lenses and other optical elements. At present NBS calibration of optical flats involves interferometric measurement with a light source whose wavelength is compared to the krypton lamp. The uncertainty reported on NBS measured flats is 0.008 micrometer (0.3 microinches).

Miscellaneous: Still other dimensional artifacts exist and NBS is involved in the measurement of many of these. Typical uses and working uncertainties for these measurements at NBS are:
(1) Ball Plates - used in calibration of measuring machines. NBS measurement uncertainty is 0.6 micrometer (25 microinches) depending upon the quality of the balls (roundness and surface finish).
(2) Grid Plates - used by the photogrammetry field and the microcircuit industry. NBS measurement uncertainty is less than 0.6 micrometer (25 microinches) for plates with fine lines (.0015 inch maximum width).
(3) Lead Screws - for precise translation. NBS uncertainty is 0.5 micrometer (20 microinches).
(4) Screw Threads - for control of production threads. NBS measurement uncertainty is 2.5 micrometer (100 microinches).

### 2.2.2.1.2 Dimensional Measurement Instrumentation

Recalling figure 1-1 we see that the largest number of dimensional measurements are made in the microdisplacement, industrial, and surveying ranges. For this reason we will consider the types of instrumentation used in these ranges and then we shall take an in-depth look, by way of the Standard Industrial Classification (SIC) codes, of how widespread the use of some of these instruments are.

Since no clear-cut classification of instrumentation exists in the dimensional measuring realm, we have developed a system for the description of the different classes of instrumentation (table 2-1). The five major classes are (1) mechanical (2) optical (3) pneumatic (4) electronic (5) measuring machines.

(1) Mechanical: Mechanical instrumentation for length measurement is comprised of items such as mechanical indicators; dial indicators; high sensitivity mechanical indicators; mechanical comparators; fixed size limit gages; micrometers, calipers and dividers; other gages; and rules and tapes. (These instruments are displacement sensing, amplifying and indicating instruments. Their purpose is to detect variations in a specific displacement and to display on a dial or scale the amplified version of that sensed displacement.)

(2) Optical: Optical instruments used in length measurement can be subdivided into four classes - (a) engineering microscopes (b) projectors (c) interferometers, and

Table 2-1. Classes of instrumentation.

LENGTH & RELATED DIMENSIONAL MEASUREMENTS

| MECHANICAL | OPTICAL | ELECTRONIC | PNEUMATIC | MEASURING MACHINES |
|---|---|---|---|---|
| Dial Indicators | Interferometers | Gages (LVDT, capacitance, ultrasonic) | Comparators | Linear |
| Micrometers | Microscopes | Laser interferometers | | Multi-axis |
| Calipers, Dividers | Projectors | Electronic Distance Measuring Devices (infrared & microwave) | | |
| Gages | Optical Gaging | Other methods | | |
| Rules, Tapes | | | | |
| Fabric-measuring devices | | | | |

(d) non-contacting gaging systems.

Since the use and application of microscopes and projectors is widespread, they will not be discussed here.

Interferometry: Light waves are extremely useful in length measurement because they are the closest link in the chain to the definition of the meter. The wave nature of light and the phenomenon of interfering light waves are the bases of measuring devices based on interferometry.

Almost all gage block interferometers are variations of Fizeau or Twyman-Green interferometers. An example of one such interferometer is shown in figure 2-9. The light source can be mercury 198, cadmium, krypton86, or a gas laser. Basically these interferometers measure the length of a gage block with respect to a base plate to which the block is "wrung". By determining the number of fringes between the base plate and the surface of the block and a known standard and multiplying this number by half the wavelength of the light used, one is able to determine what constitutes a length of the gage block.

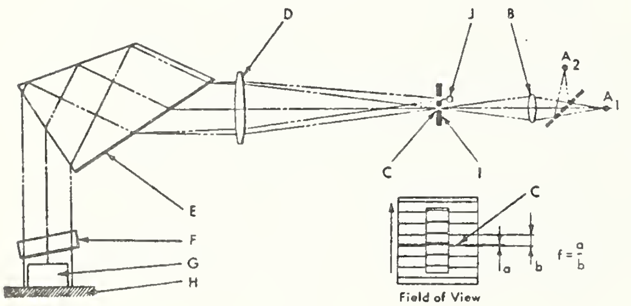



Figure 2-9. N.P.L. gage interferometer. Light from cadmium lamp (A), or Mercury 198 isotope lamp $A_2$ is collected by lens (B) and focused on entrance slit (C). Light from (C) is collimated by lens (D) from where it goes through constant deviation prism (E), whose rotation determines wavelength passed, through reference flat (F) to upper surface of gage block (G) and base plate (H) to which it is wrung. Light retraces nearly same path to mirror (J) whose fringe patterns are observed through a telescope not shown. Field of view is shown below.

Non-Contacting Gaging Systems: A relatively new product is the non-contacting optical gage used in inspection and control departments of industry. These units sight on opposite edges of the object being gaged and determine the deviation of the width or length measurement from a reference value. Resolutions as fine as 50 micorinches are claimed. Gaging time is from 2 to 40 milliseconds.

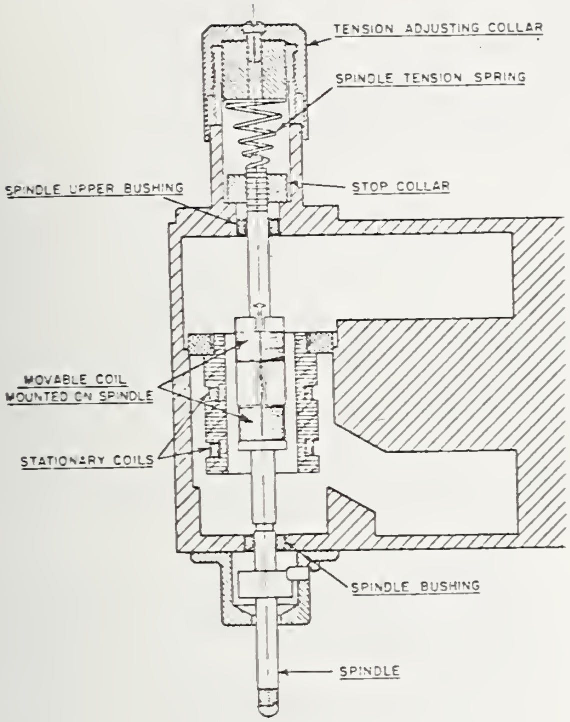
Another device utilizes a scanning laser beam and appropriate sensing operations. Resolutions of 0.0005 inch are claimed with accuracy figures of 0.0005 inches over a range of 0.0150 to 1.7500 inches. Another interesting device is a distance indicating optical probe for noncontact monitoring of thickness, diameter, roundness, contour, and surface quality of manufactured production parts. The device, so says the manufacturer, can gage parts to "10 microinch resolution while standing off at a distance of 1/8 to 1/2 inch". Speed of response is approximately 40 microseconds. The most obvious application is in automatic inspection where high-speed, precision, noncontacting measurements are basic requirements.

(3) Pneúmatic: The operation of pneumatic gaging is based on phenomena which occur when pressurized air is impeded in its free flow through an orifice by impinging against a solid surface. The distance of that solid surface from the orifice will affect the air velocity and create a back pressure. If the induced pressure and volume of air is maintained constant, the variations in the upstream pressure will be a function of the distance of the obstruction from the orifice.

(4) Electronic Instrumentation: The class of electronic instrumentation in use to measure dimensions is quite large indeed. We have broken this class of instruments into the following: (a) Electronic Gages (LVDT principle) (b) Laser Interferometers
(c) Electronic Distance Measuring Devices (EDM's) - (infrared, microwave, etc.)
(d) Other Tranducers (capacitance, inductive, eddy-current, etc.).

Electronic gages: Electronic gaging systems are in widespread use in dimensional measurement because their response time is extremely short and their output can be used to perform control functions. Most electronic systems make use of linear variable differential transformers (LVDT) which produce an output which is proportional to the displacement of a movable core within a field of several coils (fig. 2-10).

Gage blocks which are used in inspection, in the toolroom or on the production floor must be verified in a periodic manner. The most widely used method consists of comparing the actual size of the block being inspected to a master gage block of identical nominal size. Comparator gages based upon electronically amplified displacement signals are the basic instruments for length comparison.



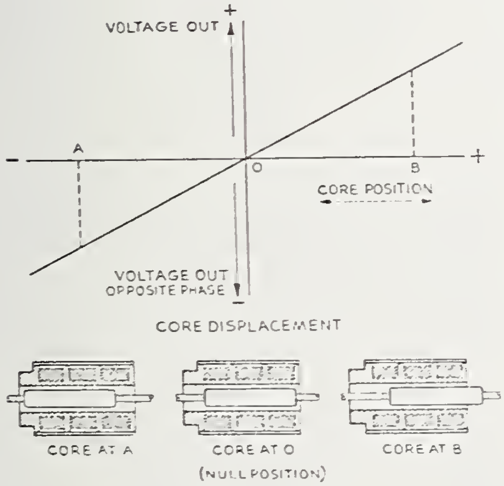




Figure 2-10. Principles of the Linear Voltage Differential Transformer (LVDT).

Electronic gages are also used in other applications such as gaging height, measuring internal diameters, checking roundness, etc. Fringe Counting Laser Interferometers: Since the advent of the laser (early 1960) it could be prophesied that it was only a matter of time before someone developed a reliable laser instrument for measuring distances. With its high degree of coherence, a laser device is usable over hundreds of meters and its wavelength can be stabilized and determined to a high degree of accuracy. One of these models has a range of 60 meters with .025 micrometer resolution and an accuracy better than five parts in $10^7$.

The laser interferometers are based on the Michelson interferometer developed in the late 1800's. If one of the two mirrors in this interferometer moves, then alternately light and dark fringes pass by the observer and their number is indicative of how far the mirror has traveled. If the wavelength of the light is known then it is a simple matter to convert the fringe count to distance. Current designs on the market are more elaborate than this in that some use two frequencies and other variations. The laser interferometer has revolutionized the machine tool industry and will be discussed in greater detail in the users' section of this report.

Electronic Distance Measuring Devices: Some of the more interesting devices used to measure long distances are devices called electronic distance-measuring devices (EDM) based on laser, microwave, and infrared wavelengths. With any type of EDM equipment, modulated waves are transmitted to a target point and returned (fig. 2-11). The modulation of the carrier wave is maintained by frequency-stabilized devices and the phase relationship between the transmitted and returned beams of radiation is determined and converted to a direct readout of distance.

EDM systems can be found in fields of surveying, urban development, construction, mining, agriculture/forestry, and hydrography. A recent dramatic example of laser ranging was the mapping of the Grand Canyon to obtain accurate profiles for a 310-square mile area of the national park. To establish a reference, four parallel lines of points were established along the canyon rims and then cross-referenced with one another with laser ranging in terms of distance and angle. The total survey was made in three days with two men, whereas traditional taping measurements would have taken one year and approximately 100 men.

(5) Measuring Machines: The configuration and size of mechanical parts are determined by more than a single measurement. Many of the dimensions are interdependent with regard to position and geometry. Characteristics such as built-in accuracy, adaptability, and versatility for measuring many configurations have resulted in diverse applications for "measuring machines" in many phases of industrial production.

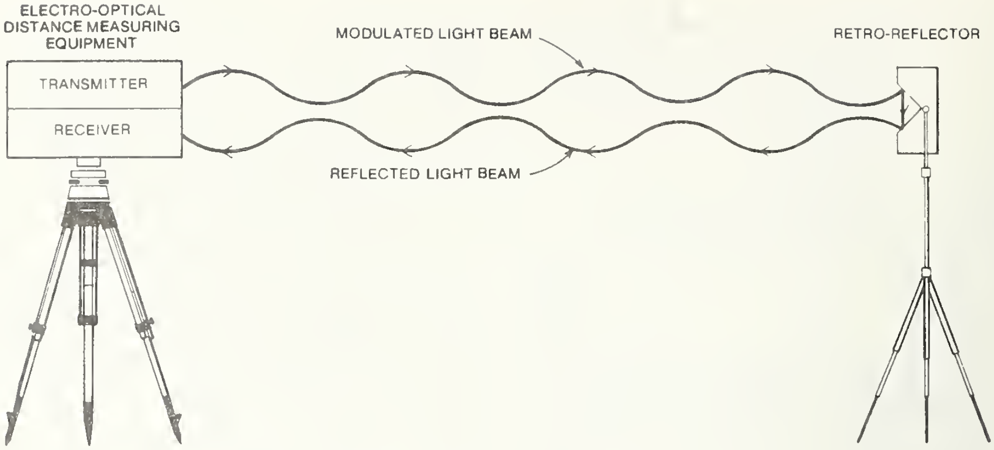



Figure 2-11. Principles of electronic distance measuring device (EDM).

Measuring machines are stationary machines (with some moving parts, such as probes) in which their own "internal standards" are used to obtain dimensional measurements. Machines for measurement along one axis only are single-axis machines while multi-axis machines are commonly referred to as coordinate measuring machines.

Single-Axis Measuring Machines: The most frequent measurement is usually a linear distance. The basic types of single-axis machines are:

(1) Instruments which utilize a master scale attached to the movable measuring spindle,
(2) Instruments having a horizontal threaded measuring spindle for the master element, and
(3) Instruments which use optical distance measuring systems incorporated in a horizontal carriage.

Coordinate Measuring Machines: In recent years a new breed of measuring machines has been developed. In these devices, the traveling member is guided along two straight line paths representing the X and Y axes of a rectangular coordinate system with mutually perpendicular axes. A third axis (Z) is available on some models.

"The Tenth American Machinist Inventory of Metal Working Equipment" published in 1968, lists the number of coordinate and contour measuring machines and gear checking machines in the various industries. Table 2-2 shows the total in each industry and the number of these which are less than 10 years old.

The chart shows that those industries which have made the greatest technological advancements during the years 1958 - 1968 have the largest percentage of new measuring machines. Typical is the Communication and Electronic Equipment Industry and its development of microcircuitry.

The cost of a coordinate, contour measuring machine during that period averaged approximately \$35,000 - the total cost for that 10 year period was \$216,000,000 or approximately \$22,000,000 per year. In 1974, the cost of only the basic coordinate measuring machine is approximately \$65,000. If it is equipped with automatic features such as numerical control (NC), punch cards or tape, and printed read-out, the cost can increase to \$150,000. The sales department of one manufacturer states that 50% of all measuring machines are sold with some type of automatic control and that the median price of all their sales is approximately \$80,000 to \$90,000. An official of the marketing department of another company, estimates that the median sale price of their measuring machines is approximately \$30,000. This latter company markets several versions of their measuring machines ranging in price from \$5,000 to \$100,000 and during the past five years has sold approximately 30 per month. This company supplies approximately 70% of all measuring machines being bought at this time. Four other companies supply approximately 25%, and several smaller companies fill the needs of the other 5%. These figures indicate that approximately 600 coordinate, contour measuring machines are being sold yearly. Based on a median sales price of \$40,000, the annual cost is approximately \$24,000,000 which is a 10% increase in sales compared to the 1958 to 1968 period.

### 2.2.2.2 The Instrumentation Industry Standard Industrial Classification (SIC)

Although SIC does not allow us to study in complete detail the national measurement system for length, we are able to utilize the classification system to obtain some quantitative numbers on certain types of

Table 2-2. Total of coordinate measuring machines per industry.

| INDUSTRY | Coordinate Contour Meas. Mach. | Under 10 Yrs. | Gear Checking Machines | Under 10 Yrs. |
|---|---|---|---|---|
| Ordnance | 497 | 200 | --- | --- |
| Primary Metal Industries | 317 | 288 | 49 | 27 |
| Fabricated Metal Products | 538 | 396 | 132 | 59 |
| Fabricated Structural Metal Products | 770 | 507 | --- | --- |
| Screw Machine Products | 193 | 123 | 39 | 11 |
| Metal Stampings | 84 | 69 | 32 | 32 |
| Misc. Fabricated Metal Products | 108 | 75 | 43 | 12 |
| Machinery (except electrical) | 1428 | 966 | 2859 | 960 |
| Engines and Turbines | --- | --- | 165 | 62 |
| Farm Machinery and Equipment | 65 | 47 | 208 | 18 |
| Construction, Mining, Oil-Field Material Handling Equipment | 36 | 29 | 204 | 59 |
| Metalworking Machinery and Equipment | 622 | 369 | 642 | 177 |
| Special Industry Machinery | 167 | 94 | 207 | 71 |
| General Industrial Machinery and Equipment | 65 | 60 | 1237 | 455 |
| Office, Computing and Accounting Machines | 92 | 92 | 53 | 37 |
| Misc. Machinery (except electrical) | 377 | 272 | 139 | 78 |
| Electrical Machinery, Equipment and Supplies | 801 | 727 | 440 | 193 |
| Electrical Equipment | 216 | 183 | 170 | 78 |
| Household Appliances | 33 | 16 | 30 | 17 |
| Communications and Electronic Equipment | 552 | 528 | 240 | 98 |
| Transportation Equipment | 623 | 415 | 1214 | 388 |
| Automotive Parts and Accessories | 256 | 131 | 553 | 140 |
| Complete Aircraft | 37 | 37 | 110 | 95 |
| Aircraft Engine and Parts | 303 | 223 | 551 | 153 |
| Ships, Boats and Railroad Equipment | 24 | 21 | --- | --- |
| Precision Instruments and Mechanisms | 323 | 258 | 245 | 106 |
| Misc. Manufacturing Industries | 101 | 58 | --- | --- |
| TOTAL | 8628 | 6183 | 9562 | 3326 |

instrumentation used in length measurements. By looking under the alphabetic index of manufacturing industries in the 1972 SIC Manual, we are able to classify our particular instrumentation for length in terms of SIC numbers versus the types of instrumentation already discussed.

Mechanical Class

| | |
|---|---|
| Measuring instruments, mechanical | 3545 |
| Rules and rulers, metal | 3423 |
| Rules and rulers, wood | 2499 |
| Rules and rulers, printers | 3555 |
| Tape measures | 3999 |

Optical Class

| | |
|---|---|
| Measuring instruments, optical | 3832 |
| Microscopes | 3832 |

Electronic Class

| | |
|---|---|
| Laser scientific and engineering instruments | 3811 |
| Laser systems and equipment | 3662 |
| Microwave test equipment | 3825 |
| Surveying instruments | 3811 |

The SIC codes should not be considered as all inclusive but they will serve the purposes of:
(1) a guide to permit us to obtain an estimate for the economic size of an instrument industry,
(2) a basis for using standard industrial terminology when we correspond with a company and for updating our data file through Bureau of Census reports.

We shall now elaborate on one type of instrumentation by making use of the 1963 and 1967 Census of Manufacturers which are exhaustive studies of industry.

Mechanical Instrumentation: 3545 - This industry comprises establishments engaged in the manufacture of cutting tools, machinist's precision measuring tools, and attachments and accessories for machine tools and for other metalworking machinery. Types of (pertinent) products include:

Calipers and dividers
Comparators (machinist's precision tools)
Gage blocks
Gages except optical: plug, ring, snap,

thread, electric, gear, pneumatic
Measuring tools and machines
Micrometers
Optical measuring devices
Scales, measuring (machinist's precision tools)
Verniers (machinist's precision tools)

This industry code has been broken down into further product codes:

| Product Code | Description |
|---|---|
| 35452 | Precision measuring tools |
| 3545211 | Comparators |
| 3545213 | Fixture type-fixed size limit gages |
| 3545215 | Thread type-fixed size limit gages |
| 3545217 | Adjustable size limit gages |
| 3545221 | Gage blocks |
| 3545261 | Dial indicators |
| 354571 | Pneumatic gages (manual and automatic) |
| 3545298 | Other machinists precision tools including micrometers, calipers and dividers |
| 35453 | Other attachments and accessories for machine tools |
| 3545351 | Toolroom specialties, including levels, angle irons, plates, squares, sine bars, V-blocks, flats, etc. |

We have obtained information for SIC code 3545 from the 1972, 1967, and 1963 Census of Manufacturers published by the Bureau of the Census and the Commerce Department. Table 2-3 shows that values of shipments for the Machine Tool Accessories Industry (3545) in 1972 totaled $1226.9 million. This amount included shipments of machine tool accessories and measuring devices (primary products) valued at $996 million, shipments of other products (secondary products) valued at $157 million, and miscellaneous receipts (mainly products bought and sold) at $74 million.

Table 2-3. Industry-product analysis for the machine tool accessories industry (SIC 3545).

| Census Year | Value of shipments | | | | | Value of primary product shipments | | |
|---|---|---|---|---|---|---|---|---|
| | Total ($ millions) | Primary products ($ millions) | Secondary products ($ millions) | Miscellaneous receipts ($ millions) | Primary product specialization ratio $\frac{\text{Col. B}}{\text{Col. B + C}}$ (percent) | Total made in all industries ($ millions) | Made in this industry ($ millions) | Made in other industries ($ millions) |
| | A | B | C | D | E | F | G | H |
| 1972 | 1226.9 | 996.0 | 156.9 | 74.0 | 86 | 1122.0 | 996.0 | 158.0 |
| 1967 | 1309.9 | 1035.9 | 176.2 | 97.8 | 85 | 1222.4 | 1035.9 | 186.6 |
| 1963 | 787.3 | 616.0 | 121.8 | 49.5 | 83 | 731.7 | 616.0 | 115.7 |
| 1958 | 511.4 | 401.7 | 73.3 | 36.4 | 85 | 470.1 | 401.7 | 68.5 |

Table 2-4. General statistics for the machine tool industry.

| Year | Industry or product class code | Industry or product class by specialization | Establishments (numbers) | All employees: Total (1000) | All employees: Payroll (millions) | Production workers: Total (1000) | Production workers: Man-hours (1000) | Production workers: Wages (millions) | Value added by manufacture adjusted (millions) | Value of shipments (millions) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1972 | 3545 | Machine Tool Accessories | 1210 | 46.0 | 450.1 | 33.1 | 66.1 | 290.5 | 863.1 | 1226.9 |
| 1967 | 3545 | Machine Tool Accessories | 1141 | 60.3 | 479.3 | 45.2 | 96.4 | 324.2 | 922.8 | 1309.9 |
| 1963 | 3545 | Machine Tool Accessories | 1038 | 40.9 | 312.8 | 34.6 | 72.0 | 208.1 | 559.3 | 787.3 |
| 1963 | 35452 | Precision Measuring Tools | 115 | 5.4 | 35.4 | 4.0 | 8.5 | 23.2 | 55.4 | 74.2 |

The value of the primary product of an industry is summarized in columns F, G, and H.

Table 2-4 presents some general statistics for the machine tool accessories establishment. Table 2-5 contains informative data on the numbers of mechanical measuring instruments which are within the national measurement system for length. We are able to obtain current figures for the industry by consulting the Annual Survey of Manufacturers 1971 - M71(AS)-2. The total figures for SIC 3545 and SIC 35452 are shown in table 2-5. It is interesting to note that the percentage ratio of precision measuring tools to machine tool accessories has fluctuated within 3% over the past 13 years. Table 2-6 shows that when the figures are adjusted for a 7% yearly inflation rate, the machine tool industry had a negative growth of 38%.

### 2.2.3 Reference Data

### 2.2.4 Reference Materials

Neither reference data nor materials play a substantial role in this part of the National Measurement System. Exceptions do occur, e.g., the "North American Datum" described in Appendix G.

### 2.2.5 Science and People

NBS and other National Laboratories can routinely measure end standards to one part in $10^{-6}$ with an uncertainty of approximately .05 micrometers. This accuracy is far better than the machine tool industry can use. Our contacts with production and quality control engineers within the industry including those involved in precision instrumentation indicate that they all would be extremely happy if they could get an "honest tenth" (the ability to machine a part and measure it to .0001 inch, 2.5μm). The inability of most quality control departments to measure within .0001 inch is usually due to the personnel rather than the measuring equipment. Some of the newer computer and numerically controlled (NC) machines are capable of achieving a "tenth" if the proper precautions are followed such as compensating for tool wear and thermal distortions of the machine and work piece. In view of this the primary research in extending the state-of-the-art

Table 2-5. Value of shipments for SIC 3545.

| Product Code | Product | Total Shipments, Incl. Interplant Transfers (millions of dollars) 1972 | 1967 | 1963 | 1958 |
|---|---|---|---|---|---|
| 3545 | MACHINE TOOL ACCESSORIES AND MEASURING DEVICES | 1226.9 | 1309.9 | 787.3 | 511.5 |
| 35452 | Precision measuring tools | 94.3 | 130.8 | 87.9 | 60.9 |
| | Machinists' precision tools: | | | | |
| 35452 11 | Comparators | 6.1 | 16.1 | 8.8 | 7.2 |
| | Fixed size limit gages (American Gage Design type -C-S8-51): | | | | |
| 35452 13 | Fixed type | 7.0 | 8.9 | 7.0 | 3.9 |
| 35452 15 | Thread type | 4.3 | 9.4 | 6.0 | 6.1 |
| 35452 17 | Adjustable size limit gages | 5.8 | 4.6 | 2.8 | 1.8 |
| 35452 21 | Gage blocks | 1.9 | 4.0 | 2.6 | 1.9 |
| 35452 61 | Dial indicators | 11.7 | 9.9 | 6.6 | 4.7 |
| 35452 65 | Micrometers and calipers[1] | 9.0 | 9.4 | | |
| 35452 71 | Pneumatic gages (manual and automatic) | 13.3 | 23.3 | 14.5 | |
| 35452 98 | Other machinists' precision tools, including micrometers, calipers and dividers | 28.0 | 36.1 | 36.8 | 27.1 |
| 35452 00 | Precision measuring tools, n.s.k* | 7.2 | 9.2 | 3.0 | 8.2 |
| 35452 51 | Toolroom specialties, including levels irons, plates, squares, sine bars, V-blocks, flats, vises, etc. | | 24.7 | 11.8 | 7.1 |

[1]For the 1963 code 35452 65 "Micrometers and calipers" was included with code 35452 98 "Other machinists' precision tools."
*n.s.k. - not specified by kind.

Table 2-6. Shipments of products and services of several industries.[2]

| | MACHINE TOOLS SIC 3541, 3542 | | ELECTRONICS COMPUTER SIC 3573 | | CHEMICAL INDUSTRY SIC 28 | | OILFIELD MACHIN. AND EQUIP. SIC 3533 | |
|---|---|---|---|---|---|---|---|---|
| | SHIPMENTS[3] | | SHIPMENTS | | SHIPMENTS | | SHIPMENTS | |
| YEAR | | ADJUSTED FOR 7% INFLATION | | ADJUSTED FOR 7% INFLATION | | ADJUSTED FOR 7% INFLATION | | ADJUSTED FOR 7% INFLATION |
| 1967 | 2,841 | 2,841 | 3,761 | 3,761 | 42,148 | 42,148 | 800 | 800 |
| 1968 | 2,817 | 2,633 | 4,163 | 3,890 | 45,622 | 42,637 | 906 | 847 |
| 1969 | 2,835 | 2,476 | 5,112 | 4,465 | 48,269 | 42,160 | 989 | 864 |
| 1970 | 2,598 | 2,121 | 5,700 | 4,653 | 49,355 | 40,288 | 1057 | 863 |
| 1971 | 2,019 | 1,540 | 4,952 | 3,778 | 51,873 | 39,574 | 1053 | 803 |
| 1972[1] | 2,270 | 1,618 | 5,546 | 3,954 | 57,437 | 40,952 | 1140 | 813 |
| 1973[1] | 2,550 | 1,699 | 6,210 | 4,138 | 63,200 | 42,113 | 1230 | 820 |
| 1974[1] | 2,850 | 1,775 | 6,690 | 4,166 | 68,200 | 42,471 | 1325 | 825 |
| % 7 yr growth | | -38% | | 10.8% | | 0.77% | | 3.19% |

[1]Estimated by Bureau of Competitive Assessment-BCABP-US Department of Commerce.
[2]Data from US Industrial Outlook 1974 - US Department of Commerce, p308.
[3]Value of shipments is in millions of dollars.

in length measurements is being done at the National Laboratory level. At NBS a continuing effort is being made by engineers and physicists to design equipment and methods to measure lengths to 1 part in $10^{-7}$. The most promising device to achieve this is the laser. Special purpose laser interferometer systems have been designed that appear, at this time, to have achieved this goal. The scientific community, universities, and pure research laboratories are generally only interested in improving the values of the physical constants such as the speed of light (c).

The c measurements in this field are so widely and so commonly made that no useful generalizations about the people doing them can be made.

## 2.3 Realized Measurement Capabilities

The reader must be warned of the difficulties of using the terms "accuracy" and "precision" to characterize an instrument or what is needed by industry, etc. If the systems analysis approach of viewing a measurement is used, then the entire process must be examined which entails:
(1) the end result of that measurement,
(2) the environment in which the measurement is made,
(3) the instrument used in the measurement process,
(4) the operator making the measurement, and
(5) the interpretation of the data.
For this reason unless a measurement process has been proven to be in statistical control, the significance of the measurement is not clear. And to prove that a process is under control, continual and extended monitoring of that process must be maintained and this does not happen overnight. For these reasons it is very difficult to obtain meaningful numbers which are representative of what industry needs in terms of accuracy because many industries do not even know what they are capable of measuring at "this point in time". The numbers used to derive figures 2-12 through 2-19 and table 2-7 were found in pertinent publications in the area of interest and generally agree with those obtained from various industrial sources during the course of this study.

Table 2-7. Typical NBS working accuracies for angular standards.

| | |
|---|---|
| Angle blocks | 0.35 sec |
| Angle generators | 0.15 sec |
| Indexing tables | 0.25 sec |
| Optical wedges | 0.25 sec |
| Polygons | 0.35 sec |

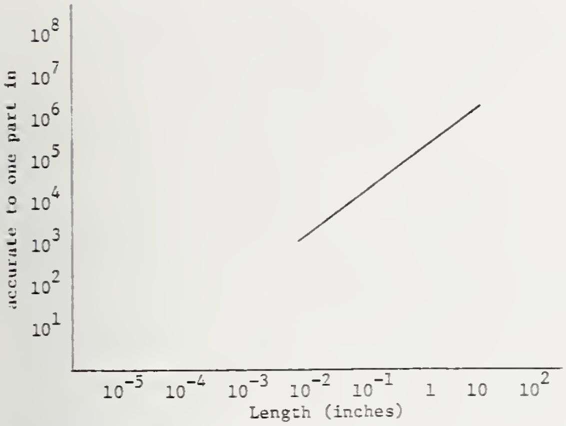



Figure 2-12. Best routine accuracy for end standard measurements at NBS.

This figure is the result of scanning various publications, and educated guesses as to the current accuracy of linear length measurements for the aerospace industry.

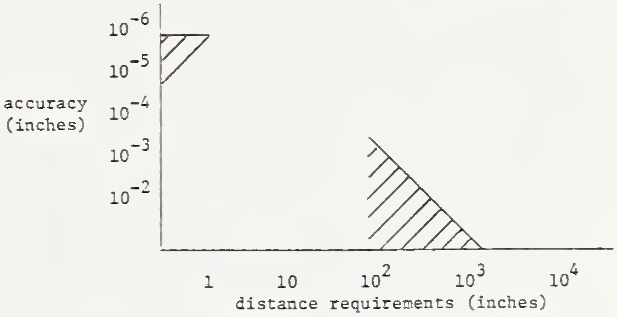



Figure 2-13. Linear length measurement capabilities in the aerospace industry.

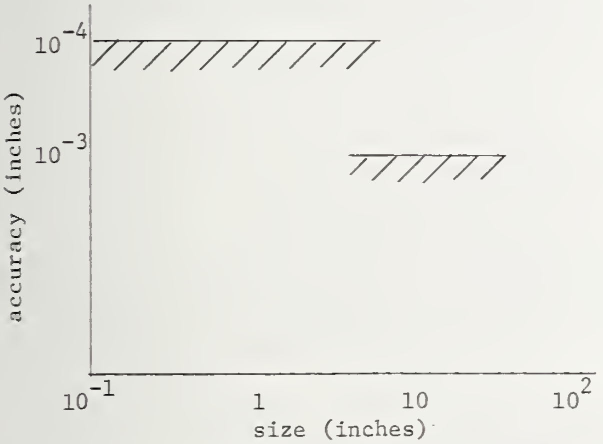



Figure 2-14. Linear length measurement capabilities in the ball and roller bearing industry.

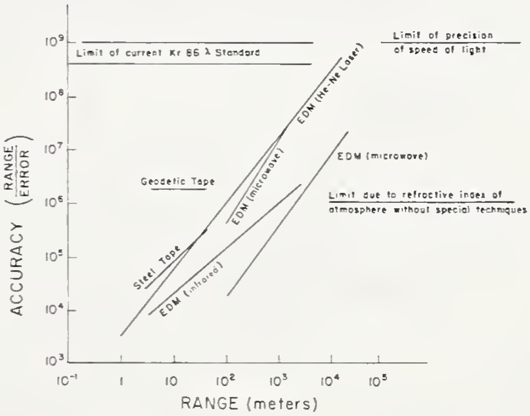



Figure 2-15. Characteristics of typical ranging devices now available.

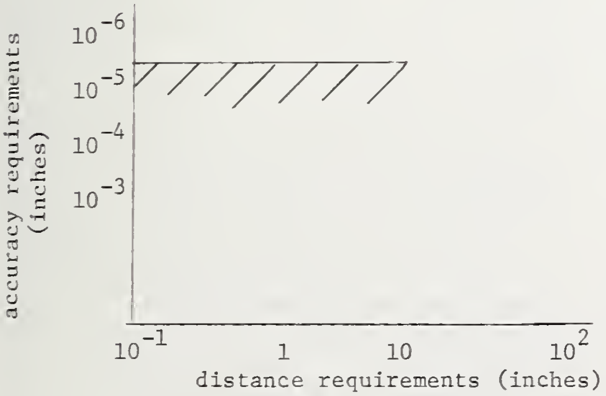



Figure 2-16. Accuracy requirements for integrated circuit camera.

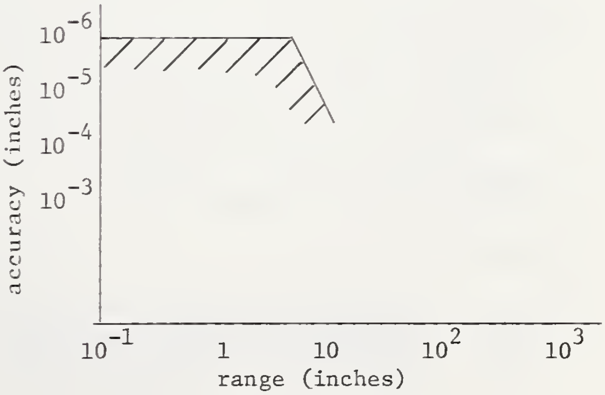



Figure 2-17. Accuracy requirements of metrology.

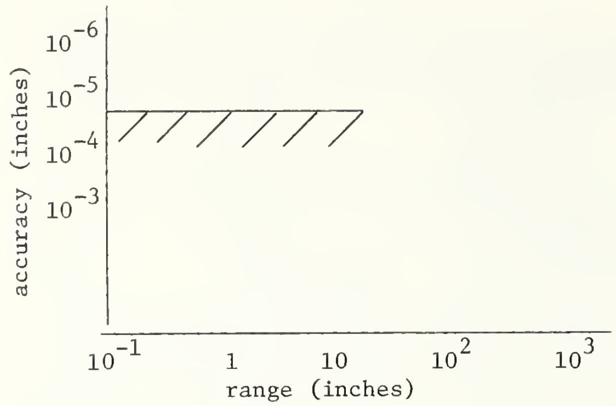


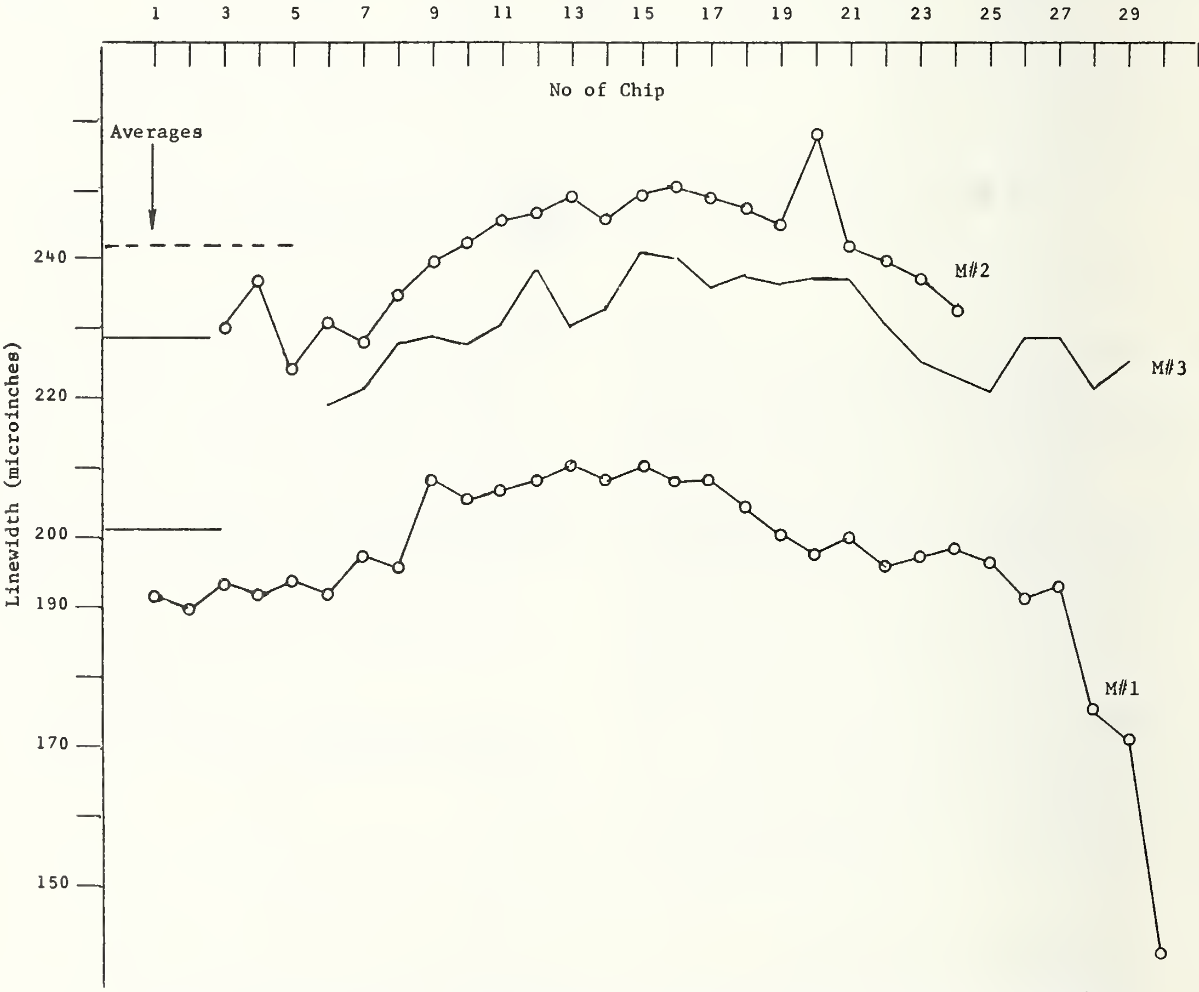

Figure 2-18. Accuracy requirements of photogrammetry.

Figure 2-13 is the result of scanning various publications and educated guesses as to the current accuracy of linear length measurements for the aerospace industry.

It is quite difficult to find meaningful accuracy statements by the industry but figure 2-14 is a sampling from some current bearing manufacturers via catalogs.

The results of several measurement audit surveys provide much illumination regarding the true state-of-the-art of realized measurement capabilities for length and related dimensional measurements.

In 1961 the National Physical laboratory (NPL) investigated the current accuracy of industrial measurements in the size range from 0.02 inch to 5.0 inches. About forty firms in England were invited to par-




Nominal 200μ" lines of a standard plate were measured on three different measuring machines. The average of each sequence is marked along the ordinate. Deviations of up to 40μ" have occurred. The results confirm the need for calibration of measurement systems to an independent (certified) standard. Since each point represents the average of four readings, curves based on single measurements will be less precise.

Figure 2-19. Results of measuring masters on three different measuring machines for integrated circuit industry.

ticipate in the survey and as many branches of the engineering industry were embraced as were likely to be interested in measurements in the range chosen. No similar comprehensive study of measurements has ever been undertaken in this country at the inspection and workshop level. However, we expect the English results to be generally indicative of the situation in this country. In some cases the conclusions and results are eye-opening, considering that in most cases gage blocks were used as reference standards.

The artifacts were manufactured by NPL and consisted of 0.02, 0.04, 0.15, 0.4, 1.0, 2.5, and 5.0-inch external diameter plugs. Rings were made with internal diameters of 0.04, 0.15, 0.4, 1.0, 2.5, and 5.0 inches. The artifacts were of hardened steel and measured to accuracies of 10 to 20 microinches by NPL. The difference between the industrial measurements and those made at NPL were calculated for each firm. To obtain an idea of the spread of the industrial measurements, values of the standard deviation for a particular diameter were plotted. In figure 2-20 the curves show that external measurements are more accurate than internal measurements but become less accurate with an increase in size. Measurements made by inspection departments differ very little in accuracy from workshop measurements on external diameters but on internal diameters are more accurate. The occurrence of large errors is rarer in the external measurements than in the internal measurements.

It is interesting that in the same study an empirical formula was developed to express the accuracy of these industries for measurements:

Equations for Standard Deviation
(Unit 0.001 Inch)

| | Inspection | Workshop |
|---|---|---|
| External | 0.10 + 0.34 d | 0.10 + 0.050 d |
| Internal | 0.25 + 0.005 d | 0.25 + 0.021 d |

where d is the diameter in inches.

Commercial comparators were available in 1961 which could easily measure parts to an accuracy of 5 microinches but it is evident that industry was losing 100 microinches or more in the measurement process. The summary said that "main error lay in the inability to transfer size from a master set of calibrated slip gages to circular parts in the form of work-pieces..."

Recent NCSL Audit: The National Conference of Standards Laboratories was established as a nonprofit organization of laboratories to coordinate and discuss measurement problems. The labs participate in

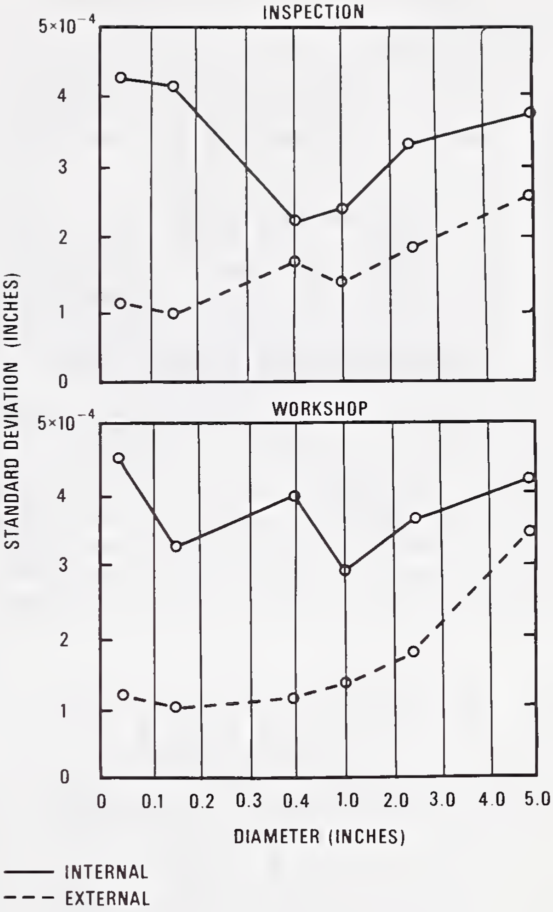



Figure 2-20. Survey by NPL. Standard deviation of industrial errors from NPL measurements.

sending audit packages around every few years to "check" on various capabilities.

We have analyzed the results from the latest survey and even though the survey is not complete we will show the results for ten participating organizations. The results have to be placed within their proper perspective because they tend to emphasize a number (the uncertainty) and not the whole process. The organizations include:

(1) A laboratory in the automotive field
(2) Standards laboratory (space vehicle field)
(3) Manufacturer of precision instrumentation
(4) Manufacturer of aircraft
(5) Manufacturer of industrial equipment
(6) Manufacturer of electrical equipment and components
(7) Army standards lab
(8) Air Force standards lab
(9) Manufacturer of electrical instruments

(10) Manufacturer of aviation components and systems.

The artifacts which were sent to these organizations consisted of the following:

(1) Two 0.2 inch gage blocks of one type
(2) Two 0.2 inch gage blocks of another type
(3) Two 4.0 inch gage blocks
(4) One 24.0 inch gage block
(5) Two 1.8502 inch internal ring gages
(6) Two 2.0000 inch internal ring gages
(7) Two 0.0625 inch diameter master balls
(8) Two 0.1250 inch diameter master balls
(9) Two 5 degree angle blocks
(10) Two 15 degree angle blocks.

Instructions were given to "measure each item listed to the highest accuracy available within your activity." Figure 2-21 shows the measurement results for one type of a 0.200 inch nominal gage block with the measurement uncertainty estimated by each participating organization. Figure 2-22 shows the results for aa 2.0000 internal ring gage. The small circle in each bar indicates the mean of the measurements and the shaded area is the uncertainty of NBS measurements which must be considered as the standard to which all others are compared. The measurement data for No. 1 Ring of figure 2-22 shows that laboratory No. 42 has good precision but poor accuracy while laboratories Nos. 38 and 74 show neither precision or accuracy. Figure 2-23 are results for a master steel ball. The capability of various labs for measurement of angle is depicted in figure 2-24.

Table 2-8 is a tentative summary of the results of these measurements with the figure for standard deviation being computed from the values reported by each participant. It is interesting to note that measurements involving a linear length cause the "least" amount of trouble while measurements of internal diameters and spherical diameters appear to cause the most trouble. This is similar to the results of the NPL survey and a

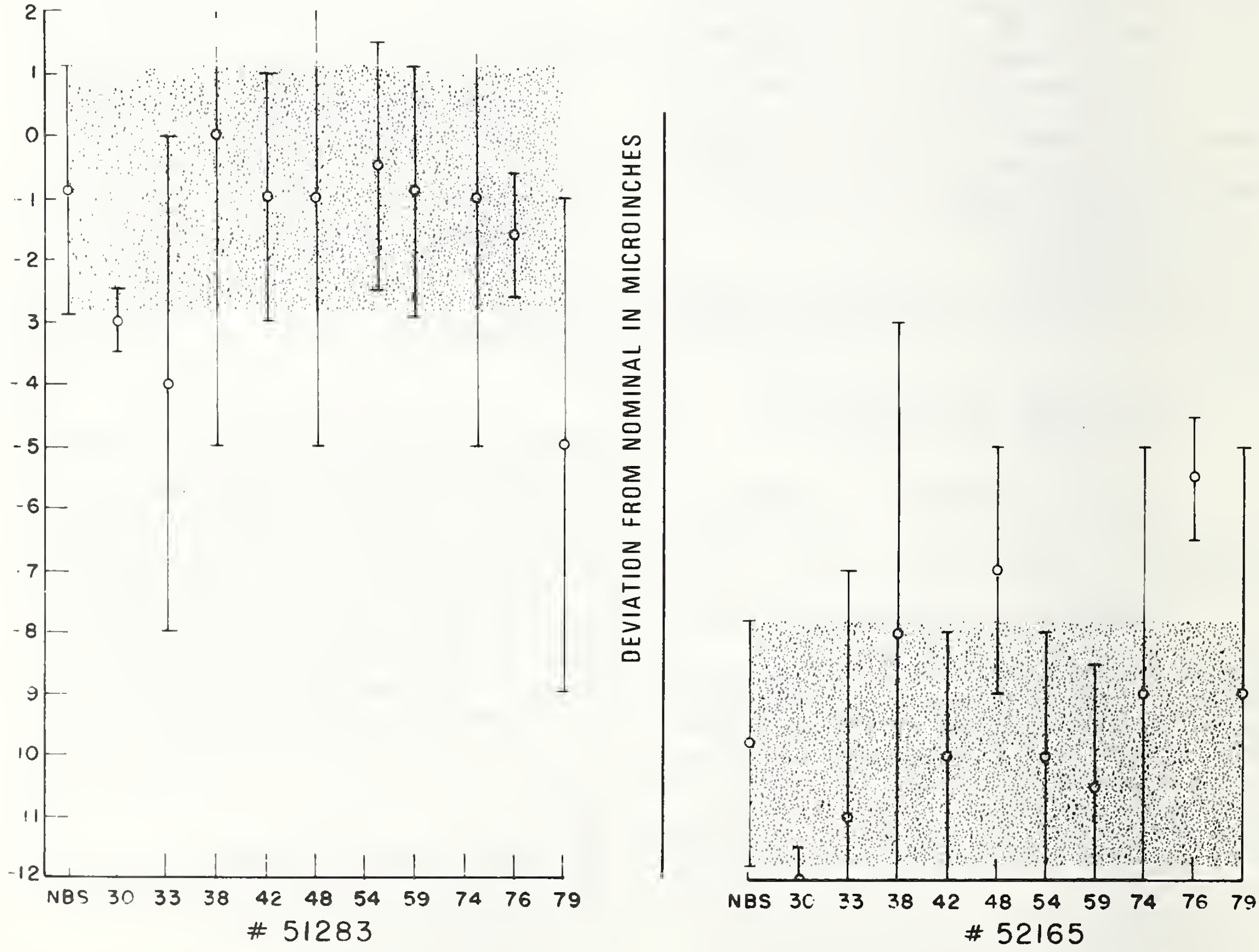



Figure 2-21. Recent NCSL survey. 0.2 inch gage blocks showing measured values and estimated uncertainty for NBS and ten other participating labs.

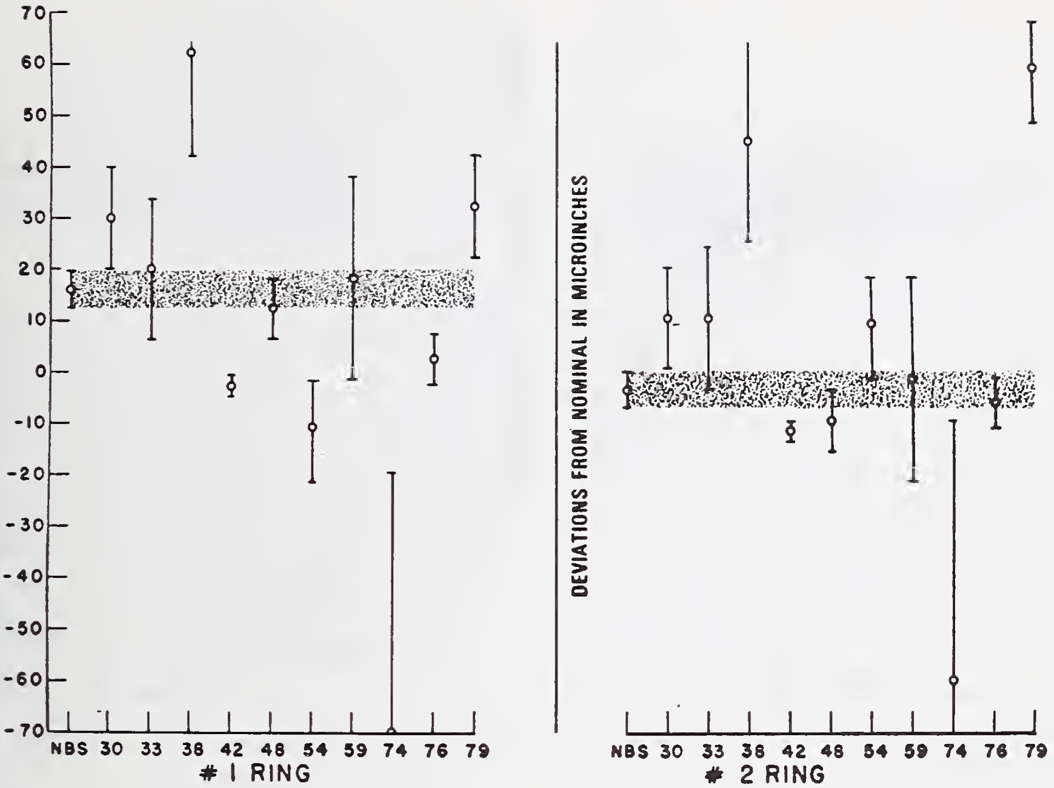



Figure 2-22. Measurements on internal diameters. 2.000 inch ring gages showing measured values and estimated uncertainty for NBS and other labs.

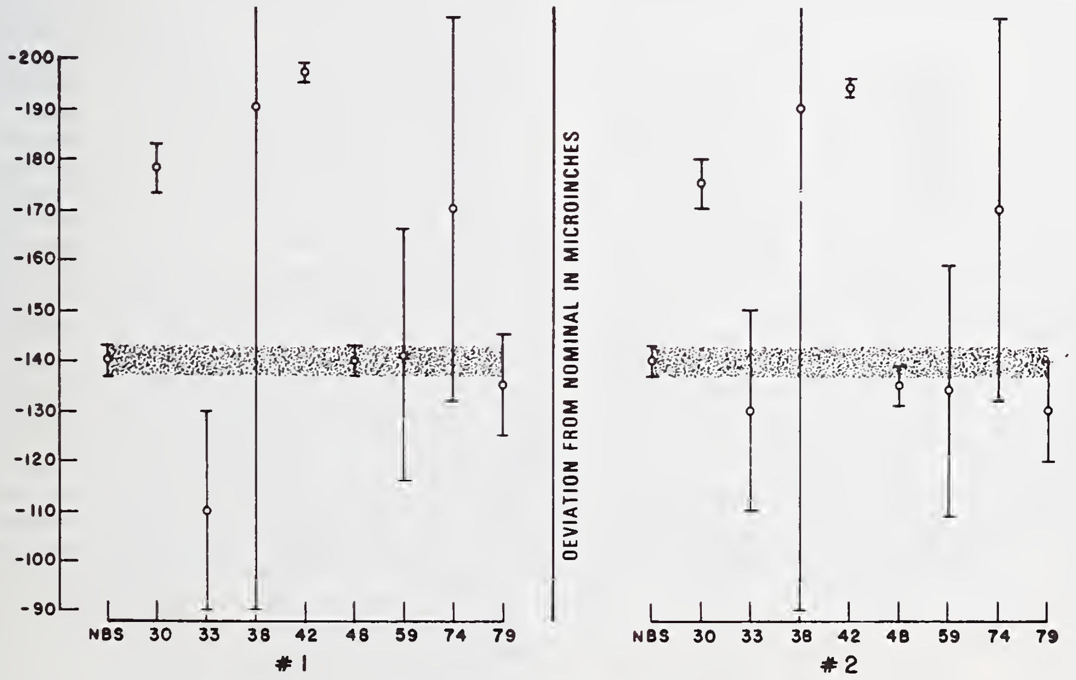



Figure 2-23. External diameter measurements. 0.1250 inch steel balls showing measured values and estimated uncertainty for NBS and other labs.

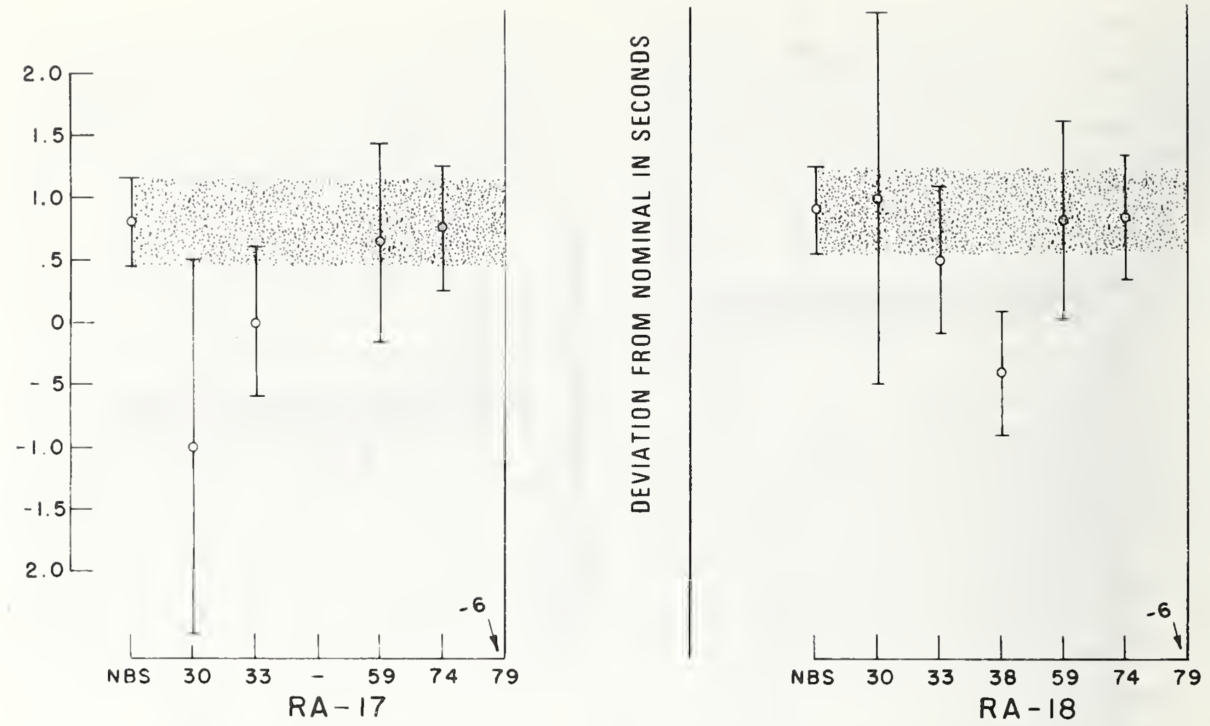



Figure 2-24. 5 Degree angle blocks showing measured values and estimated uncertainty for NBS and other labs.

Table 2-8. Results of partially completed audit among industrial/government labs with computed standard deviation for all results.

| Item | Identification | Standard Deviation |
|---|---|---|
| Gage Blocks | | |
| 0.2 inch | #51283 | 1.6μin. |
| 0.2 | #52165 | 3.1 |
| 0.2 | #4620 | 2.5 |
| 0.2 | #4671 | 2.2 |
| 4.0 | #4852 | 16.3 |
| 4.0 | #4866 | 15.3 |
| 24.0 | | 55.4 |
| Internal Ring Gages | | |
| 1.8502 inch | #1 | 26.4μin. |
| 1.8502 | #2 | 27.0 |
| 2.0000 | #1 | 32.9 |
| 2.0000 | #2 | 30.9 |
| Master Balls | | |
| 0.0625 inch | #1 | 30.6μin. |
| 0.0625 | #2 | 23.5 |
| 0.1250 | #1 | 29.2 |
| 0.1250 | #2 | 26.7 |
| Angle Blocks | | |
| 5.0 degree | #1 | 2.6seconds |
| 5.0 | #2 | 2.5 |
| 15.0 | #1 | 1.1 |
| 15.0 | #2 | 1.2 |

survey of the Aerospace Industry Association (AIA).

It is evident from looking at the results of some recent "round-robins", table 2-8, that the claims of industry to measure accurately objects other than simple end standards are optimistic. Even though gage blocks are available in accuracies of a part in $10^6$, not many industrial labs have the capability to transfer these measurements to other artifacts with great precision and accuracy.

The precision of instrumentation today far outpaces the capability of personnel to utilize these devices fully in accurate dimensional measurements. In many cases accurate dimensional measurements are only needed to satisfy functional requirements e.g. to ensure that mating parts will fit properly at assembly.

Often the industrial contacts which we have made yielded no earth-shattering news concerning needs for more accuracy. The main area of concern was need for more help with the day-to-day mundane problems. One solution to this problem is to publish more articles in journals describing the measurement philosophies of NBS and to describe in greater detail the various measurement processes.

The main area of impact which new instrumentation is having in dimensional measurements is in the surveying field. Tapes are still used quite extensively in the industry, mainly by private individuals, but in the past year or so low cost electronic distance measuring devices have been revolutionizing the surveying industry. With these devices surveyors can measure distances of over one kilometer with accuracies limited only by their ability to determine the atmospheric corrections.

The computer has proven to be a valuable tool in the area of inspection and quality control. If tied into an automatic gaging system, the computer can print out the inspection result of every part. The computer is also a valuable tool for sampling and control. The process can be set up so that if the production process is under control, no action will be taken, but if a parameter changes, corrective action may be taken.

The computer can also be a vital tool in the use of coordinate measuring machines. As the artifact is probed, the computer can compare the dimension measured against a nominal dimension and record the deviations.

In the past few years numerical control for manufacturing processes has been increasing. The impacts which NC has upon dimensional measurements are:
(1) 5% savings of direct labor cost from NC machine for improved accuracy
(2) 30% savings of inspection costs due to improved process repeatability
(3) 80% or more of actual inspection time can be saved through NC inspection over manual methods.

Many manufacturers claim that the resolution of their units may be within 50 or 100 microinches. Not many machine tools can produce to these accuracies. There are screws, lead screws, beds, ways, spindles, and columns made of metal and subject to tolerances. All of these play a role in determining the final machining capability which is the one parameter of primary concern. Thus it behooves the user to know what can be obtained from his machine.

From communication with various industrial concerns we have seen that the need of industry for the next three to seven years in dimensional measurements is in the area of better measurements in three dimensions. There are many measuring machines on the market today but most of them have the fault that inaccuracies are defined in terms of one axis. There is no assurance that if you start at point (1,1,0) and terminate at point (0,0,1) in a working volume that your inaccuracy can be expressed as linear combinations of the individual axis errors. What is needed are methods to characterize these errors. (This is under development now at NBS with the 3 dimensional facility.) One of the main purposes of the study of the National Measurement System is to find efficient means to disseminate our work to the people who need it as our project progresses.

### 2.4 Dissemination and Enforcement Network

#### 2.4.1 Central Standards Authorities

Organizations which deal with measuring systems are classified into either scientific metrology or legal metrology. The scientific metrology category watches over the values assigned to particular units and maintains the definition of certain standards. The recognized international authority on weights and measures is the International Bureau of Weights and Measures which was established as a result of the Treaty of the Meter. Legal metrology organizations are set up to deal with the legalities of measuring devices and their usage. The recognized international authority here is the International Organization of Legal Metrology whose functions include:
(1) Translation of regulations existing in different nations.
(2) Establishment of a plan for the inspection and checking of measurement instruments.
(3) Promotion of closer ties between various facilities responsible for legal metrology.

Since the desideratum of any unit is precise availability for the user, the adoption of a specific wavelength of visible radiation has extended the number of commercial/industrial laboratories in possession of the unit. Although it might be theoretically conceivable that all products used in manufacturing and inspection could be checked against basic measuring standards, it is not at all practical. The obvious solution is to use the primary standard for calibration of secondary standards, then disseminate the secondary standards to a large number of scientific, industrial, and military laboratories whereby a reliable link can be created between the basic standards and the instruments used for measurements of industrial products.

In the case of length, the embodiment of the unit within the physical system is the $^{86}Kr$ lamp. The most fragile link in the chain is the transfer from the wavelength standard to "physical" standards or material artifacts. This first transfer usually occurs in the international laboratories around the world: Bureau International des Poids et Mesures (France), National Physical Laboratory (Great Britain), Physikalisch - Technische Bundesanstalt (West Germany), National Bureau of Standards (USA), etc.

#### 2.4.2 State and Local Offices of Weights and Measures

The capabilities of the states' Weights & Measures Laboratories in the area of dimen-

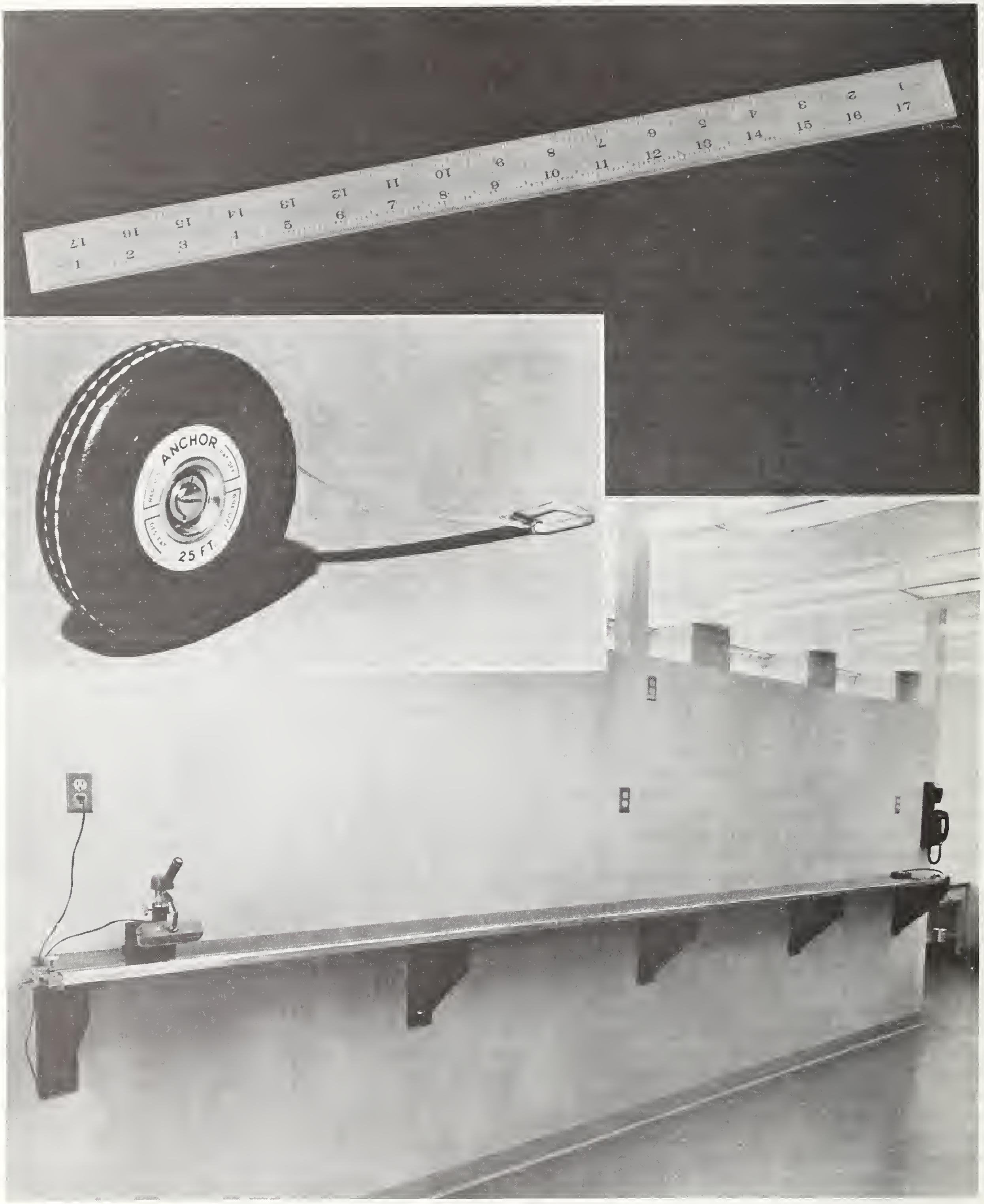



Figure 2-25. Length bench in State's Weights and Measures Lab and associated standards.

sional measurements are shown in Appendix E. Figure 2-25 shows examples of the type of length standards supplied to the state laboratories by NBS Office of Weights & Measures.

The National Conference on Weights and Measures, composed primarily of state, county, and city weights and measures officials, meets annually to consider problems arising in weights and measures administration and enforcement.

The National Bureau of Standards Office of Weights and Measures cooperates closely with the conference Committee on Specifications and Tolerances to set up regulations for commercial measuring devices. The result of this is NBS Handbook 44 which contains codes to meet the changing conditions of trade and the new developments of the equipment industry. In the area of length measurements, the categories covered in Handbook 44, are linear measures, fabric-measuring devices, wire and cordage-measuring devices, taximeters, and odometers. (See Appendix B).

### 2.4.3 Standards and Testing Laboratories and Services

The National Conference of Standards Laboratories (NCSL) is a non-profit organization of laboratories which coordinates and discusses problems in measurements among its members. An NCSL committee formulates voluntary standards of practice, studies the calibration needs of science and industry, conducts measurement agreement comparisons, and holds periodic workshops and conferences. The calibration capabilities of various NCSL members and laboratories in the area of dimensions are published annually (see Appendix F).

The Primary Standards Laboratories of Department of Defense calibrate the gages and the standards of the Secondary Standards Laboratories against their master gages which in turn were calibrated against the national artifact at NBS. The DoD Secondary Standards Laboratories calibrate all the standards, including micrometers, plug and ring gages, thread gages, etc., of the roving or mobile laboratories. The mobile laboratories calibrate the operating equipment *in situ*.

As a check on the calibration link between NBS and the mobile laboratories or field laboratories, the Primary Standards Laboratories circulate an audit package of a standard, i.e. a set of balls. All the laboratories in the calibration chain including NBS calibrate this package using their customary calibration technique and process. If the results of any one of the laboratories differ from that of the others or NBS, it shows that the technique or process is out of control and steps are immediately taken by that laboratory to correct it.

Detailed fiscal data for just one of the services are represented: The annual operating budget for the U.S. Army Metrology Calibration Center is approximately \$6.5 - \$7.0 million. The cost of in-place equipment for length measurement represents 3.6% of this annual operating cost. The operating cost (salaries, overhead, etc.) for length measurement represent 2.2% of the total so that dimensional measurements represent approximately 5.8% of the Army Standards Lab operating budget [3].

### 2.4.4 Regulatory Agencies

Regulatory agencies are not really relevant to this field.

## 2.5 Direct Measurements Transactions Matrix

### 2.5.1 Analysis of Suppliers and Users

The matrix, table 2-9, was formed using twenty selected customers and users of NBS length and related measurements. It is modeled after the Input-Output (I/O) matrices used in the field of economics, and will often be referred to here as the "I/O Matrix." The lack of information relating to the interaction between the suppliers and users is due to the difficulty in obtaining meaningful data. For example, how much of the measurement output of the steel industry is used in the aerospace industry is probably not reliable and not very relevant to a study of NBS length and related measurements.

Some of the data are what one would expect, e.g. DoD, the machine tool industry, the aerospace industry and the precision instrument industry are heavy users of NBS length measurements. However, there are some surprises. The chemical industry and the petroleum industry are also heavy users, but the auto and truck industry and the auto parts industry are not.

### 2.5.2 Highlights Regarding Major Users

The following paragraphs relate the various industries to the National Measurement System and show how their technologies depend upon a viable connection to it.

#### 2.5.2.1 Air Frames, Engines, Aircraft Equipment, Guided Missiles, and Space Vehicles and Parts

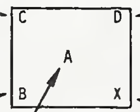
We can characterize this user as the aerospace industry with SIC codes 3721, 3724,

Table 2-9. Direct measurements transactions matrix.

| DIRECT MEASUREMENTS TRANSACTIONS MATRIX FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS / USERS / SUPPLIERS | KNOWLEDGE COMMUNITY 1 | INTERNATIONAL METROLOGY LABS 2 | DOCUMENTARY SPECIFICATION ORGANIZATIONS 3 | PRECISION INSTRUMENTS 4 | MACHINE TOOL 5 | NBS 6 | STATE & LOCAL OFFICES OF WEIGHTS & MEASURES 7 | OoD & PRIVATE STANDARDS LABS 8 | OTHER FED. LABS (PRIMARILY NASA) 9 | PETROLEUM INDUSTRY 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 KNOWLEDGE COMMUNITY | X | X | 1 D 1 D D | 1 1 1 0 E | 1 1 1 0 E | 1 1 1 0 E | | 1 1 1 D E | 1 1 1 0 E | |
| 2 INTERNATIONAL METROLOGY LABS | X | 2 1 3 0 A | 2 2 1 0 E | 2 1 2 0 A | 2 1 2 0 A | 3 1 1 0 A | | | | 4 1 3 2 B |
| 3 DOCUMENTARY SPECIFICATION ORGANIZATIONS | 1 0 1 D D | 2 2 1 0 D | 2 1 2 D E | 2 1 2 0 D | 2 1 2 0 D | 2 1 2 0 E | 3 1 2 D E | 3 1 2 0 E | 3 1 2 0 E | 2 1 2 0 D |
| 4 PRECISION INSTRUMENTS | 1 1 1 0 E | 2 1 2 0 C | 2 1 1 0 D | 2 1 4 0 A | 2 1 2 0 A | 3 1 2 0 E | 2 1 2 0 A | 3 1 3 0 C | 2 1 3 0 A | |
| 5 MACHINE TOOL | 1 1 1 0 C | 2 1 2 0 C | 2 1 2 0 E | 2 1 2 0 E | 2 1 4 0 A | 2 1 3 0 E | | 2 1 1 0 C | 2 1 1 0 C | 2 1 1 0 C |
| 6 NBS | 1 1 1 0 D | 3 1 4 0 B | 2 1 2 2 D | 3 1 3 0 B | 3 1 4 2 B | 2 1 4 0 A | 3 1 1 0 B | 3 1 4 0 B | 3 1 3 0 B | 4 1 4 2 B |
| 7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES | | | 2 1 2 0 E | 1 1 2 0 A | | 2 1 1 0 E | 2 1 2 0 A | 2 2 2 0 B | | |
| 8 OoD & PRIVATE STANDARDS LABS | 1 1 1 0 E | | 2 1 2 2 E | 2 1 2 0 B | 2 1 2 0 B | 3 2 1 0 B | 2 2 2 0 B | 2 2 4 0 B | 2 2 2 0 B | |
| 9 OTHER FED. LABS (PRIMARILY NASA) | 1 1 1 D E | | 2 1 2 0 E | 2 1 1 0 B | 2 1 1 0 B | 3 1 2 0 B | | 2 1 1 0 E | 2 1 1 0 A | |
| 10 PETROLEUM INDUSTRY | | 3 1 2 0 E | 2 1 2 0 D | | 2 1 1 0 D | 3 1 3 0 D | | | | 2 1 4 D A |
| 11 MACHINERY GENERAL | | | 2 1 2 0 E | 2 1 2 0 E | 2 1 2 0 E | 1 1 1 0 E | | 2 1 1 0 E | | 2 1 3 D E |
| 12 AEROSPACE AND AIRCRAFT INDUSTRY | 1 1 1 0 E | | 1 1 2 0 E | 2 1 2 0 E | 2 1 2 0 E | 2 1 2 0 E | | 2 1 2 0 E | 2 1 2 0 E | |
| 13 AUTO AND TRUCK INDUSTRY | | | 2 1 2 0 E | 2 1 2 0 E | 1 1 2 0 E | 2 1 2 0 E | | | | |
| 14 OTHER TRANS. EQUIP. R.R., MARINE, ETC. | | | 2 1 2 0 E | | | 1 1 1 0 E | | | | |
| 15 CHEMICAL INDUSTRY | | | | | 2 1 1 0 E | 2 1 2 0 E | | | | |
| 16 ELECTRICAL AND ELECTRONIC INDUSTRY | | | 2 1 1 0 E | 2 1 2 0 E | 2 1 2 0 E | 3 1 3 2 E | | 2 1 2 0 E | 2 1 1 0 C | |
| 17 FERROUS AND NON-FERROUS METAL INDUSTRY | | | 2 1 2 0 E | | | 3 1 1 0 E | | | | 2 1 1 0 D |
| 18 RETAIL STORES, SURVEYORS, ENGINEERS, ARCHITECTS, ETC. | 2 1 1 0 E | | | 2 1 1 0 E | | 2 1 1 0 E | 2 1 2 0 E | | | |
| 19 FOREIGN COUNTRIES | X | 4 1 3 0 E | | 1 1 1 0 E | 1 1 1 0 E | 3 1 1 0 A | | | | 3 1 2 0 B |
| 20 GENERAL PUBLIC | 1 1 1 0 E | | | | | 1 1 1 0 E | 1 1 1 0 E | | | |

| SUPPLIERS | MACHINERY GENERAL 11 | AEROSPACE AND AIRCRAFT INDUSTRY 12 | AUTO AND INDUSTRY 13 | OTHER TRANS. EQUIP. R.R., MARINE, ETC. 14 | CHEMICAL INDUSTRY 15 | ELECTRICAL AND ELECTRONIC INDUSTRY 16 | FERROUS AND NON-FERROUS METAL INDUSTRY 17 | RETAIL STORES, SURVEYORS, ENGINEERS, ARCHITECTS, ETC. 18 | FOREIGN COUNTRIES 19 | GENERAL PUBLIC 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 KNOWLEDGE COMMUNITY | | 1 1 1 0 E | | | | | | 2 1 1 0 E | X | 1 1 1 0 D |
| 2 INTERNATIONAL METROLOGY LABS | | | | | | | | | 4 1 3 2 B | |
| 3 DOCUMENTARY SPECIFICATION ORGANIZATIONS | 2 1 2 0 D | 2 1 2 0 D | 2 1 2 0 D | 2 1 2 0 D | | 2 1 2 0 D | 2 1 2 0 D | | | |
| 4 PRECISION INSTRUMENTS | 1 1 1 0 C | 2 1 2 0 C | 1 1 1 0 C | | | 2 1 2 0 C | | 2 1 4 0 C | 2 1 1 0 C | |
| 5 MACHINE TOOL | 2 1 1 0 C | 2 1 4 0 C | 2 1 4 0 C | 2 1 3 0 C | 2 1 1 0 C | 2 1 2 0 C | | | 2 1 1 0 C | |
| 6 NBS | 3 1 3 0 B | 3 1 3 N B | 3 1 1 N B | 1 1 1 0 B | 3 1 3 0 B | 3 1 3 2 B | 3 1 1 0 B | 3 1 1 N B | 3 1 1 2 B | 1 1 1 0 B |
| 7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES | | | | | | | | 3 2 3 0 B | | 3 1 2 0 B |
| 8 OoD & PRIVATE STANDARDS LABS | 2 1 2 0 B | 2 1 2 0 B | | | | 2 1 2 0 B | | | | |
| 9 OTHER FED. LABS (PRIMARILY NASA) | | 3 1 2 0 B | | | | 2 1 1 0 B | | | | |
| 10 PETROLEUM INDUSTRY | 2 1 1 0 D | | | | | | 2 1 1 0 D | | 2 1 1 0 D | |
| 11 MACHINERY GENERAL | 2 1 4 0 A | 2 1 2 0 E | 2 1 2 0 E | | | 2 1 2 0 E | 2 1 2 0 E | | 2 1 1 0 E | |
| 12 AEROSPACE AND AIRCRAFT INDUSTRY | 1 1 2 0 E | 1 1 3 0 A | | | | 2 1 2 0 E | 2 1 2 0 E | | | |
| 13 AUTO AND TRUCK INDUSTRY | 1 1 2 0 E | | 1 1 3 0 A | | | 2 1 2 0 E | 2 1 2 0 E | | | 2 1 2 0 C |
| 14 OTHER TRANS. EQUIP. R.R., MARINE, ETC. | | | | 1 1 3 0 A | | | 2 1 2 0 E | | | 2 1 2 0 C |
| 15 CHEMICAL INDUSTRY | | | | | 1 1 3 0 A | | | | ? | |
| 16 ELECTRICAL AND ELECTRONIC INDUSTRY | 2 1 2 0 C | 2 1 2 0 D | 2 1 2 0 C | | | 1 1 3 0 A | | | 2 1 2 0 C | 1 1 1 0 D |
| 17 FERROUS AND NON-FERROUS METAL INDUSTRY | 2 1 1 0 D | 2 1 2 0 D | 2 1 2 0 D | 2 1 2 0 D | | | 1 1 2 0 A | | X | |
| 18 RETAIL STORES, SURVEYORS, ENGINEERS, ARCHITECTS, ETC. | | | | | | | | 2 1 3 0 A | | 2 1 4 0 A |
| 19 FOREIGN COUNTRIES | 1 1 1 0 C | | X | | | 2 1 2 0 C | X | | 2 1 1 0 A | |
| 20 GENERAL PUBLIC | | | | | | 1 1 1 0 E | | | | 1 1 4 0 A |

KEY TO MATRIX ENTRIES




C - IMPORTANCE OR CRITICALITY OF TRANSACTIONS

1 = Purely matter of convenience
2 = Economically compelling; strongly desirable
3 = Legally required, alternate sources unsatisfactory
4 = Matter of life & death; sole source; essential

D - (IN)ADEQUACY OF TRANSACTION SERVICES

0 = No forseeable improvement needed
1 = Under control
2 = Marginally OK
3 = Seriously deficient
4 = Out of control

A - MAGNITUDE

0 = Trivial
1 = Minor
2 = Moderate
3 = Important
4 = Major

B - RATE OF CHANGE

N = Declining volume or needs
0 = Stable
2 = Growing
4 = Explosive growth or discontinuity on hand

X - TYPE OF TRANSACTION

A = End use measurement data
B = Other meas. services (e.g. calibrations)
C = Measurement instrumentation & associated software
D = Measurement "how-to" info
E = Measurement "needs" info

? = Don't know
X = Exluded from study

3728, 3761, 3764, and 3769. In the matrix, table 2-9, sector 12, Aerospace and Aircraft.
3721 - Establishments primarily engaged in manufacturing or assembling complete aircraft.
3724 - Establishments engaged in manufacturing aircraft engines and engine parts.
3728 - Establishments primarily engaged in manufacturing aircraft parts and auxiliary equipment.
3761 - Establishments primarily engaged in manufacturing complete guided missiles and space vehicles.
3764 - Establishments primarily engaged in manufacturing guided missile propulsion units and propulsion unit parts.
3769 - Establishments primarily engaged in manufacturing guided missile and space vehicle parts and auxiliary equipment.

Examples of users:

(1) In the inertial guidance system manufacturing process critical tolerances are placed upon the subassemblies. The gyroscope (gyro) rotor (ball in fig. 2-26) is suspended within an enclosure by static levitation and its center of mass is displaced from the geometric center. The rotor spins on the center of mass and its geometric center rotates about the center of mass in a circular plane perpendicular to the rotation. This mass/geometry center imbalance causes a sinusoidal voltage signal to be produced across opposite plates of the cavity. A 12 millionths of an inch displacement between the centers produces a signal resolvable to one part in ten thousand. Four such sine signals are produced by the cavity which give different phase angles and thus result in the gyro pointing signal.

Imperfections in the spherical geometry of the cavity and rotor affect directly the accuracy of the gyro. These imperfections can be corrected but usually airborne computer capacity is not large enough to accommodate all error analysis. During functional testing the gyro system "tests" the spherical perfection of these parts with a sensitivity beyond the ability of the manufacturer to measure dimensions. A special device for measuring these dimensions was constructed with a stated measurement sensitivity of $1 \times 10^{-7}$ inches, but the manufacturer's gage blocks calibrated at NBS failed to support the measurements.

(2) Jet engines periodically undergo extensive overhauls in which they are completely disassembled and examined to determine suitability for re-use. Jet engine blades are subject to extremely high stresses, and defects, such as cracks, can increase stress effects by many orders of magnitude. A typical jet engine contains over 1500 compressor and turbine blades. A current technique for automated inspection of these blades can detect cracks exceeding the design specification of 0.0005 inch wide by 0.002 inch long by 0.002 inch deep.

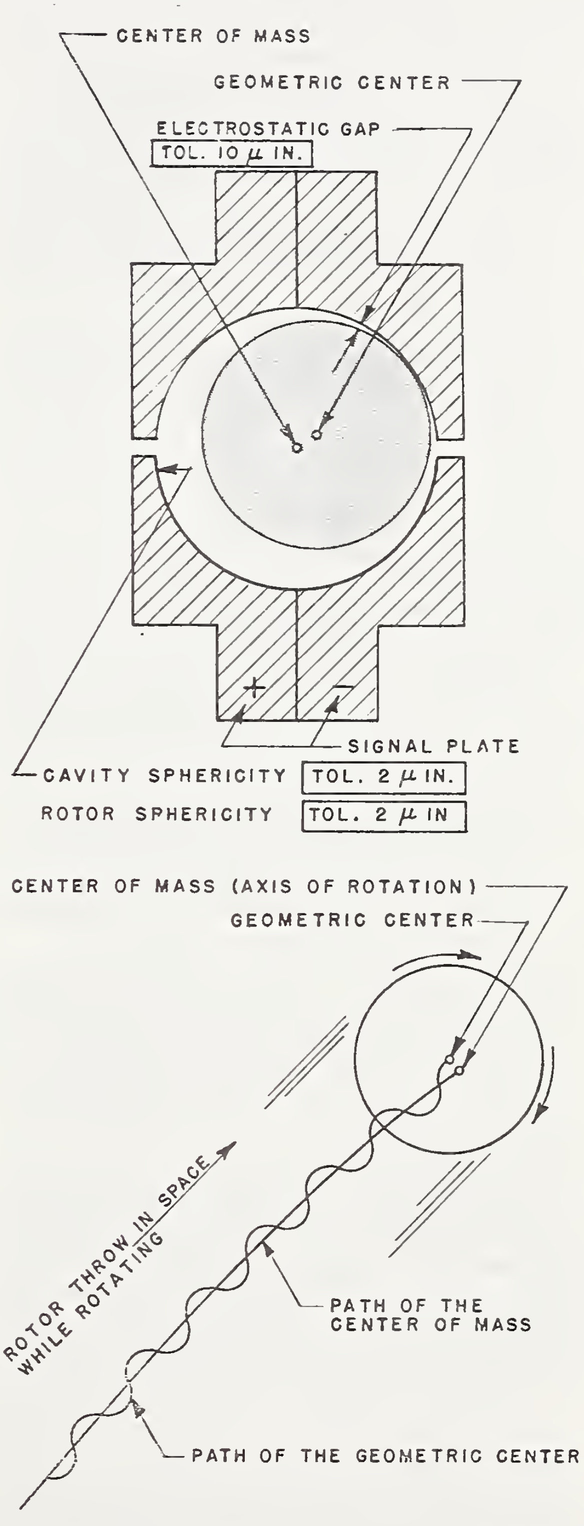



Figure 2-26. Example of dimensional measurements needed by aerospace industry.

Current Capabilities: In the period 1955-1964, the role of "accuracy" became disguised as a kind of culprit. Startling and expensive crises in industry developed - unprecedented rejection of products and system failures. In one case a series of failures in airborne hardware assemblies was traced to close cylindrical fits having a history of inconsistent measurement of component inside diameters. In another case a gyro producer found rejects soaring to 70% with a loss of thousands of dollars. In another plant failures in testing complex missile subassemblies ran into millions of dollars and were traced to a complex contour which was subject to measurement errors.

In recent years the mass production of modern ultra-precise equipment for measuring has become widespread. But in 1958 an Aerospace Industries Association (AIA) survey disclosed "variations totaling over 80 microinches on an identical inside diameter of a sample part, as measured by six of the most competent laboratories in the country, or 80 times the accuracy of the best gage block measurements of the period, with the best laboratories of the government and the gage manufacturers unable to agree to better than 70 microinches". A later AIA survey revealed that 44% of companies (representing 80 of the nation's most advanced firms) reported insufficient measurement accuracies on internal diameters below 0.250 inch.

Figure 2-13 (section 2.3) shows the accuracy requirements of the aerospace industry for their various length measurements, i.e., for measurement of 1 inch or smaller the accuracy required ranges from 100 parts/million to 5 parts/million.

Economic Impact: Current fiscal figures for the aerospace industry are shown in table 2-10 from the Bureau of Domestic Commerce. After serious setbacks in the last few years, internal cash flows are insufficient to support the high development costs of new programs.

Foreign manufacturers have under development major projects aimed at the markets of the late 1970's and early 1980's. In most cases the new foreign aircraft will have no direct competition from U.S. suppliers. Estimates of the total volume of airline equipment business in the 1974 - 85 period range from $55 billion to $148 billion.

### 2.5.2.2 Ball and Roller Bearings

Establishments primarily engaged in manufacturing ball and roller bearings and parts are classified in SIC code 3562. Sector 4, Machine Tool, in the Measurement I/O Matrix, table 2-9, includes this SIC category.

Table 2-10. Aerospace: economic trends and projections.

| | Value of Shipments (billions of dollars) 1974 | 1980 |
|---|---|---|
| SIC 3761 Complete guided missiles | | |
| Industry[1] | 3.950 | 5.100 |
| Product[2] | 3.600 | 4.700 |
| SIC 3721 Aircraft | | |
| Industry | 11.700 | 10.200 |
| Product | 9.000 | 8.500 |
| SIC 3724 Aircraft engines and parts | | |
| Industry | 3.410 | 3.240 |
| Product | 3.100 | 2.700 |
| SIC 3728 Aircraft equipment | | |
| Industry | 2.700 | 3.900 |
| Product | 3.300 | 4.900 |

[1] includes value of all products and services sold by establishments in this industry.

[2] includes value of products primary to this industry produced by all industries.

Sample Uses and Accuracies: Bearings are used in practically all mechanisms which incorporate wheel and shaft operations. The automotive industry is the principal consumer of bearings with farm and construction machinery close behind. Aerospace and makers of general industrial equipment also use ball and roller bearings. Extra-precision bearings are required for gyro applications and in one commercial version total clearance gaps are 2.0 micrometers.

Calibrated master balls are used as a standard for measurements of production balls by the ball bearing industry. The ANS Ball Standard B3-12-1964 defines master balls as "Master balls shall be made of steel, 64 Rc or higher with permissible diameter variation of 1/10 of the diameter tolerance per ball... or 0.000002 inch whichever is larger." Master balls are primarily used in comparator measurements of other balls which in turn are used to check production sizes.

Figure 2-14 (section 2.3) shows the accuracy requirements of the ball and roller bearing industry which is 100 parts/million for the smaller balls to 1000 parts/million for the larger ones.

Economic Impact: Shipments by the ball and roller bearing industry will climb to $1.5 billion in 1973 and estimates for 1980 are that SIC 3562 will be a $2.1 billion industry. Demand for high precision in bearings will continue as requirements of the computer and instrument, aerospace, construction machinery, and machine tool accessories become more stringent.

2.5.2.3 Gears

SIC codes 3714, 3751, 3728, 3462, and 3566 refer to gears for motor vehicles, motorcycles and bicycles, aircraft power transmissions, and other power devices which use gears. Sectors 11 - 12, of the I/O Matrix Machinery - General and Aerospace and Aircraft. Table 2-9 includes these SIC categories.

Today's production gears are expected to function quietly and provide long wear life. This requires that a gear be checked for dimensional accuracy and also for nicks and cracks. There are many types of gear checking machines on the market and a typical one will inspect a gear for size (to 0.0005 inch tolerance), length (to 0.005 inch), pitch diameter (to 0.003 inch), eccentricity (to 0.002 inch), and nicks (to 0.0005 inch).

The accuracy needs of today's production gears are being met adequately by many of the machines on the market. There are some who feel they have special needs that are not being met. (The Navy Department requires extremely quiet reduction gears for their nuclear submarines since the most reliable systems for the detection of submarines rely on sonic detectors. Quiet gears require more accurate gear tooth profile and better surface finish).

Total value of shipments for all the above SIC codes for 1971 was $24.2 billion. It has been estimated that the gear industry comprises approximately 3 - 6% of that total.

2.5.2.4 Geodetic Investigations

The field of geodetic sciences, for the purposes of this study, will be considered to encompass surveying, mapping, geodesy, photogrammetry, geodetic cartography, cadastral surveying, and engineering surveying and construction. Sector 18, Surveyors, Architects, Engineers, of the I/O Matrix (table 2-9) includes this field.

Construction people use linear measurement all day long, reaching for a rule, a tape, etc. For short distances, rules work well but for long measurements, tapes and electronic distance measuring systems are called for.

To obtain an idea of the number of engineer surveyors and land surveyors in the U.S., we contacted the American Congress on Surveying and Mapping in Washington, D.C. In the United States in 1971, there were approximately 15,300 active professional engineer surveyors plus some 14,800 land surveyors. It was estimated that each one uses one measuring steel tape and possibly two or three, so we have a range of 30,000 to over 100,000 steel tapes in use for land surveying purposes.

Accurate geodetic information is needed by many groups and individuals:

(1) Rural, urban, city, and regional engineers; planning, construction, and surveying groups.

(2) Automated transportation systems and other activities using addresses from geodetic coordinates.

(3) Federal work, including the surveying and mapping of the Geological Survey, the Forest Service, the Army Corps of Engineers, the Coast and Geodetic Survey and NASA.

(4) Surveys and planning for water resources, highways, and utilities.

(5) Mining and related engineering surveys.

(6) Scientific uses.

(7) Legal aspects.

Electronic distance measuring (EDM) equipment, optical reading theodolites, and small electronic computers are now commonly used by engineers and land surveyors. They easily obtain the needed accuracies ranging from one part in 10,000 to one part in 100,000, which requires that the accuracy of the basic control net (discussed in Appendix G "The North American Datum" by NOAA) approach one part per million.

An example of the accuracies of this EDM in the microwave (1,000 MHz to 10,000 MHz) region compared to surveyed distances by other means is shown in table 2-11.

The precision practicably attainable today in geodetic measurements on the earth's surface is about one part per million. This may well be the limiting engineering precision on such measurements for the next few years because this "limit" is imposed by problems of calibration and use of geodetic tapes and by the effect of the atmosphere on the propagation of an electromagnetic wave. The cost of making a measurement with tapes is three to four times that of the geodimeter traverse method. It is an easy measurement in the laboratory where vacuum and air paths can be readily compared to parts in $10^8$, but for very long distances, out of doors, the appropriate meterorological parameters must be measured at several points to obtain an average value for n to better than $10^6$. A method for sampling n continuously using a two-color (red and blue) geodimeter, (the difference between the optical paths observed for the two wavelengths is proportional to the index of refraction) achieved an accuracy approaching 1 part in $10^7$ over distances approaching $10^4$ meters.

Table 2-11. Typical measurements with EDM microwave ranging device.

RIDGEWAY BASE

| Line | Observer | Distance | Difference from mean |
|---|---|---|---|
| Whitehorse-Liddington | 1 | 11260.643 | -0.014 |
| Liddington-Whitehorse | 2 | 11260.653 | -0.004 |
| Whitehorse-Liddington | 1 | 11260.601 | -0.056 |
| Liddington-Whitehorse | 1 | 11260.660 | +0.003 |
| Whitehorse-Liddington | 2 | 11260.667 | +0.010 |
| Whitehorse-Liddington | 3 | 11260.702 | +0.045 |
| Liddington-Whitehorse | 4 | 11260.670 | +0.013 |
| | Mean | 11260.657 | |

| | | |
|---|---|---|
| Standard Error of a Single Measurement | 0.028 | 2.5ppm |
| Standard Error of the Mean | 0.011 | 1.0ppm |
| Difference from Catenary Length of 11260.677 | 0.020 | 1.8ppm |

CAITHNESS BASE

| Line | Observer | Distance | Difference from mean |
|---|---|---|---|
| Warth Hill-Spital Hill | 1 | 24828.706 | +0.135 |
| Spital Hill-Warth Hill | 2 | 24828.730 | +0.159 |
| Warth Hill-Spital Hill | 1 | 24828.728 | +0.157 |
| Spital Hill-Warth Hill | 2 | 24828.447 | -0.124 |
| Spital Hill-Warth Hill | 2 | 24828.452 | -0.119 |
| Spital Hill-Warth Hill | 5 | 24828.563 | -0.008 |
| Spital Hill-Warth Hill | 4 | 24828.396 | -0.175 |
| Warth Hill-Spital Hill | 2 | 24828.549 | -0.022 |
| | Mean | 24828.571 | |

| | | |
|---|---|---|
| Standard Error of a Single Measurement | 0.127 | 5.1ppm |
| Standard Error of the Mean | 0.045 | 1.8ppm |
| Difference from Catenary Length of 24828.633 | 0.062 | 2.5ppm |

An EDM has been tested on the Ridgeway and Caithness bases in the United Kingdom. The results obtained, and the comparison with the surveyed distances, are given in the table above. It should be noted that these figures have been checked and confirmed by the British Ordinance Survey. All distances are quoted in meters.

There is an excellent technology assessment "North American Datum" by the National Academy of Sciences and the National Academy of Engineering which discusses in detail why there is a need for more accurate measurements and readjustments of the North American Datum. We have been in contact with representatives at NOAA and they expressed a desire to work with NBS concerning the problem of calibration of EDM's. One of their concerns is that they have no simple way of verifying the index of refraction and would like NBS to set up a 4 - 5 Km (folded) baseline.

There exists some skepticism concerning the accuracy of electronic distance measuring systems under operational conditions. The practical operating range along a high-precision geodetic traverse is 15 to 35 Km. Recent measurements made over a taped baseline in New Mexico are as follows:

| | Instrument No. 155L | Instrument No. 441L |
|---|---|---|
| | 18,289.038 meters | 18,289.035 meters |
| | .041 | .038 |
| | .035 | .039 |
| | .048 | .046 |
| Mean: | 18,289.040 meters | 18,289.040 meters |

Taped length 18,289.046 meters

As to the economic impact of EDM's the Coast and Geodetic Survey in the past few years has completely converted to the use of EDM's for measuring distance. Tapes are only used for the calibration of these devices to the extent that the tape permits.

2.5.2.5 Integrated Circuit Industry

The semiconductor industry (SIC 3674) consists of establishments engaged in manufacturing semiconductor and solid state devices, integrated microcircuits, and transistors, etc. Values of shipments for the industry will total more than $1.675 billion in 1973, a 5% increase from 1972. (See Sector 16, Electrical and Electronic, in the transactions matrix, table 2-9).

A fundamental part of the IC industry is dimensional mask technology. A mask is a two dimensional array of patterns which must satisfy certain criteria to be useful in the manufacturing process of integrated circuits. The photoengraving masks which give the geometry definition on the silicon wafer are made through the use of high resolution photographic and photoreduction equipment, step and repeat camera, and precision drafting equipment. Using these techniques, a series of masks are prepared which define the areas for diffusion, contacts, etc. Each mask must be precisely registered with all of the others (there may be over 200), so that when the masks are superimposed, the registration between masks is kept within narrow tolerances.

One method used to produce a matrix of circuit patterns is the step-and-repeat process (fig. 2-27) which produces a two-dimensional array of images by a multiplicity of exposures. Each exposure forms one image. It is evident that the movement of the photographic plate between exposures must be done with great accuracy and, in fact, it is usually performed on an X-Y coordinate measuring machine. The lack of accuracy is unimportant as long as all masks are stepped on the same step-and-repeat system (lead screw errors are repeatable and will position the mask at the same place for each overlay). But when a manufacturer is using many repeaters then the problem of checking the output of these machines is complicated. One such example of checking the lines of a standard plate is shown in figure 2-19 in section 2.3 where three different measuring machines were used.

In modern microelectronics, complicated structures with very small dimensions must be fabricated on active-device materials. This task has been traditionally accomplished by photolithographic techniques but recently small dedicated computers have been interfaced with scanning electron microscopes for the purpose of generating, registering and fabricating microelectronic devices and cir-

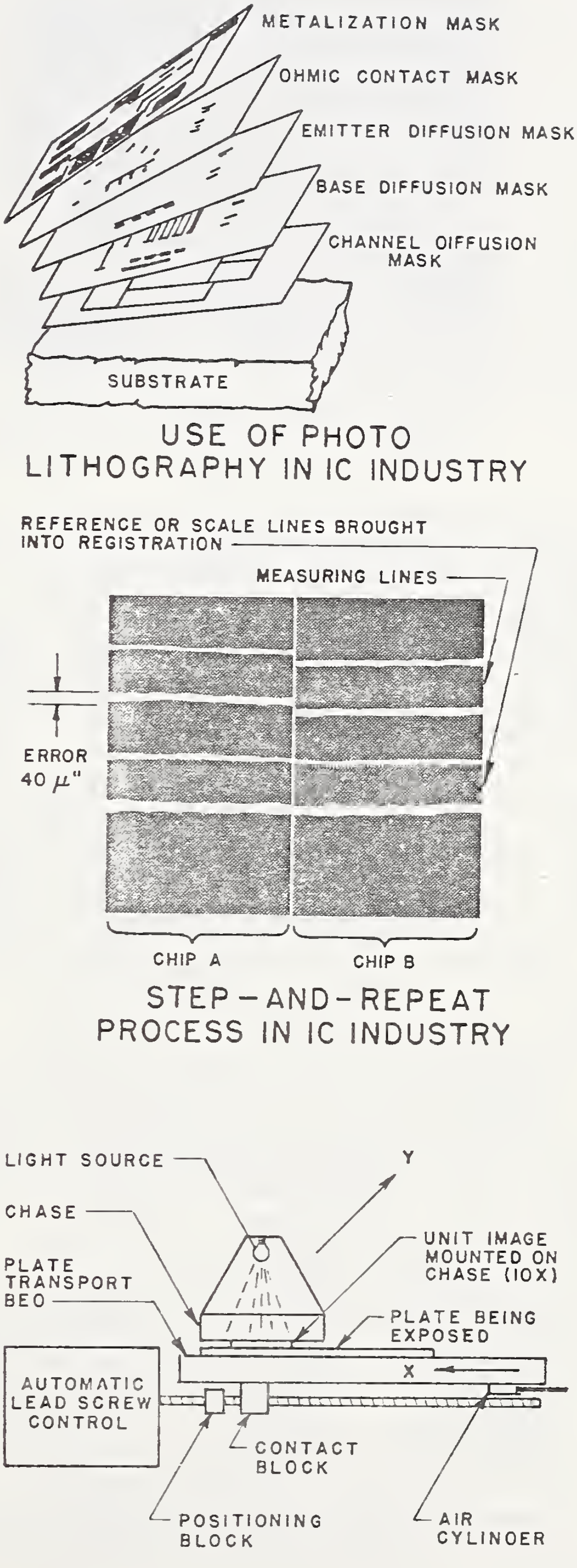



Figure 2-27. Photolithography and step-and-repeat process in IC industry.

cuit patterns with submicron dimensions. Registration accuracy of 0.1 micrometer over a $950 \mu m^2$ pattern field has been achieved [4].

A similar computer controlled electron beam machine automated for fabrication of microcircuits has been developed. Considerable time and effort is being expended by the various research laboratories to use the electron beam as a machine tool to generate more accurate lines, holes or shapes on a sub-micron level. At present these dimensions are approaching the optical limit of some of the most sophisticated measuring machines. New methods must be developed to accurately measure these microelectronic devices so that the manufacturer can correct errors before they become too costly.

### 2.5.2 6 Machine Tool Industry

The metalworking machinery and equipment industry (SIC 3541, 3542, 3544, 3545, and 3548) constitutes by far the largest single category user of length and dimensional measurements (see Sector 4, Machine Tool, in the transactions matrix, table 2-9). Values of shipments from these SIC codes industries should total more than $5.03 billion in 1973 an average of a 12% increase over 1972.

Increased demand for high accuracy in mass-produced machine parts has made it important for a manufacturer to have a working knowledge of his tools. The determination of the overall accuracy of the machine is important for:

(1) increasing productivity by producing less scrap,

(2) reducing inspection time because more parts will fall between the tolerance zones, and

(3) maximizing the full potential accuracy of the machine.

The machine tool and gage manufacturers use either the base units of the national measurement system and/or the base units of the SI system of measurement. A plug or ring gage or a measuring machine made by any gage manufacturer may be used to measure a ball bearing manufactured in another part of the country. For example, the bearing must fit on an axle made in Detroit, Michigan, which may have been measured by a gage made in Massachusetts. It may also have to fit into a wheel made in Ohio and measured by a gage or machine made in Providence, R.I. If the machines that manufactured the ball bearing, axle, and wheel were not closely tied into the National Measurement System through gages that were calibrated against the national artifact at NBS, chaos would result. If the gaging tools and measuring machines were not calibrated, interchangeability would be nonexistent. Mass production as it is known today would quickly come to a halt.

The tool and gage manufacturers must also adhere closely to the national standards issued through ANSI since the majority of tools and gages are purchased in accordance with an ANSI Standard. All ANSI Standards require that the tool or gage be compatible with the National Measurement System via a calibration chain to the national artifact at NBS. The transactions matrix shows that this category is a major user of NBS measurement services.

### 2.5.2.7 Marine Engineering

Establishments primarily engaged in the building and repairing of all types of ships are classified by SIC code 3731 (see Sector 14, Other Transportation Equipment, in the I/O Matrix, table 2-9). Dimensional measurements are important in all aspects of ship building, for example, vibration and noise in large reduction gears may be due to improper alignment or errors in roundness of the shafts running in the bearings.

The value of work done in ship building and repair yards on the U.S. mainland in 1973 is expected to total some $3.5 billion. This improved market has spurred R & D toward new production techniques such as welding technologies, automation, and the applications of laser technology for the alignment of hull modules.

### 2.5.2.8 Metrology

Next to the metalworking industry, the largest user of precise and accurate dimensional measurements exists within the metrological community. Dimensional metrology, in a broad sense, means the science of all measurements which are made by comparing the dimensionally measurable condition of an artifact to the unit of measurement (see sections 5, 6, 7, and 8 in table 2-9.

As shown in table 2-9, DoD and Private Standard Laboratories are very important users of NBS measurement services since it is the sole source for verifying their measurements against the national artifacts and it is the only means by which they can be sure that their measurement system is in control.

Metrology is invaluable to product design in the manufacturing realm because measuring techniques can be agreed upon to assure the designer that the product will be measured to meet functional requirements.

The metrological community has been thought of as maintaining the highest standards for accuracy and precision. We can show the approximate need for accuracy by figure 2-17 shown in section 2.3.

2.5.2.9 Petroleum Industry

One of the major users of accurate dimensional measurements is the petroleum industry. The industry uses threaded pipes in drilling for oil all over the world and the form and size of these threads must be controlled within tight limits. The threads must be able to withstand extremely large stresses and thus the need for accurate thread form is great. The SIC code for the establishments primarily engaged in manufacturing machinery and equipment for use in oil and gas fields is 3533 (see section 9, Petroleum Industry, in the I/O Matrix, table 2-9).

Sample Uses: Figure 2-28 is a photograph of some of the standard gages developed by the American Petroleum Institute (API) and used world-wide by the oil industry. A typical drill-stem assembly is shown in figure 2-29. Considering the large number of threads in an average oil well the importance of accurate dimensional measurements of the thread forms is easy to appreciate.

Specialized standards are seldom used in the Dimensional Technology Section at NBS with the exception of the following API standards:

(1) API STD 3 - API Specification of Cable Drilling Rods
(2) API STD 5B - API Specification for Threading, Gaging, and Thread Inspection of Casing, Tubing, and Line Pipe Thread
(3) API STD 5L - API Specification for Line Pipe
(4) API STD 7 - API Specification for Rotary Drilling Equipment
(5) API STD 11B - API Specification for Sucker Rods.

All applicable API components are manufactured to these standards. Regional and reference master gages' dimensions are measured by NBS in accordance with the limits set forth in the applicable standard. If the gage is within the acceptable limits, NBS issues a certification of that fact to the owner or manufacturer. If the gage is not acceptable, NBS notifies the owner or manufacturer and returns it for rework or replacement. NBS is the sole source, worldwide, for some of these measurements.

Economic Impact: The nations' demands for more energy has reached critical proportions in recent years. To obtain oil you must drill, of course, and to drill you need machinery and equipment. We can see the trend of SIC 3533 by looking at Census Bureau figures.

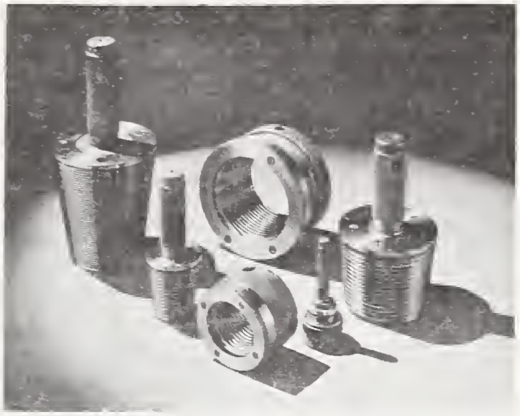


Figure 2-28. Standard gages developed by the American Petroleum Institute (API).

| SIC Code* | Value of Shipments (millions of dollars) | | | | |
|---|---|---|---|---|---|
| | 1958 | 1963 | 1969 | 1970 | 1971 |
| 3533 | 496.1 | 572.7 | 813.0 | 933.5 | 962.2 |
| 35531 | 222.0 | 217.2 | 322.8 | 372.6 | 376.5 |
| 35332 | 43.3 | 38.8 | 60.6 | 52.8 | 59.0 |
| 35333 | 175.4 | 261.4 | 308.4 | 355.1 | 360.6 |
| 35334 | 40.7 | 43.3 | 79.7 | 116.6 | 136.1 |
| 35330 | 14.6 | 11.9 | 41.5 | 36.4 | 30.0 |

*SIC codes are as follows:

3533 - Oil Field Machinery
35531 - Rotary Oil Equipment
35332 - Other Oil Drilling Machinery
35333 - Oil and Gas Production Machinery
35334 - Other Oil Field Machinery
35330 - Oil Field Machinery, not classified

Other data which are equally staggering is the large number of threaded pipes which must be produced to drill oil and gas wells. From the API Petroleum Fact and Figures we can obtain some interesting data on the number of wells drilled in 1968.

| | Number of Wells | Footage |
|---|---|---|
| Oil Producers | 14,227 | 58,817,277 |
| Gas Producers | 3,385 | 20,170,589 |
| Dry Holes | 12,987 | 64,737,319 |
| Stratigraphic and Core Tests | 876 | 1,039,909 |
| Service Wells | 1,439 | 3,279,504 |
| Total | 32,914 | 149,287,860 |

By assuming the average length of pipe tubing to be approximately 30 feet we begin to get a feel for the immense need of con-

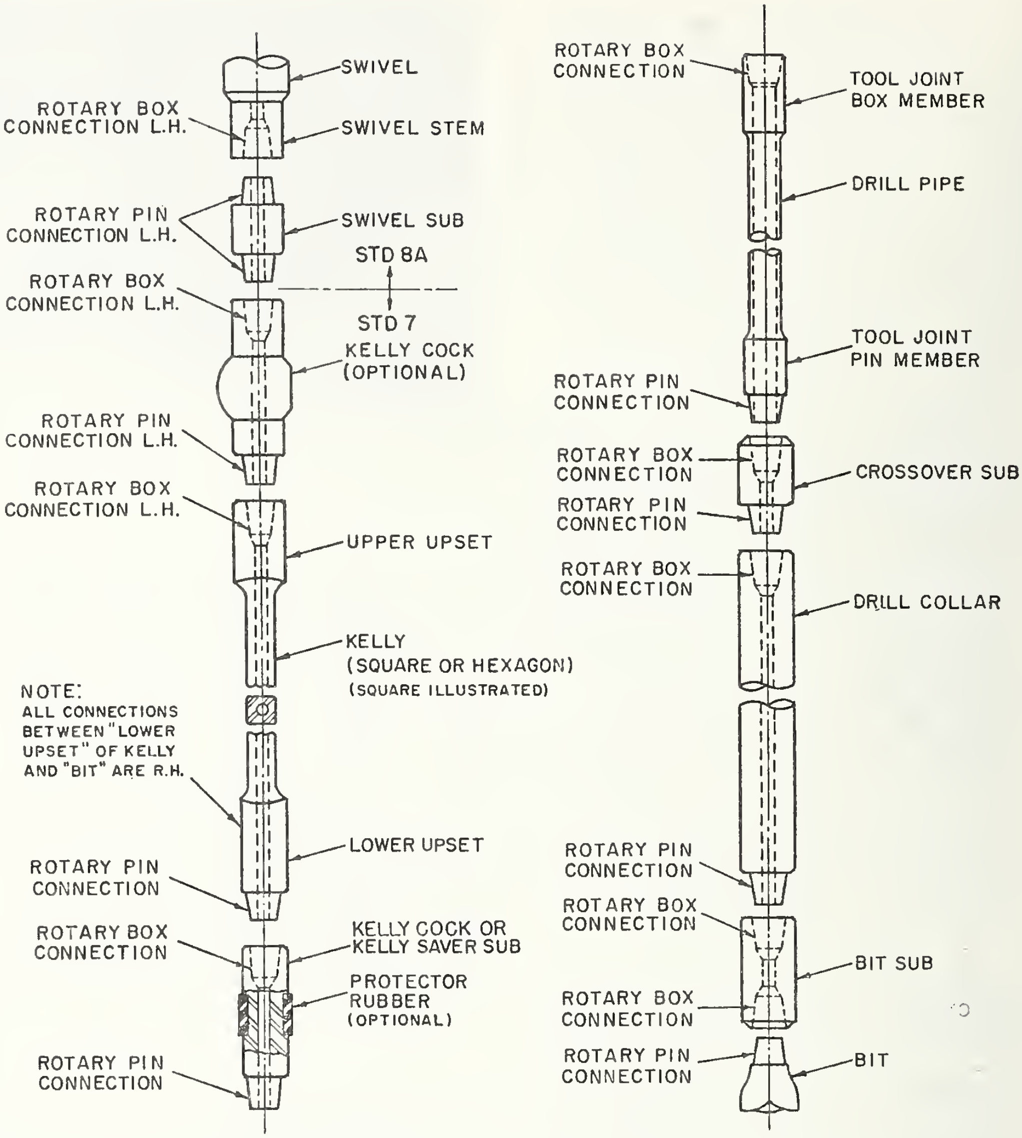



Figure 2-29. Typical drill-stem assembly for oil industry (from API Spec 7).

trolling dimensions on these items. (Over 6.4 million threaded components.)

In 1969 the total production of crude oil, natural gas, and natural gasoline was approximately $4.75 billion. The petroleum industry is dimensional measurement-intensive in a large subtle way.

2.5.2.10 Photogrammetry

Photogrammetry is the science and art of obtaining surveys by means of photography. The results of photogrammetry have second and third-order impacts on geology, defense, forestry, agriculture, and even archaeology and medicine.

The industry is quite large so a complete SIC code 3811341 was developed for photogrammetric equipment. It is included in Sector 3, Precision Instruments, of the I/O Matrix, table 2-9. The value of shipments for this industry was $5.9 million in 1967.

With the advent of coordinate measuring machines, photogrammetry has been advanced Large grids (X-Y coordinates) are reproduced on a glass and sent to NBS and other organizations for calibration and in turn are used within industry 3811341. It has not been possible for us to evaluate the impact of these devices upon that industry. Figure 2-18 in section 2.3 is from reliable sources.

2.5.2.11 Research and Development

The role of accurate and precise length

determination is varied in the field of R & D. In many cases the use of the value for the speed of light is the dominant factor in an experiment. Examples are: (a) ranging from the earth to the moon by use of lasers to obtain the distance to the retroreflectors left on the surface, (b) study of strain in parts of the earth's crust, (c) study of movements across geological fault lines to develop data bases for possible earthquake prediction, and (d) determination of fundamental constants, i.e. G, the gravitational constant, where the distance between two points has to be known to a high accuracy, and g, acceleration due to gravity, where a laser interferometer measures the drop of a retroreflector.

2.5.2.12 Screw Thread Industry

The screw machine industry (SIC 345) has been and is a major user of dimensional measurements. The form and size of threaded products must be consistent if any degree of interchangeability is to be achieved in our modern society. SIC 3451 comprises establishments engaged in manufacturing automatic or hand screw machine products from rod, bar, or tube stock of metal, fiber, plastics, or other materials. SIC 3452 comprises establishments primarily engaged in manufacturing bolts, nuts, screws, rivets, washers, and special industrial fasteners. This industry is included in Sector 4, Machine Tool, of the I/O Matrix, table 2-9.

Sample Uses: Dimensional control is an important aspect of the production of threaded parts. The function of a thread is to transmit a force, serve as a fastening agent or control displacement, e.g. move the table of a measuring machine. Thus we see that to ensure a consistent fit one must have dimensional control when the screw thread acts as a fastener. When the screw thread serves as a force transmitter dimensional control is still very important because sufficient mechanical strength is necessary to prevent failure and this strength is a function of dimensional parameters of the screw. If it is to be used to control displacement the pitch and/or lead must be accurate.

A simple example of measurements in the screw thread industry is shown in figure 2-30 which shows current practices for the measurement of pitch diameters for thread gages. The most notable work on screw thread standardization is NBS Handbook H28 Screw Thread Standards for Federal Services.

Economic: Recent figures for the fastener industry from the Census Bureau are shown at right:

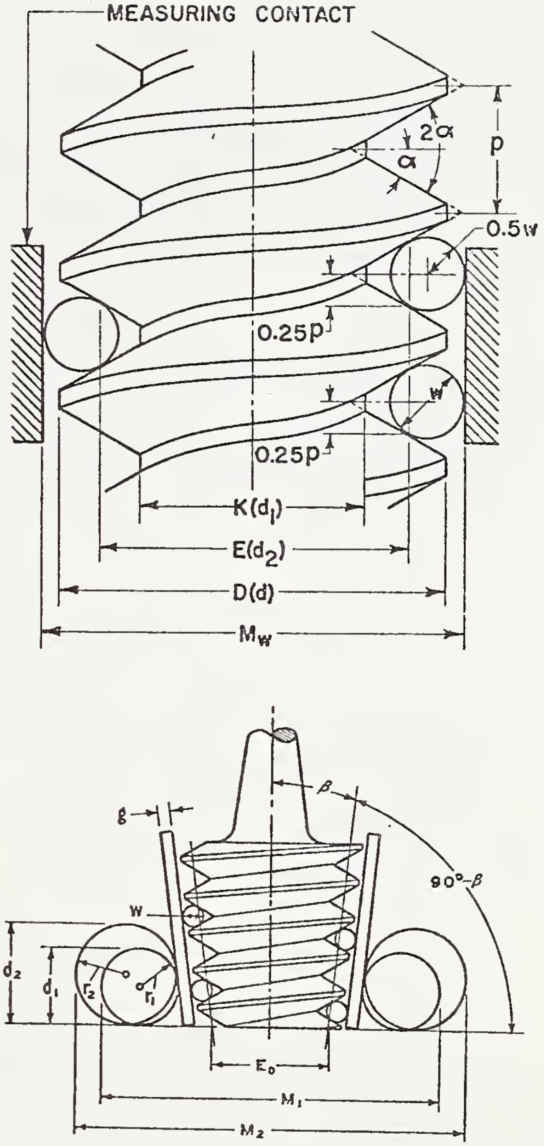



Figure 2-30. Example of measurements in the screw-thread industry.

| SIC Code | Value of Shipments (millions of dollars) 1963 | 1969 | 1970 | 1971 |
|---|---|---|---|---|
| 3451* | 588.9 | 1176.5 | 1088.0 | 987.6 |
| 3452* | 1218.2 | 1823.2 | 1617.0 | 1625.1 |
| 345 Total | 1807.1 | 2999.7 | 2705.0 | 2612.7 |

*SIC Code identification: 3451 Screw Machine Products and 3452 Bolts, nuts, rivets, and washers.

2.5.2.13 Watch Industry

The watch-making industry is a major user of dimensional measurements. When one considers the precision and craftsmanship which go into a modern watch, one realizes that tight tolerances must be held to produce a quality product. SIC code 3873 is for establishments primarily engaged in manufacturing clocks and watches. It is included in Sector 3, Precision Instruments, of the I/O Matrix, table 2-9. In 1971 the value of shipments of watches and clocks was $741 million.

This industry uses high grade micrometers of various shapes and sizes, precision dial indicators, toolmakers' measuring microscopes and projectors. Plug gages are used in the interest of speed and accuracy. The manufacturing interests are mainly in maintaining an "in-tolerance" condition rather than determining exactly where in that range the size falls.

#### 2.5.2.14 General Public

The general public, Sector 20 of the I/O Matrix, table 2-9, is a minor user of NBS measurement services. The Dimensional Technology Section has an open door policy which permits any qualified individual with a measurement problem to use our measuring equipment at no expense for a short period of time (2-3 hours). Since many of these measurements are unique, NBS gains an insight to some of the problems that the individual artisan faces when developing a new idea or product.

### 2.5.3 Summary Discussion of Major Users of NBS Services

The machine tool, oilfield machinery, chemical, and electronic computer industries are major users of NBS length measurement services. The accompanying table 2-6 shows the sales trends in these industries during the period 1967 to 1974. It is important that we talk about "real" growth, i.e. adjusted for inflation. Therefore, the numbers have been adjusted for a 7% annual inflation rate. When this is done, we see from the tables that:

(1) The oilfield machinery and electronic computer industries have had a real growth during the period 1967 - 1974.

(2) The chemical industry has remained flat.

(3) The machine tool industry has had a negative growth. We also include the sales figures for a "typical" machine tool company. It is obvious that its sales performance is significantly different from the industry as a whole. This raises two points: (a) the obvious fact that the performance of individual companies can depart significantly from the average, and (b) it may be that the four digit SIC code is an overly fine tuned method of reporting the sales in the machine tool industry. This company sells products which are not classified under SIC codes 3541 and 3542.

Table 2-12. Sales of a "typical" machine tool manufacturer 1967-1974

| Year | Sales ($ Million) | Sales adj. for 7% inflation ($ Million) | |
|---|---|---|---|
| 1967 | 32.9 | 32.9 | |
| 1968 | 33.1 | 30.9 | |
| 1969 | 32.0 | 28.0 | $\frac{30.1}{32.9} = 0.915$ |
| 1970 | 32.7 | 26.7 | |
| 1971 | 28.7 | 21.9 | |
| 1972 | 32.4 | 23.1 | -8.5% growth |
| 1973 | 39.8 | 26.5 | in 7 years |
| 1974 | 48.3 | 30.1 | |

(Data from Value Line Investment Survey 12/74).

## 3. IMPACT, STATUS, AND TRENDS OF THE MEASUREMENT SYSTEM

### 3.1 Impact of Measurements

That the meter is defined as 1,650,763.73 vacuum wavelengths of light resulting from the unperturbed atomic energy level transition $2p_{10}$-$5p_5$ of the krypton isotope having an atomic weight of 86, is of little concern to the person on the street. To be able to relate to a user of length and dimensional measurements is a task. The field is so vast that only a sampling can be taken. To do this we have assembled an array of numerous branches of industry which are likely to be concerned with accurate dimensional measurements. (See fig. 3-1.) This array contains firms, industries, and technologies which have large economic and social impacts upon the economy.

#### 3.1.1 Functional, Technological, and Scientific Applications

In the previous sections, many applications of length and related dimensional measurements have been discussed in context with specific industrial application areas, specific instrumentation, and the like. From these discussions, the following basic categories of functional, technological or scientific applications and their impacts can be derived:

Functional: Few people are interested in the spectral width or the coherence path length of the iodine stabilized Helium-Neon laser even though it is the *de facto* standard of length in the United States and is one hundred times more reproducible than the krypton line. Most people are interested only in the answer to the questions, "will it work?" and "am I getting my money's worth?" The largest volume of measurements

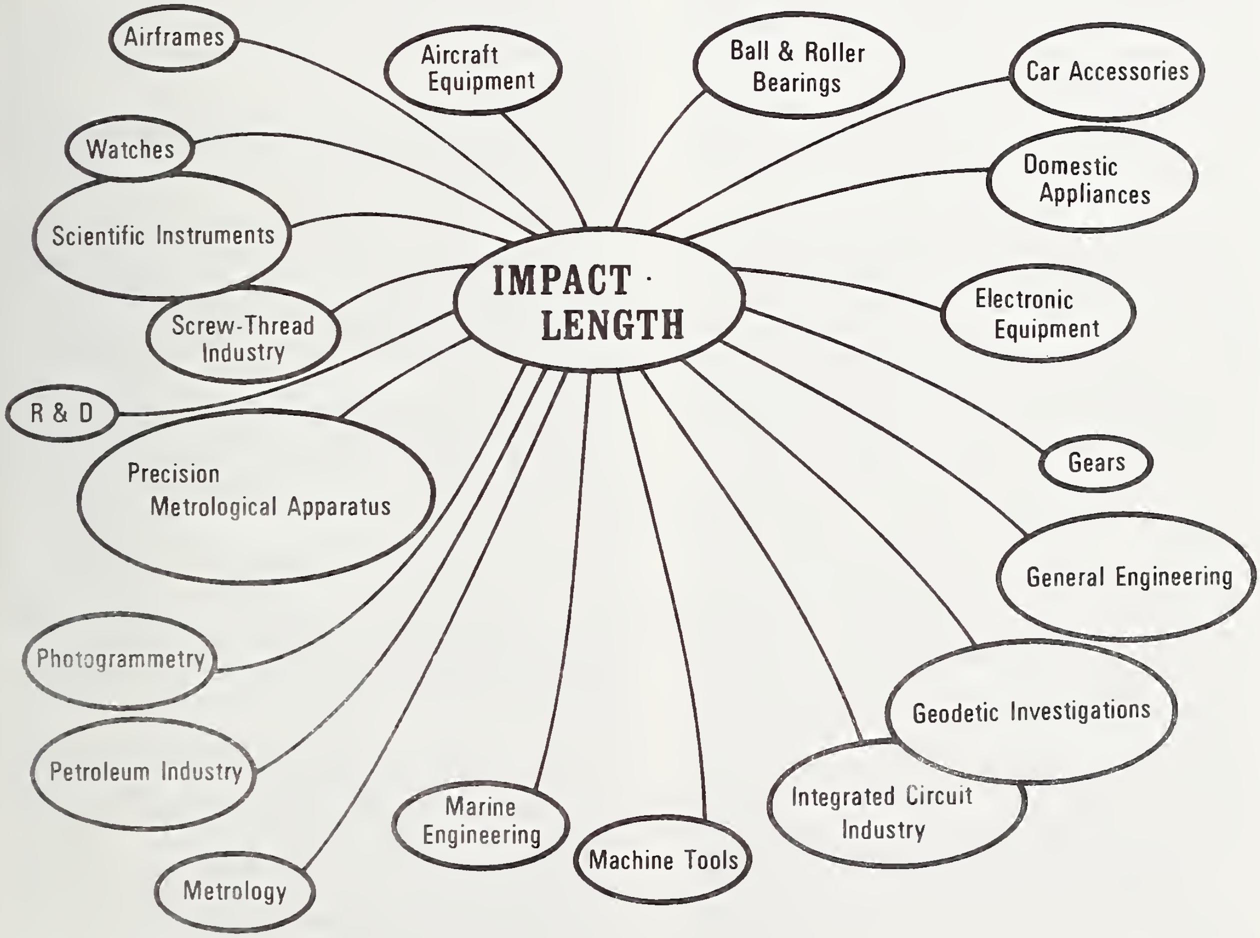



Figure 3-1. Impact of length.

falls in this functional category. An error of one percent in our length standard could mean a loss (or gain) of literally millions of dollars to the consumer. That this has not happened nor is likely to happen appears to be due not to the high precision of our ultimate standard but rather to the law enforcement arm of the office of Weights and Measures and the integrity of the American people. The National Measurement System must include a standard to which all other measurements can be referenced but to be most effective in this area, NBS should serve as its standardizing agency. It is of greater importance that all manufacturers make tile in standard sizes than whether or not an individual tile is 0.0001 inch longer or shorter than the nominal size. This can best be done on a voluntary basis but to serve as a catalyst and to protect unrepresented parties, the Bureau of Standards should take an active role in these voluntary standardizing groups.

Technologies: The problems are different in the high technology industries such as space and aircraft. In these industries, measurements of component parts are often needed to an accuracy comparable to that obtainable at the top measurement laboratories. The Bureau of Standards must maintain a technical proficiency to meet these needs by being able to make these measurements and by disseminating information or participating in cooperative programs that enable the companies to make their own measurements to the desired accuracy. There is a continuing struggle to keep up with design engineers who are now putting tolerances on gyroscope parts to a few microinches. The Bureau must not only keep up with industry but must anticipate future needs and be prepared to provide even greater accuracy.

Scientific: Avogadro's constant and the speed of light have recently been determined to an accuracy several times greater than the previous determinations. These advances were due at least partly to improved length measurement technology. The inability to make accurate length measurements has been the limiting factor for some time in obtaining more accurate values for several of the fundamental constants. Like much basic research, the impact on the economy or GNP of knowing a fundamental constant more accurately is often difficult to assess but the scientific community believes it to be a desirable and worthwhile goal and is also one of the tasks of the Bureau of Standards as defined by Congress.

### 3.1.2 Economic Impacts - Costs and Benefits

For clarity, the industry size and the importance of measurements for the various industries was discussed earlier in sec. 2.5.2.

### 3.1.3 Social, Human, Person-on-the-Street Impacts

The many industrial applications of length measurements obviously have major social significance. In addition, untold millions of length measurements are made daily by the various groups of people who have direct impact on our daily lives. Some of these groups are listed below:

(1) Architects
(2) Construction Industry
(3) Craftsmen
(4) Lumbermen (gaging diameters of logs)
(5) Homeowners
(6) Housewives
(7) Doctors
(8) Police Department Accident Crews (each car carries a measuring tape to see how far a car skidded, street widths, etc.)
(9) Printers
(10) Retail Stores
(11) Schools
(12) Surveyors
(13) Tank Gaging (tapes to gage the level of liquids in oil and gas tanks)
(14) Utilities
(15) Auto and Truck Drivers.

Thousands of individuals make daily length measurements without realizing that they are proving the viability of our National Measurement System. The housewife who measures the length and width of a window for a pair of curtains is not aware that the length of her cloth measuring tape or wooden yardstick is traceable to the national artifact at NBS, however remotely, in the same manner as the length measuring device used by the cloth manufacturer or seamstress. When a typist sets the margins on a typewriter, a length standard is being set to which all other typed lines are being compared. When a small boy stands back to back with his father to determine how much he has grown, he is measuring his length against a standard - his father.

If the organized National Measurement System were allowed to expire, the average person-on-the-street would in all probability not realize it for a period of 10 to 15 years. Sometime during that time he would find that some changes had occurred. For instance, the automobile mileage between Washington, D.C. and New York City was no longer 240 miles but was now measured by the auto odometer as 220 or 260 miles dependent upon the car he was driving - the difference being due to incorrect gear diameters in the odometer or to differences in tire diameters of "standard" tires made by various manufacturers, etc.

The automobile industry would probably be the first to notice that close tolerance parts were not assembling properly and that the gages used by the various parts manufacturers throughout the country were wearing at different rates. Since there was no national artifact to calibrate these gages, serious disagreements between supplier and user would result. The big "loser" would be the consumer who would receive inferior products at higher cost. Although such inconsistencies would be miniscule during the early years, over a long period of time chaos would result and industry would no doubt force the National Measurement System back into existence.

### 3.2 Status and Trends of the System

The status of the system has been discussed at length in other sections of this report. In summary, the system is under control, in a state of dynamic equilibrium. No major deficiences exist, but many improvements are being made as new technologies are applied to let "old" measurements be made with more precision, more accurately, more rapidly, more inexpensively, and in more detail. The true status of the system is best perceived by examining the current trends in the system. This is best seen by examining the current trends in instrumentation in the field.

We have developed the picture by looking through some of the current trade journals to get an overview of the new trends in instrumentation, gaging, and inspection which appear in them.

*Mechanical Engineering and Management* - August 1972:

"A new philosophy seems to be emerging in many production areas - to eliminate human intervention in making measurements and interpreting the results of those measurements as much as possible.

"Electronics - Air gaging is still around and is extremely useful but the current trend, even in companies that have made their reputations in air gaging, is to electronics. Because the price of electronics is coming down, it is now a matter of electricity versus compressed air and electronics usually wins because of its faster response time. Another reason for the trend is in in-process gaging, electronics has the capability to provide low magnification during heavy stock removal and high magnification in the finishing passes. This means that control of size has increased exponentially.

"Lasers and minicomputers - As in the fields of machine control, inspection and quality control have felt the impact of the laser and minicomputers. Examples are in surface plate calibration, roundness inspection, surface finish inspection, and measuring machines. Coupling the laser with a minicomputer has resulted in an entirely new concept of flaw detection in pipes and containers. It is designed to check not only surface finish, but is capable of detecting flaws such as scratches and holes. The system was designed for inspection of automotive cylinders and data concerning the three related parameters - flaws, surface finish, and holes - are printed out in ten seconds.

"Transducing - The next big breakthrough in gaging is likely to be in the transducer (gage head). Pratt and Whitney's Small Tool Division has been developing an entirely new concept to the transducer.

"Metrication - According to most manufacturers, the lethargy of Congress in passing the metric bill has had little or no effect on industry. Like it or not, the opinion is we're heading for a metric America."

*Iron Age*, October 25, 1973:

"A single-axis electronic inspection instrument reduces by as much as 80% the time required to accurately measure the height of an engineered part.

"...the instrument supersedes devices such as vernier and micrometer-type height gages, reference gage blocks, surface gages and precision squares.

"...was designed for use on conventional surface tables. It incorporates an 8-digit readout and offers repeatability to within 0.0002 inch."

*American Machinist*, October 15, 1973:

"Value engineering has been helped by metrology in this example where an air conditioner manufacturer that had previously purchased his refrigerant pumps decided to build them in-house. The company did not really know what was necessary to make a good pump but adopted the philosophy that 'the closer you measure prototype parts, the better you can evaluate design criteria and manufacturing techniques and the better you can plan for the critical production jobs'

"So what the air conditioning company did, in effect, was to temporarily hire a 25-man toolmaking and gaging shop to produce prototype parts, which could never be produced to the same tolerance (such as 50 millionths) on the production floor, and then to go through a program of dimensional and functional analysis to select critical dimensions and methods of producing and gaging them at a practical level."

*Bendix Technical Journal,* Summer/Autumn 1972:

"In addition to increased productivity, computer-based automation is resulting in high product quality, more efficient utilization of scarce natural resources....

"As the cost of... minicomputers continues to drop, it will be possible to identify an expanding set of cost-effective applications for automation in industry."

*Laser Focus,* January 1973:

"For industrial applications, sales of laser instruments will increase (in 1973) 19.5% to about $19.8 million... for such tasks as interferometry, alignment and testing. With tax incentives designed to encourage modernization of machine tools in the United States, industry officials expect a dramatic increase from the meager 2% that have precision numerical control - and therefore can justify interferometers."

*Laser Focus,* October 1973:

"As was the case two years ago, the principal military role of laser-related technology is to find a target by measuring its distance from a weapon, illuminating it, then guiding ordnance to it.

"These types of devices will perhaps spill over to the commercial sector. A system to be delivered to Wright Patterson Air Force Base for evaluating various types of tracking methods will be able to do ranging up to 20 miles."

*Optical Spectra,* May 1973:

"Constructing, mining and mapping are only three of the fields that have benefited from the introduction of laser distance-measuring equipment. It has been estimated that these applications currently may account for the single biggest share of the laser market (now a $216 million industry).

"The widespread conversion to EDM equipment by the surveying profession is a direct outgrowth of the demand for speed and reliability in meeting escalated topographical and construction requirements...

"Laser units have attained a dominant position in the field because of high measuring ranges and high reference accuracies."

*Hewlett-Packard Journal,* August 1970:

"Increased demand for high accuracy in mass-produced machined parts has forced the machine tool industry to rely less on the skill of the machinist and more on the accuracy of the machine tool itself. This has made it imperative that builders and users of machine tools continuously study and improve their tools' operating characteristics, particularly positioning accuracy.

"...the development of the laser interferometer finally provided the machine tool industry with a high accuracy length standard which could be used on machine tools of all sizes."

Conversation with Engineer at Cincinnati Milicron:

"Laser interferometers have revolutionized the measurement of distances in excess of two feet. We use four laser interferometer systems on the shop floor for production and testing in an automatic feedback loop."

Cincinnati Milicron is a company engaged in the manufacture of grinders, forming machines, lathes, and other machine tools (SIC 3541). Its annual sales are $25 - 50 million.

Trends in the screw thread industry are of particular interest at this time. In 1970, the members of the Industrial Fasteners Institute, a screw thread manufacturers' trade association, initiated a "Study to Optimize Metric Fasteners" because the US manufacturers want to export metric fasteners. The present ISO Metric Fastener System was not developed on sound engineering principles but was the result of many compromises from the existing unified inch screw thread standards and many national metric thread standards. All of these standards have one common fault - proliferation of sizes causing excessive stock inventories.

In May 1971, an ANSI Special Study Committee was organized and is known as the Optimum Metric Fastener Study, OMFS. Its objectives are technical improvements and the simplification of fasteners. The committee is working on a total system with dimensions and properties stated in metric units. The goal is the fewest possible sizes, series, types, styles, and grades. The committee activities cover product design, screw threads, form and dimensions, material performance, and inspection and quality assurance.

NBS has participated in this study (Appendix H) through one of its staff, who is a member of this committee. At their request, NBS gaged several hundred screws and nuts, of various sizes, selected randomly from several screw manufacturers to determine if the thread elements of these samples were within the limits specified by Handbook H28, Screw Thread

Standards for Federal Services. The data from this sampling will be used by the Committee to determine the thread tolerances for the proposed Optimum Metric Screw Thread System.

# 4. SURVEY OF NBS SERVICES

## 4.1 The Past

In this section we will mention four past developments in length measurements at NBS. The first is the line scale interferometer designed and built at NBS. Using lightwaves from a laser source, the instrument measures line standards directly in lengths up to one meter and achieves an accuracy of about 1 part in $10^7$ [5].

The second development was the computerizing of gage block calibration data in 1958 to 1959. Both mechanical and interferometric measurements were programmed.

The third development was a program to improve the stability of gage block materials. This was a cooperative program between the Metrology and Metallurgy Divisions. Improved metallurgical techniques made gage blocks more stable. As of 1960, three sets of gage blocks from two materials were developed which showed a dimensional stability of $2 \times 10^{-7}$ in./in./year over an observed period of one year.

The fourth development was the NBS-Meggers Standard Mercury 198 Lamp, created by Dr. W. F. Meggers and initially distributed in 1951. These lamps were capable of calibration to a precision of 1 part in 100 million, as opposed to the 1 part in 10 million possible with the standard meter.

## 4.2 The Present - Scope of NBS Services

### 4.2.1 Description of NBS Services

The Dimensional Technology Section of the NBS Institute of Basic Standards carries out the Bureau's function in developing an adequate system of physical measurement for length and related dimensional measurements and in providing calibration services for related industrial, military, and governmental standards. Its staff continually reviews the advances in science and trends in technology and uses these to devise new measuring devices and measurement techniques. A continuing program is under way to extend the range and improve the accuracies of all length related measurements.

The principal emphasis is on the calibrations requiring such accuracy as can be obtained only by direct comparison with NBS standards. Test of measuring instruments to determine compliance with specifications or claims are made when the evaluation is critical in national scientific or technical operations and when suitable facilities are not available elsewhere. Referee tests are also made in certain cases when clients are unable to agree upon the method of measurement, the results of tests, or the interpretation of these results. The parties must agree in advance to accept the findings of NBS.

### 4.2.2 Users of NBS Services

The principal users of NBS length calibration, consultant, and advisory services are the Department of Defense Primary Standards Laboratories, gage manufacturers, commercial standards laboratories and various industrial laboratories. These laboratories send in their primary standards for calibration and then use these data to check their working standards.

In the appropriate parts of section 4.3 there are several tables which contain a comprehensive listing of customers who required some form of length calibration during the past few years.

### 4.2.3 Alternate Sources

There are many private standards laboratories that will calibrate industry standards such as gage blocks, angle blocks, optical flats, etc. for a fee. These laboratories use standards that are routinely checked against the national artifacts at NBS. Since the calibration services at these laboratories are continuous and could be called mini-production, the fees for their calibration services are always less than those at NBS. Many of the large corporations maintain their own standards laboratories but not all of them will perform calibrations for anyone outside the corporate structure. A partial listing of some of these industrial laboratories is shown in Appendix F.

The DoD also maintains its own standards laboratories. The labs calibrate the primary and secondary standards used by the military. Again the standards used by the primary DoD labs are routinely checked against the national artifacts at NBS.

### 4.2.4 Funding Sources for NBS Services

The fees charged for calibration of length and related dimensional standards are "incremental," i.e. the number of hours actually required to do the job including set-up time. No other source of funds is available to pay for this service. Research and miscellaneous brief consulting services (e.g. answering the mail and the telephone), are financed from congressional appropriations.

4.2.5 Mechanism for Supplying Services

NBS Special Publication 250 "Calibration and Test Services of the National Bureau of Standards" lists all of the calibration services provided by NBS together with the cost of each particular service. For a unique item not listed in SP 250, a special fee is mutually agreed upon after a discussion of the method and accuracy of measurement is determined between NBS and the user-usually by telephone or personal contact.

4.3 Impact of NBS Services

The impact which length and dimensional measurements have on various industries, technologies, and science has been discussed previously. What we now need is some methodology to document a portion of the NBS user category.

The Dimensional Technology Section at NBS has the responsibility for the NBS program in length and its associated quantities. Providing calibration services to the nation is a basic function of this section; therefore, it is assumed that this data and the customers we do business with would be a worthwhile data base. A comprehensive customer list for past years within certain areas of dimensional specializational was assembled. From this an analysis was performed of each company utilizing data contained in:

(1) Standard and Poor's Index of Corporations, and

(2) Moody's Handbook of Common Stocks.

When time permitted, the facilities of the library of the Department of Commerce were utilized.

It should be emphasized that this is only a preliminary analysis of our customers. We have attempted in all cases to obtain at least a 50% evaluation of all NBS customers to attain a reasonable sampling basis. Many of the customers which we do business with could not be found in standard reference texts (S & P, Moody's, Dun & Bradstreet) so we have begun other searches. One of the items which we are considering is a comprehensive computerized analysis of our customers using many SIC codes and other economic figures. The purpose will allow us to simply add new data every time a new company appears on our customer list. In many cases the NBS customer profiles which we have already made have been very informative.

4.3.1 Economic Impact of Major User Classes

For the purposes of our study, we have sought to obtain trends in the interpretation of our customers' Standard Industrial Classification (SIC) numbers instead of attaching significant weight to the individual numbers, since many of our customers are conglomerates.

4.3.1.1 Gage Blocks - End Standards

Table 4-1 is a listing of private sector customers who have sent gage block artifacts to NBS for calibration for the previous four years. (The DoD laboratories are not included in this list.) A decision was made to include several years in the base survey because some companies may send in items every other year and thus only a year's sampling would not have as much meaning. Figure 4-1 is a plot that shows the companies with the highest sales do not necessarily use NBS capabilities to any greater extent than do other firms.

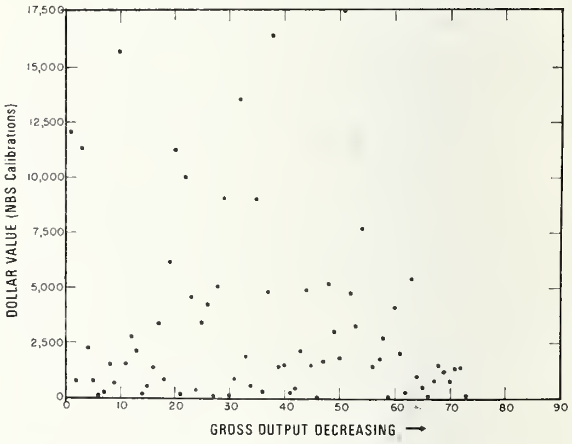



Figure 4-1. NBS customer profile - gage blocks, 74% evaluation - total value of NBS calibrations for companies 1970 to 1973 base period.

Figure 4-2 is an interesting diagram which is a plot of the frequency of listing of SIC codes (first two digits) for NBS customers. By far, the largest user is Division D - Manufacturing.

From the Standard Industrial Classification Manual, manufacturing is defined as: "...those establishments engaged in the mechanical or chemical transformation of inorganic or organic substances into new products, and usually described as plants, factories, or mills, which characteristically use power-driven machines and materials handling equipment. Establishments engaged in assembling component parts of manufactured products are also considered manufacturing if the new product is neither a structure nor other fixed improvement."

Table 4-1. Gage block - NBS customer list - including company name, annual sales and standard industrial classification (SIC) code number.

Aerojet Liquid
Air Research
AVCO sales $687.3 mil. SIC 3722,3662,4832, 4833,3522
Bell Helicopter sales $400-500 mil. SIC 3728
Bendix sales 1.599 bil. SIC 3729,3714,3599, 3651
Boeing sales $3.040 bil SIC 3721,1925,3729
Browne and Sharpe Mfg. sales $52 mil. SIC 3541,3494,3545
Bulova Watch sales $146.6 mil. SIC 3871,3651, 3679
Burroughs sales $932.7 mil SIC 3574,3573, 3579,3679,3955
C.E.J. Gage Co. (Subs Johannsen)
CPIC
Cincinnati Milacron Heald sales $25-50 mil SIC 3541
Clark Equipment sales over $741 mil SIC 2541, 2542,3322,3325,3444
Continental Machines sales $14-16 mil SIC 3545,3549,3561
Detronics sales $1 mil SIC 3678
Dial Indicator
Dupont sales $3.879 bil. SIC 2892,2821,2818, 2819,2815
Eastman Kodak sales $2.975 bil. SIC 3861,2821, 2221,2899,2281
Fairchild Camera sales $193.1 mil. SIC 3861, 3611,3679,8911,3674
Farrand Controls SIC 3679
Federal Products SIC 3545
Ford Motor sales $16.433 bil. SIC 3711,3712, 3713
Freeland Gauge sales over $1 mil SIC 3829
General Dynamics sales $1.812 bil SIC 3721, 3731,1925,3661,3679
General Electric sales $9.425 bil. SIC 3634, 3741,3621,3511,3651
General Instrument sales $275.9 mil. SIC 3674, 3673
General Motors sales $28.624 bil. SIC 3711, 3632,3585,3639,3741
Global Associates sales $40-50 mil. SIC 7399
E. Gottschalk sales $17-20 mil SIC 5311
Hughes Aircraft SIC 1925,3674,1941,3573,3611
IBM sales $8.274 bil SIC 3662,3573,3679,3572, 3579
IMI Metrology
Inspection Control
Intergraphic
Keuffel and Esser sales over $56 mil. SIC 3811
Litton Industries sales $2.446 bil SIC 3573, 3651,3579,3821,3679
Lockheed Aircraft sales $2.852 bil. SIC 3721, 3679,3731,4171,1925
MTI Corporation
B.L. Makepeace SIC 2752,3861,3952
David W. Mann (Div GCA Corp) sales $22.1 mil. SIC 3811,3831
Marquardt Company
McDonnell Douglas sales $2.069 bil SIC 3721, 3679,1925
C. W. Menard
Metrolonics
Minnesota Mining & Mfg. sales 1.6 bil. SIC 2295,2299,2641,2899,3042
National Astro Labs (Subs Comtel) sales $1 mil. SIC 7391
North American Rockwell sales $2.4 bil. SIC 3566,3552,3732,3565,3811
Paper, Calmenson and Co. SIC 5091,3441,3542
Philco Ford sales $900 mil-1 bil. SIC 3651, 3632,3585,3631,3662
Pratt and Whitney (Subs. Colt Ind.) sales 707.3 mil. SIC 3541
Quality Tool Supplies
Rank Precision (Subs Rank Org. Ltd) sales $142 mil SIC 7813,7011,3651,5099
Raytheon sales $1.2-1.3 mil SIC 3671,3673, 3679,3612,3693
Sanders Associates sales $100-200 mil. SIC 3494,3662,3811,8911,3679
Size Control (Div AM Gage & Machine) SIC 3545,3541,3729
Southern Gage
Sperry Rand sales $1.823 bil. SIC 3522,2531, 3569,3566,3621,2623
Standard Gage
L. S. Starrett sales $25-30 mil. SIC 3999, 3544,3545
TRW Systems SIC 8911
Taft-Peirce Mfg. SIC 3541,3544,3545,3599
Taper Micrometer (Div. IMC Elect.) sales below $1 mil SIC 3545,3841
Teledyne sales $214 mil SIC 1382,3399,3499, 3674,3699,3722
Thiokol Chemical sales $215.7 mil SIC 2822, 3722,2821,3079,2818
Timken sales $250-400 mil. SIC 3562,3313,3532
Turman Construction
Ultralab
Union Carbide sales $3.037 bil. SIC 3624, 2819,2821,2833,3679
United Standard
Van Keuren sales $1-3 mil. SIC 3545
Veritek
Western Gear Sales $90-120 mil SIC 3391, 3729,3312,3555,3551
Westinghouse sales $4.63 bil SIC 3613,3534, 3622,3631,3632

Note: The sales figures are from Standard & Poor's Corporation Register, 1973.

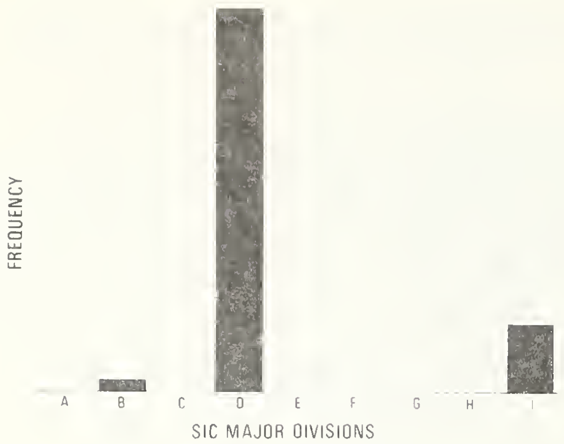



Figure 4-2. NBS customer profile - gage blocks, 74% evaluation - frequency of listing of SIC codes.

In the United States the manufacturing sector accounts for approximately 40% of the gross national product (GNP). (1973 GNP was $1.27 trillion). Many manufacturing products and services are produced to exacting shapes and sizes, therefore accurate control of dimensions is necessary. Since many of these products and services are exported and thus enter into foreign countries, the need for tight control becomes more apparent.

We may consider the other major groups of figure 4-2, such as B and I, as "residuals", and these may have significance as second and even third-order impacts upon the economy. A tentative observation for major group "I" is that this group includes establishments primarily engaged in rendering services to individuals and business establishments, such as medical, legal, engineering, and other professional services; educational institutions; and other miscellaneous services.

Figure 4-3 and figure 4-4 are more complete analyses of the NBS gage block customers in that the major divisions (D & H) of figure 4-2 have been broken down into two and three-digit SIC codes.

We will analyze the most requent listing of SIC codes from figures 4-3 and 4-4.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 36 | Electrical machinery, equipment, supplies |
| 2 | 35 | Machinery, except electrical |
| 3 | 28 | Chemicals & allied products |
| 9 | 37 | Transportation equipment and Ordnance and accessories |
| 1 | 367 | Electronic components and accessories |
| 2 | 354 | Metalworking machinery and equipment |
| 3 | 356 | General industrial machinery and equipment |
| 4 | 366 | Communication equipment |

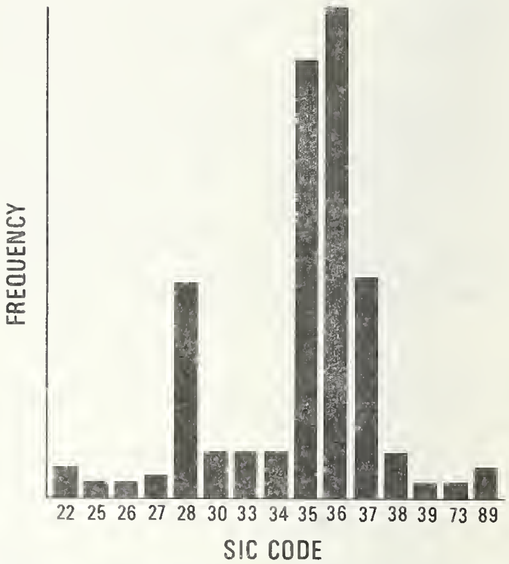



Figure 4-3. NBS customer profile - gage blocks, 74% evaluation - frequency of listing of SIC codes.

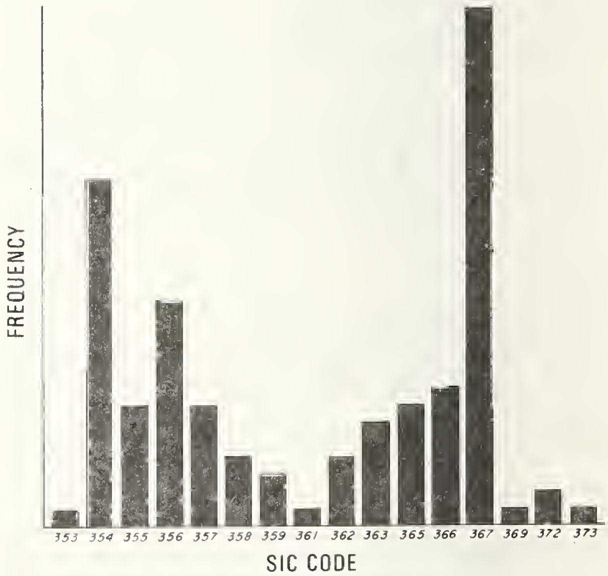



Figure 4-4. NBS customer profile - gage blocks, 74% evaluation - frequency of listing of SIC codes.


Figure 4-5. NBS customer profile - gage blocks, 74% evaluation - number of companies versus value of shipments.

Figure 4-5 shows that the value of individual company shipments for the customers of NBS gage block calibration services was from $.616 million to $14.5 billion. The total cost of NBS calibrations for these companies for the base years 1970-1973 was approximately $256,535 or roughly $64,133 per year.

4.3.1.2 Tapes - Line Standards

The Customer Profile for the area of steel tapes (linear line standards) is somewhat different. Table 4-2 is a comprehensive listing of NBS customers for the past four years, and we immediately see that the category of users is unique in that it includes almost all of industry as well as individual surveyors.

Table 4-2. NBS customer list - tapes.

Industry

Allied Structure
American Standard
Arbaugh Engr. Supply
Arco Pipe Line
Ashland Oil
Babcock & Wilcox
Michael J. Baker
Baker-Wibberley
Homer Banks, Jr.
Beatty Machine
Bechtel Corp.
Bethlehem Steel
Brandis Sons
Burgess Behr
Robert M. Case
Canton City Blueprint
Chicago Bridge Inc.
Chicago State Tape
Ciobra Spies
Colonial Hardware
County Engineering
John Davis
Davis Benoit
A. James DeBruin
Des Moines Steel
Eugene Dietzgen
Drago Supply Co.
J. J. Duenas
Henry Eagleton
R. P. Eastman
Eastman Kodak
Harold Eaton
R. H. Elrod Constr.
Evans Rule
Florida Level Trans.
Fort Pitt Bridge
Friedl Harris
Gandolfo Kuhn
Garcia Hancock
General Iron Works
Georgia Blueprint
Great Blueprint
Green Engr. Affil.
Green-Massman
H. Greenstreet
I. M. Greenwood
David Grimes
H. T. Hall Co.
Thomas J. Harris
Harman Construction
Hawaii Engineering
Hayevard & Paken
Peter B. Heidema
Highway Engineer
Hoffman Butler
Hubbill Roth
Illinois Regional Land Surveyors
Int'l Nickel Co.
Kansas City Steel
Keson Industries
Keuffel & Esser
Peter Kiewet & Son
Kral Zepl Frei
Kratzent Jones
Lakeside Bridge
G. W. Leach Co.
G. Lengemann Co.
Lietz Co.
Lockheed Shipping
Marke Lovejoy
Lowe Engineers
Lufkin
B. L. Makepeace
Charles Martin Insp.
Maxson Corp.
McGraw Edison
Measuregraph Co.
Charles W. Menard
Meridian Engineering
Midwest Surveyor
National Forge
National Surveying
Northern States
Nupla Corp.
Owen Steel Co.
PGH Des Moines
Paper Calmenson
Patton Harris
E. Lionel Pavlo
Pharmer Engr.
Kenneth B. Piper
Portland Precision
E. S. Preston, Assoc.
C. Marvin Raynor
Robbins Instrument
Justus Roe & Sons
Saltsman Constr.
D. L. Saundermann
E. W. Saybolt Co.
Schneider Technology
Schofield Bros.
Shea-Ball
Shell Oil Co.
Shephers Inc.
Andrew J. Shyka
Thorpe Smith
Southwest Tube
Spratt-Seaves
Standard Blueprint
Standard Oil (Ca.)
The Stanley Works
Stanislaus Co.
L. S. Starrett
G. A. Steadman
Stearnes-Roger
Steers-Kiewit
Sterling Maddox
Stone & Webster
Sun Pipe Line
Superintendence
Surveyors Instr.
Dean R. Swift
Swindell-Drift
Mrs. J. W. Teacher
Union Carbide
U.S. Industries
Warren Knight
Westinghouse
Whaling Ciry
W. S. Wilson Corp.
Windsor Power
Zenith Surveying

Government

Agriculture Dept.
Air Force
Army
Baltimore City
Baltimore County
California
Commerce Dept.
Defense Mapping
Georgia
Indiana
Interior Dept.
Iowa State Hwys.
Los Angeles County
Maine
Monroe County
Navy Dept.
Nebraska
Pennsylvania
Redwood City
Texas Hwys.
Town of Trumbull
Transportation Dept.
West Virginia
Town of Winchester

Educational

Oregon Tech. Inst.
Palomar College

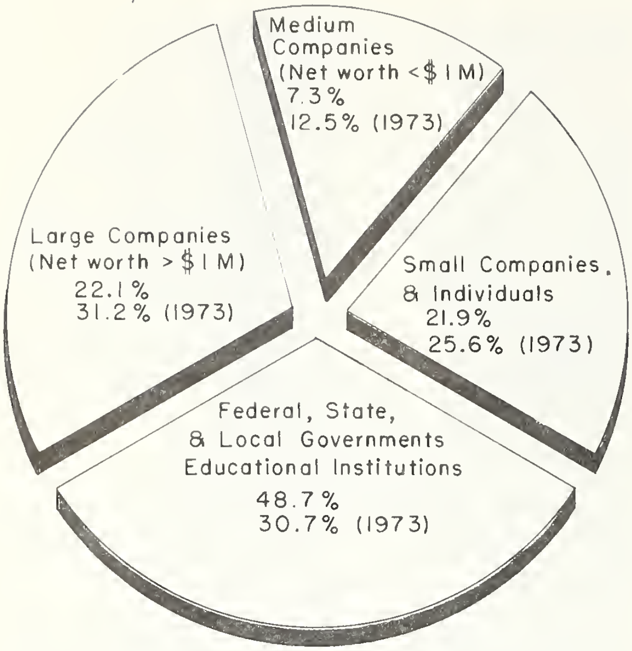



Figure 4-6. NBS customer profile - tapes, 46% evaluation - NBS total calibrations for system for years 70-73.

Figure 4-6 shows a breakdown into four parts:
(1) Federal, state, and local governments and educational institutions
(2) Large companies (those whose net worth is greater than $1 million)
(3) Medium size companies (those whose net worth is less than $1 million)
(4) Small companies and individuals (this is a general grouping of the companies not listed in either S&P, Moody's, or Dun and Bradstreet, plus indivuduals).

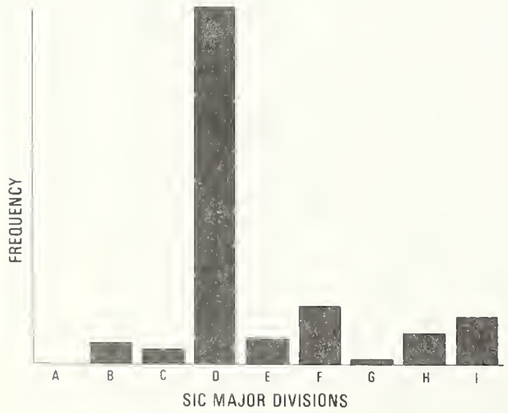



Figure 4-7. NBS customer profile - tapes, 46% evaluation - frequency of listing of SIC codes.

Figure 4-7 shows again that the predominant user of NBS tape calibration services is the manufacturing sector - Division D. But we now have customers from divisions (F) Wholesale and retail trade, (I) Government, (H) Services, (B) Mining, (E) Transportation, communication, electric, gas and sanitary services (SIC Code breakdown in tables 4-3, 4-4).

Table 4-3. Users of tapes other than industrial.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 34 | Fabricated metal products, except ordnance, machinery and transportation |
| 2 | 35 | Machinery, execpt electrical |
| 3 | 36 | Electrical machinery |
| 4 | 59 | Miscellaneous retail stores |
| 5 | 38 | Professional, scientific, & controlling instruments |
| 6 | 33 | Primary metal industries |
| 6 | 50 | Wholesale trade |

Table 4-4. Users of tapes other than industrial.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 344 | Fabricated structural metal products |
| 2 | 599 | Retail stores |
| 3 | 356 | General industry machinery and equipment |
| 4 | 342 | Cutlery, hand tools, and general hardware |
| 5 | 353 | Construction, mining, and materials handling machinery and equipment |
| 6 | 355 | Duplicating, addressing, blueprinting, photocopying, mailing, and stenographic services. |

Figures 4-8 and 4-9 show that the value product shipments in 1972 for the customers of NBS tape calibration services in the "medium-size" company category was from $3.9 to $36.2 million. The value of product shipments for the "large companies" who used NBS tape calibration services was from $4.625 to $13.805 billion for 1972 (fig. 4-10 and 4-11).

Other Line Standards: Tables 4-5 and 4-6 are lists of NBS customers of the line standard calibration service for the years 1970 - 1973. Figure 4-12 and figure 4-13 show the results of a similar analysis of the cutomer list and again we see the manufacturing sector is a large user of NBS services. Another class of

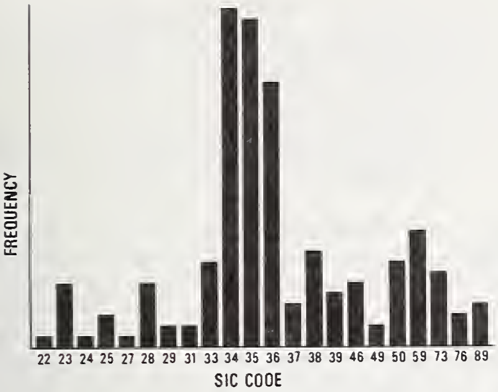



Figure 4-8. NBS customer profile - tapes, 46% evaluation - frequency of listing of SIC codes.

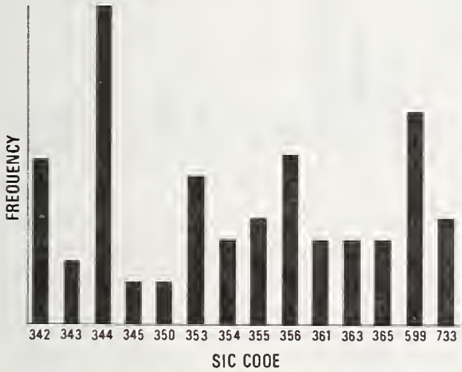



Figure 4-9. NBS customer profile - tapes, 46% evaluation - frequency of listing of SIC codes.

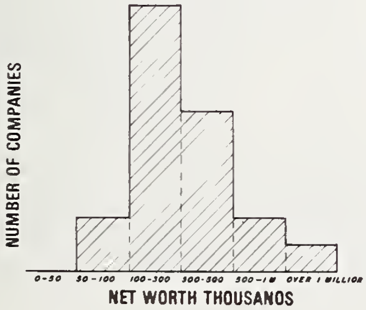



Figure 4-10. NBS customer profile - tapes cross section of "medium-size" companies.

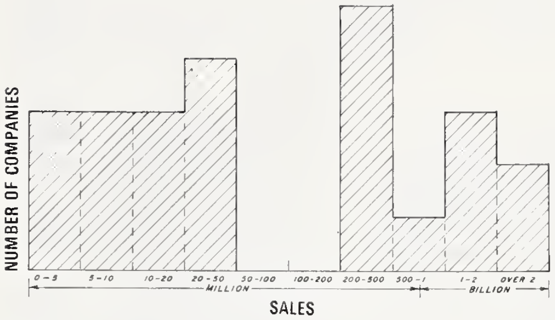



Figure 4-11. NBS customer profile - tapes cross section of "large companies".

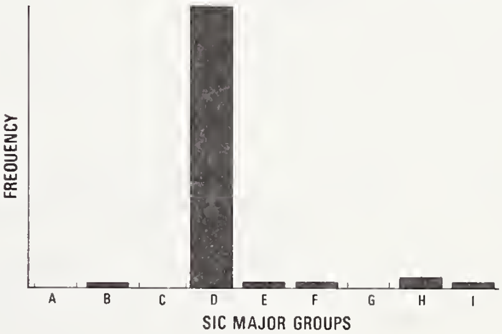



Figure 4-12. NBS customer profile - line standards, 46% evaluation - frequency of listing of SIC codes.

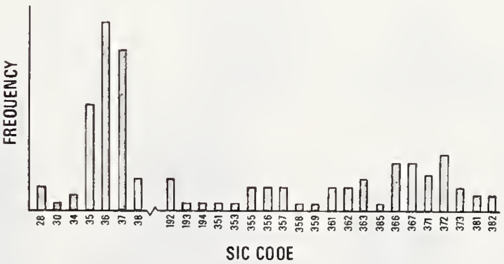



Figure 4-13. NBS customer profile - line standards, 76% evaluation - frequency of listing of SIC codes.

user is category I or federal, state, and local governments.

Table 4-5. NBS customer list for line standards.

| Industry | |
|---|---|
| Bendix | D. W. Mann Co. |
| Bliss Portland | Mark V Lab. |
| Brush Beryllium | McDonnell Douglas |
| Consul Metok Ltd. | Olympus Corp. |
| Dynamics Research | Opto-Metric Tool |
| General Dynamics | Rockwell Int'l |
| Hutchinson Ind. | Texas Instr. |
| IBM | Union Carbide |
| ITP Inc. | Western Electric |
| Lockheed Georgia | Westinghouse |
| **Government** | |
| Army | New State Standards |
| Illinois | |
| **Educational** | |
| University of California | |

Table 4-6. Users of line standards other than tapes.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 36 | Electrical machinery, equipment, & supplies |
| 2 | 37 | Transportation equipment |
| 3 | 35 | Machinery, except electrical |
| 4 | 348 | Ordnance and accessories |
| 5 | 38 | Professional, scientific, & controlling instruments |
| 1 | 372 | Aircraft and parts |
| 2 | 366&367 | Communication equipment, electronic components |
| 3 | 363 | Household appliances |
| 4 | 371 | Motor vehicles & motor vehicle equipment. |


Figure 4-14. NBS customer profile - line standards, 76% evaluation - value of shipments.

Figure 4-14 is illustrative that the range value of shipments of users of NBS line standard calibration services was from \$2 million to \$9.5 billion in 1972.

4.3.1.3 American Petroleum Institute (API) Gages

Table 4-7 is a comprehensive list of the customers who have used NBS calibration services for API gages for the past ten years. As in the previous cases, we utilized reference S & P and Moody's to research each company and break it down into its SIC component codes. Figure 4-15 is a compilation of these results and we see:

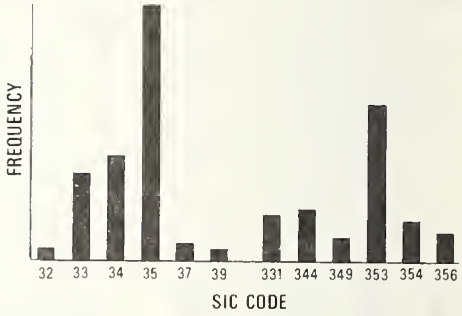



Figure 4-15. NBS customer profile - API gages, 65% evaluation - frequency of listing of SIC codes.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 35 | Machinery, except electrical |
| 2 | 34 | Fabricated metal products |
| 3 | 33 | Primary metal industries |
| 1 | 353 | Construction, mining, machinery & equipment |
| 2 | 344 | Fabricated structural metal products |
| 3 | 331 | Blast furnaces, steel workers, rolling and finishing mills |
| 4 | 354 | Metalworking machinery and equipment |

It is interesting to note that SIC 3533 occurred the most frequently at this four digit level (establishments engaged in manufacturing machinery and equipment for use in oil and gas fields).

Table 4-7. NBS customer list - API Gages

Acme Fishing Tool Co. SIC 3533,3391
ARAI Iron Works Ltd. Japan
ARMCO Steel Corp sales \$1 bil. SIC 3461, 3312,3533,3561,3323

Abegg & Reinhold Co. net worth over $1 mil. SIC 3533
Alameda Gage Co. net worth $75-125,000 SIC 3545
Baash-Ross(Div Joy Mfg) sales $200-235 mil. SIC 3536,3564,3561,3532
Baker Oil Tools Inc. sales $80-90 mil. SIC 3533,1389
Bucyrus-Erie Co. sales $100-150 mil. SIC 3531,3533
Brewster Co. sales $6-9 mil. SIC 3533,3323, 3553
Booz-Allen Applied Research Inc. SIC 7391
Creusot-Loire Div Material DeForage (France)
Canadian Reed Drilling Tools Ltd.
Coventry Gage and Tool Co. Ltd. (England)
Continental-Emsco Co.(Div Youngstown Sheet & Tube, SIC 2177
Drilco (Div Smith Int'l) sales $75-80 mil. SIC 3533,3449,3537
Dalmine Sp. A. (Italy)
Dover Corp. sales $162 mil. SIC 3599,3433, 3461,3533,3534
Dover Corp. (Canada)
Eastman Oil Well Survey Co. net worth over $1 mil. SIC 1381
George E. Failing Co. (Div Azcon Corp) net worth over $1 mil. SIC 3533
Grant Oil Tool Co. sales $5 mil. SIC 3533, 5084
Gardner-Denver Co. SIC 3332,3345,3339
Greenfield Components Corp. sales 1-3 mil. SIC 3999
Homco International Inc.
Hughes Tool Co. SIC 3533,3721,3531,3532
Hunt Tool Co. sales $10 mil. SIC 3533,3443, 3731
Hydril Co. sales $15-35 mil. SIC 3533,3494, 3443
Herramientas de Acero S.A. De C.V. (Mexico)
Harbison-Fischer Mfg. Co. sales $10 mil. SIC 3533,3561
Jones & Laughlin Steel Co. sales $950-1000 mil. SIC 3312,3491,3494,3317
Kuroda Precision Ind. Ltd (Japan)
Lone Star Tool Co. SIC 3533
Liberty Mfg. Co. of Texas net worth over $125,000 SIC 3533
H.E. Morris
Mannesmannroehrer-Werke A.G. (Germany)
National Standards Lab (Australia)
U.S. Steel Sales over $1 bil. SIC 3312,3315, 3316,3441,3443
Pratt & Whitney (Subs Colt Ind.) SIC 3541, 3545
Pipe Machinery Co. sales $6-8 mil. SIC 3541, 3542
Reed Tool Co.
Star Iron Works SIC 3591
Smith Tool Co. (Div Smith Int'l) sales 75-80 mil. SIC 3533,3449,3537
Soc. P. AZ. James Massarenti (Italy)
Southern Gage Co.(Div. N.A. Woodworth) sales $6-9 mil SIC 3545,3544
Spang and Co. SIC 3533,3297,3295,3341,3441
Steel Co. of Canada Ltd. sales $500-590 mil. SIC 3312,3316,3441,3498,3481
Texas Iron Works net worth over $125,000 SIC 3533
Tsukamoto Seiki Co. Ltd (Japan)
Uie-Division Marep (France)
Usine Metallurgique de Domine (France)
U.S. Ind. sales $1.2 bil. SIC 2311,2335,2337, 2341,2329
Alfred Wirth & Co. (West Germany)

Note: The sales figures are from Standard & Poor's Corporation Register, 1973. The net worth figures are from Dun & Bradstreet Reference Book, Jan. 1967.

4.3.1.4 Angular Standards

The category of angular standards includes angle blocks, polygons, indexing tables, angle generators, optical wedges and prisms. Table 4-8 is a listing of NBS customers according to uses of angle block calibrations, angle generators, polygons, autocollimators, and step mirrors and wedges. Figure 4-16 is a SIC code analysis of the users of angle block calibrations for industry. The most frequent occurring is SIC 36 - Electrical machinery, equipment and supplies.

Figure 4-17 is a similar SIC code analysis for other angular standards - polygons, angle generators, autocollimators, indexing tables, and step wedges, and mirrors. We again see that the most frequent are SIC 36 and 35.

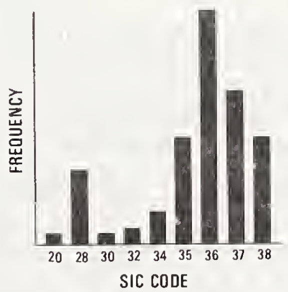



Figure 4-16

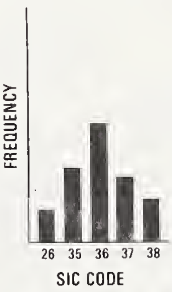



Figure 4-17

Figure 4-16. NBS customer profile - angle blocks - 93% evaluation.

Figure 4-17. NBS customer profile - other angular standards - 87% evaluation.

Table 4-8. NBS customer list - angular standards.

Angle Blocks - Industry

| | |
|---|---|
| Aerojet Liquid | IBM |
| American Optical | Kollmorgen |
| AVCO | LTV |
| Engis Equipment Co. | Lockheed Georgia |
| GTE Labs | Lockheed Missile |
| General Dynamics | McDonnell Douglas |
| General Electric | Rockwell Intl. |
| General Motors-AC | Sperry Gyroscope |
| Goltschalk Co. | L.S. Starrett |
| Hercules Powder Co. | Thiokol Chemical |
| Hewlett Packard | Timken Roller Bearing |
| Honeywell, Inc. | Union Carbide |
| Hughes Aircraft | Webber Gage |

Angle Blocks - Government

| | |
|---|---|
| Army Depot-Frankford | Navy-Newport, R.I. |
| Army-Redstone | Navy-NAB Norfolk |
| Dayton Air Force Depot | Navy-North Island |
| NASA/MSFC | Navy-Pensacola |
| Navy-ESL & WSL | Navy-Quality Assurance |
| Navy-Indianapolis | |

Angle Generators - Industry

| | |
|---|---|
| General Dynamics | Moore Special Tool |

Angle Generators - Government

| | |
|---|---|
| NASA | Navy |

Polygons - Industry

| | |
|---|---|
| Airesearch | Kollmorgen |
| Bendix | Philco Ford |
| General Dynamics | Rockwell Intl. |
| General Motors | Surface Finishes, Inc. |
| IBM | Union Carbide |

Polygons - Government

Newark Air Force

Autocollimators - Industry

| | |
|---|---|
| Bendix | Sperry Rand |
| Kaman Corp. | Texas Instruments |
| Rahn Granite | United Standards Lab. |

Step Mirrors & Wedges - Industry

| | |
|---|---|
| Barnes Engineering | Keuffel & Esser |
| Davidson Optronics | Union Carbide |
| GTE | |

4.3.1.5 Related Dimensional Artifacts

This category of NBS customers includes manufacturers and users of thread measuring wires, rings and plugs, roundness standards, gears, calipers, optical flats, penetration needles, balls, etc.

Table 4-9 contains an exhaustive listing of NBS customers in other dimensional areas for the past four to six years. Figure 4-18 is the result of compilation of the SIC analysis of companies who use the NBS optical flat calibrations services. Again the largest category is within electrical machinery, equipment and supplies. Figure 4-19 is an analysis of other users of NBS services for other related dimensional standards such as those listed in table 4-9.

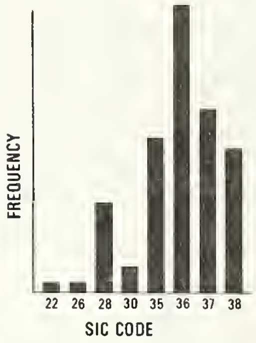



Figure 4-18

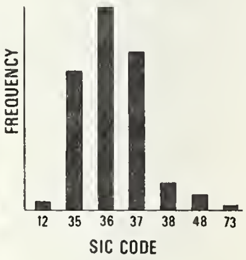



Figure 4-19

Figure 4-18. NBS customer profile - optical flats, 64% evaluation.

Figure 4-19. NBS customer profile other dimensional standards, 71% evaluation.

Table 4-9. NBS customer list - other dimensional standards.

Optical Flats - Industry

| | |
|---|---|
| A. C. Electronics | Hercules Powder Co. |
| Acme Scientific | Hewlett Packard |
| Advanced Optics | Honeywell |
| Aerojet General | Hudson Precision Optics |
| Airesearch | Hughes Aircraft |
| American Optical | ITE Circuit Breaker |
| Autonetics | Intl Optical |
| AVCO Corp. | Kollmorgen |
| Bausch & Lomb | Koppers Co. |
| Barnes Engineering | Korad Corp. |
| Bendix | Legensohn Intl. |
| Boeing | Lockheed |
| Buhl Optical | Martin Marietta |
| Chrysler | McDonnell Douglas |
| Continental Machines | McMann Optical |
| Cosmo Optics Inc. | Melpar |
| Crane Packing Co. | Memorex |
| Davidson Optronics Inc. | Minn. Mining & Mfg. |
| Dell Optics Co. | Muffolitto Optical |
| E & W Optical Co. | Northrop |
| Fairchild Ind. | Optical Coating Lab |
| Farrand Optical | Optic-Electronic |
| J. W. Fecker Co. | Orbitec Optical |
| Fensor Optics | Perkin Elmer |
| General Dynamics | Philco Ford |
| General Electric | Raytheon |
| Goerz Optical | |

| | |
|---|---|
| Sandia | Three B. Optical |
| Scheer-Tumico | Tinsley Labs |
| Space Optics | Union Carbide |
| Special Optics | Van Keuren |
| Speedlap | Webber Gage |
| Sperry Rand | Westinghouse |
| Starrett | Willey Optical |
| Surface Finishes | Wollensak Optical Prod. |
| Texas Instruments | Zygo |
| Thiokol Chemical | |

Optical Flats - Government

| | |
|---|---|
| Army-Redstone | Navy-ESL |
| NASA | Newark |

Roundness Standards - Industry

| | |
|---|---|
| Aerojet General | Hughes Aircraft |
| Airesearch | Natl Accelerator |
| Cincinnati Milicron | Rank Organization Ltd. |
| General Dynamics | Ringler-Dorin |
| General Motors | Rockwell Intl. |

Roundness Standards - Government

Army-Redstone

Gear Profiles - Industry

| | |
|---|---|
| Boeing | Landis Machines |
| Fellows Gear | Mich. Tool(sub. EX-CELL-O) |

Gear Profiles - Government

Army-Redstone

Calipers - Industry

| | |
|---|---|
| Chrysler | LTV Aerospace |
| Duluth | Tinius Olson |

Calipers - Government

State of Michigan

Penetration Needles - Industry

| | |
|---|---|
| AVCO | Humbolt Mfr. |
| Chunking Machines | Koehler Instruments |
| Comsat | Precision Scientific |
| General Dynamics | Van Keuren |

Penetration Needles - Government

State of Missouri

Balls - Industry

| | |
|---|---|
| Aerojet General | Mechanical Tech. |
| General Motors | SKF Industries |
| Hughes Aircraft | Sandia |
| Industrial Tectonics | Union Carbide |

Balls - Government

Navy

Thread Wires - Industry

| | |
|---|---|
| Airesearch | General Dynamics |
| Bendix | Hughes Aircraft |
| Boeing | LTV Aerospace |
| Bulova Watch | Lockheed |
| Deltronic | McDonnell Douglas |
| National Astro Labs | Trane |
| Pennoyer Dodge | Ultralab |
| Philco Ford | Union Carbide |
| Sandia | United Standards Lab |
| Size Control | Van Keuren |
| Teledyne | Westinghouse |
| Texas Instruments | |

4.3.2 Technological Impact of NBS Services

Detailed information on this aspect will be found in section 4.4, but in general there appears to be no great effect on technology because of or due to NBS services. Industry cannot use and does not require the accuracies to which NBS calibrates their standards. The greatest service NBS could supply to improve the technology of industry would be to provide more "cook books" or "how we do it" manuals for use by technicians.

4.3.3 Pay-off from Changes in NBS Services

With the acquisition of our large 3-axis measuring machine, we have been able to provide calibrations of large ball plates, 24 x 48 inches, for industry. By adapting a mini-computer to this machine, we have reduced calibration time for 12 or 18 inch step gages by more than 50% with a corresponding decrease in cost. By using laser interferometers as the measuring device instead of the machine lead screw we have increased the reported accuracy of our calibrations more than 50%. We are continually adapting more of our routine calibration work to use this computer-aided measuring machine. In the near future we expect that most of our API gage calibrations will be routinely made on this computer-aided machine.

4.4 Evaluation of NBS Program

One of the major advantages of this study of the National Measurement System for Length and Related Dimensional Measurements is the tremendous number of formal and informal contacts which we have established with other governmental agencies and the industrial sector. The major reason for these contact was not specifically to test our NBS model but to develop better ties with industry so that we might understand the "health" of the system, i.e., how well are dimensional measurements being made throughout the country? This is a difficult question to answer because as we have already pointed out, one must continually monitor the measuring process before one can be sure a measurement is being made.

Contacts throughout the industry were made by the following methods:

(1) An industry canvas and also telephone interviews with selected people,
(2) contacts with technical societies and/or publications in the area of interest,
(3) "Outreach" program,
(4) literature search for pertinent "round-robins" or audit packages.

4.4.1 Response to Questions in Industry Canvass

Question: If you use the services of NBS, please state in what way. Why do you use these services? Do you find these services adequate or inadequate? Plese tell how you feel these might be improved.

"NBS calibrates our grandmaster gage blocks which provide a double check on our own measurements and the NBS traceback necessary to conform to MIL and Federal Specifications. Service is quite adequate for our needs. We would like to see a precision of 0.1 millionth in measurements, but realize some limitations are in the geometry of the items being measured."

"NBS services provide us with traceable master standards for the calibration laboratories which insures a high confidence level of inter changeability of manufactured parts. NBS services have been adequate but could be improved by a reduction in turn-around time for calibrating standards."

"Use NBS for calibration to achieve traceability. Service adequate for our needs."

"Calibration of primary line scales. None of our customers know how to use you and might not anyway because of time consideration."

"Certifying and measuring steel tape - for 100(?) years. Service is slow."

"Masters calibration (blocks and wires). Also some use of NBS standards and literature. Service on blocks has been excellent. Wire calibration too undependable delivery wise, and too expensive."

"Gage block calibration for traceability. Assurance and forced by government regulations. Adequate but expensive."

Question: Do you feel that NBS gives enough assistance to various manufacturers around the country? Please explain how you think the situation might be improved?

"No. We believe this situation could be improved if NBS would become more involved in recommending specific measuring systems and techniques which would result in a finished product of a specified accuracy level."

"With new gage makers association, perhaps combined meetings in various regions semi-annually (or oftener) would be worthwhile."

"Most people do not know or understand the NBS role. Government regulations, as they filter down through channels, have a way of changing from original intent through human bias and become quite restrictive and burdensome to many. A good example of this is a change of a government inspector in your plant. The regulation did not change but the interpretation did. Cost consciousness seems to be lost in their dealings. Documentation rather than actual practice has more importance, regardless of cost of this documentation in relationship to its use."

Question: Are there any problems in your manufacturing processes where an improvement in the accuracy or precision or method of dimensional measurement might help raise productivity?

"Measurement processes are not now a deterrent to productivity."

"Generally, surveys have shown that adequate accuracy and precision has been available to meet our needs."

"No. At present there are some areas we could improve productivity by updating the equipment presently available but the economics don't justify equipment cost."

"...lead accuracy of screws. NBS could most likely help in the theoretical areas because you are staffed with brilliant men, but the actual solutions are practical resolutions with a resultant economical piece of equipment by industry. Accurate and precise non-contacting type of equipment that can be mounted on the manufacturing machine would be a Utopia!"

Question: If some of your personnel attended the NBS Dimensional Accuracy in Manufacturing Conference in 1972, what were their impressions? How could the conference have been improved?

"did not attend."

"...comments that the conference was educational but was conducted above his working level. The conference should be repeated regularly and either have professional metrologists attend or lower the level of the material presented."

"Varied. Any conference on your discipline is good. Especially interesting is the interface through questions after the lectures. One problem is that the mundane important items in every day life are not exotic enough to talk about. Many are involved with problems in the areas of .000050, and they hear laboratory talk of parts per billion. Some subjects are confined to specialized fields that do not have universal appeal. Feeling of some was that the subjects were of more interest to NBS in a laboratory field than to the attendees in the practical application of laboratory findings."

Question: Do you feel that if you had to "prove" the accuracy of your measurements in a court of law, you would have sufficient evidence to convince the jury?

"We have never had a court test. If necessary, we see no difficulty in convincing a jury because of our traceback and agreement with NBS measurements."

"We believe our measurement accuracy is provable since we maintain written records of the calibration of measuring devices and are able to prove traceability to NBS. Such proof is important to any manufacturer."

"Bureau masters. Traceability and current calibration reports on working masters, etc. Yes, we believe we could 'prove' our case."

"This would be very difficult. Would depend upon personalities. How could you avoid the twisting by a lawyer that the measurement has inaccuracies caused by the instrument, the operator, the product and the process? Your terminology alone of precision and accuracy and statistical means would be like Greek to the jury. The type of evidence would have to be plausible, easily understandable explanations. It would be difficult to prove that this particular article involved in fact did get measured under a sampling system, and even though it did not, that you have assurance that it, in fact, is a good article.

"In the present situation of our marketplace, we see no need for this proof."

Question: What type of training - seminars and/or publications would you like to see emanate from NBS in these areas of interest?

"Practical training in the use of general type of dimensional measuring devices with an emphasis on the expected accuracy when using a particular device. Example: Can you expect a measurement to be accurate to 0.0001 inch just because the readability of the micrometer is 0.0001 inch? Material should be personal and published in trade and management magazines."

"...capable of training personnel ourselves to meet present needs."

"How to make accurate optical length measurements. What to do - not simply what to avoid doing! Linear and angular encoder industry. Quality Assurance and Engineering."

"Available services to industry and civil engineer. With the advent of increased usage of metric, engineering associations should be advised of your capabilities to service metric graduated tapes as well as English. One factor that has reduced the Bureau's capability image is the continued cry for additional operating funds. Industry will add additional staff and equipment because of fear that (the) Bureau will not have enough capable operating personnell and equipment."

"Let *Quality Management* magazine and *ASQC* handle training (i.e., seminars at various colleges around country, etc.). Publish with society and *QM* magazine for best distribution."

"Accomplishment of reliable measurements in less time under practical conditions rather laboratory conditions. Most supervision gets quite a few magazines across their desk. This would be the best vehicle. Feel quite certain that *Quality Management & Engineering* would welcome Bureau articles. This seems to be quite universally read by those involved with measurements."

Question: What is your current concept of NBS? How do you visualize NBS as you think it should be?

"Our current concept is generally favorable with some qualifications regarding the fact that the cost of NBS measurements now often exceeds the manufacturing cost of the item to be measured. Our opinion on what NBS should be is that its activities should encompass: (1) measurement authority - (a) perform calibrations of primary standards only for gage block manufacturers, qualified commercial calibrating laboratories and government agency calibration facilities. Other than primary standards calibrations could be done by manufacturers or commercial labs, thus freeing NBS of expended costs in handling measurements that do not take full advantage of their abilities. (b) NBS should establish accuracy and precision standards, as well as methods of measurement for the calibration of primary standards and the instrumentation involved in such measurements. (2) Arbitration - In instances of stalemates in agreement on measurements between contractors and suppliers, NBS should be the arbitrator. (3) Research and Development - To continue to advance the state-of-the-art in instrumentation, methods of measurement and standards without the necessity of such programs being financially subsidized by private industry."

"We believe that NBS is responsible for providing the basic standards for the national measurement system. NBS should provide leadership and direction in national measurement problems such as metrication."

"Repository of standards. Far-out research projects. Promulgation of H-28 (and other reference material). Above are all necessary functions. Perhaps more practical application of theoretical to industries' needs and dissemination of those ideas into better media."

"Varied, from no concept through a government agency that is the final answer of what is standard to a group of dedicated, intelligent scientists who are working in laboratory conditions on very interesting subjects in basic research. They are splitting millionths while we are chasing tenths.

"We have standards organizations on top of standards organizations, and government agencies, establishing standards, and many times conflicting standards, on every aspect of our environment. We need a clearinghouse for these that is working closely with and a part of international organizations such as the *ISO*.

"The National Bureau of Standards should be a clearinghouse for these standards as well as physical standards."

### 4.4.2 Contacts with Technical and Trade Societies and Journals

We felt it might be desirable to contact pertinent journals and/or technical societies in the area of dimensional measurements and establish a dialogue with certain individuals within these organizations.

The Executive Editor of *Manufacturing Engineering and Management* was contacted and was extremely interested that we were interested in the problems of industry. "The image of NBS... could be enhanced by a concerted public relations effort. It needs to communicate better with the manufacturing community as to its ability, and desire to become more involved in the real world - beyond certifying the calibration of gage blocks. It is somewhat paradoxical to have to sell what you are prepared to give away, but I believe this to be critical to your effort."

The Associate Editor of *American Machinist* attended the Dimensional Conference in 1972, and we have had several telephone conversations with him since that time. He is, of course, close to the machine tool industry because of the nature of his magazine. His idea of more meaningful dialogue between NBS and industry comes under the heading of more and better organized symposia. In fact, the services of the McGraw-Hill Manufacturing Research Institute were offered in the area of questionnaires and seminar organization. He also commented in a recent letter that "our publisher (McGraw-Hill)... mentioned that we should improve our contact with NBS."

Another publication *Machine Design* was contacted for an analysis of their contacts with industry and the feelings of those contacts toward NBS. Their Technical Editor responded again that industry needs more exposure to NBS - its capabilities and resources.

In all of our encounters with the area of trade journals, etc. the editors have been extremely interested and willing to help in the dissemination of any material which we might develop.

Several individuals within the Society of Manufacturing Engineers (SME) were contacted and asked to explore with their associates the idea of our developing better ties in industry. Two volunteered to send out queries to various members with the intention of gaging feelings toward NBS and seeing if any measurement-intensive problems do exist in the areas under SME.

It is interesting to note that as a result of these queries, we received a reply from a manufacturer who was having extreme problems in areas of nondestructive testing of jet engine components. The problem revolved around detection of cracks, 50 microinches wide with a depth of four times the width, in a repeatable manner. A telephone conference was established and as more information unfolded, we were able to steer our contact to the appropriate man at NBS. Thus, from an inquiry made in one field, we were able to help another area in a measurement problem of vital importance for consumers who ride in airplanes.

The Director of the Technical Activities Division of SME was in contact with us recently and invited us to become familiar with the Inspection and Quality Control Division of SME. The Division is composed of the QC and Management subdivision, Inspection and Metrology subdivision, and Surface Integrity subdivision. The Chairman of the Division was contacted recently and informed of our studies. The Division is now in the process of being reorganized but we were invited to participate in the Division after it is reorganized. SME represents thousands of companies and this looks like a good opportunity for NBS to strengthen its contacts with industry.

The Executive Director of the American Society for Quality Control (ASQC) was also contacted. The ASQC is a technical society of more than 20,000 members engaged in the management, engineering, and scientific aspects of quality and reliability. There exists within the ASQC a metrology division and a chairman of a gage lab corporation was contacted to discuss any potential dimensional measurement problems. He had some definite ideas on how NBS could interact better with industry through practical seminars and workshops on topics such as the usage and capabilities of laser interferometers and various calibration procedures.

Other organizations we have contacted and are developing interactions with are: *The National Machine Tool Builders Association, American Ordnance Association, American Congress of Surveying and Mapping, MacCalester College* in St. Paul.

In the early 1960's, the Aerospace Industries Association, representing 80 of the nation's most advanced firms, surveyed industry concerning their measurement needs. To see if there were currently any measurement-intensive needs, we contacted the Washington headquarters of the AIA for information. We were informed that a standing committee was established and learned of the Chairman of the Quality Assurance Committee. We contacted him recently and learned he had been chairman for over 20 years. He was aware of many problems which were dimensional measurement-intensive back in the early 1960's but lately he has not received any calls concerning present or future needs.

4.4.3 "Outreach" Program

In the past few years, the management of the Dimensional Technology Section at NBS started to "reach out" to the outside world by sending personnel on fact-finding missions to various companies around the country. Anytime someone visited a part of the country on either personal or business reasons, the area is usually searched to find any interesting visits that might be made. Well over 50 personal visits have been made by NBS Dimensional Technology personnel or reciprocal visits by industry to NBS since early 1972. A brief chronology will give the reader an idea of the scope of our contacts. In many cases no earth-shattering needs were uncovered, but lasting contacts have been established.

(1) In 1972, a few members of the Dimensional Technology Section attended the American Ordnance Association meeting for the purpose of becoming better acquainted with members of that organization. Benefits derived from the meeting were familiarity with some of the measurement problems encountered in the ordnance areas and getting to know various individuals.

(2) In the Fall of 1972 we attended the International Machine Tool Show in Chicago sponsored by the International Machine Tool Builder's Association. 1972 was the first year for the show to go international in scope and over 70,000 people attended. This provided an excellent opportunity to see new equipment and to talk with various individuals over the possibility of whether better dimensional measurements might help raise productivity. The consensus of opinion was that the honest tenth (0.0001 inch) was the most diligently sought for accuracy in industry. It was also borne out that the manufacturer would like to be able to produce and inspect the part on-the-fly as well as obtain some information concerning the operational characteristics of his machine. This particular comment has been repeated many times to us by people in the industrial sector.

(3) At the same time while we were in Chicago, a commercial lab was visited. There are several independent laboratories scattered around the country which offer industrial firms a chance to remain competitive by providing them with the opportunities to keep quality in their manufactured products without a major investment in testing and calibrating equipment. The midwest Gage Laboratory which is part of the American Gage & Machine Company was visited. The Director was concerned over the high cost of many of NBS services, but felt the cost was justified considering the quality of the service and employees needed at the Bureau. His main suggestion was that NBS keep up dialogue with industry through meaningful publications, either through trade journals or NBS documents which will reach the real user.

(4) In June 1972, the US Army Metrology and Calibration Center at Redstone Arsenal, and the Quality and Reliability Assurance Laboratory of NASA's Marshall Space Flight Center, were visited. The John M. Core Laboratory at Redstone occupies 39,000 square feet with the physical standards lab occupying approximately half that total. The Chief of the Electrical Standards Lab presented a general overview of the facility and had no complaints over the availability of services of NBS. (He was concerned over his inability to obtain a VOR azimuth angle standard from NBS.)

A Group Leader of the Temperature and Vibration Section felt that more should be done with keeping people "up-to-date" on new procedures and measuring techniques. The Group Leader of Length, Angle, and Mass would like to have seen publications on surface finish, a heat transfer study of a typical metrology room to prove to management the "need for the stringent precautions," results of our evaluation of a laser interferometer system, and involute profiles. A technician in the group was pleased with the performance of NBS but had reservations concerning the relatively new method of calibrating long gage blocks and wanted to see reports covering the "build-up" wringing uncertainty for long blocks and the uncertainty due to elastic deformation occurring during the measurement of artifacts.

The major impression received was that these people were overwhelmed that we were aware of their existence and were willing to help. They were reluctant to admit their mundane problems until prodded gently. The consenses of opinion here was the need for more publications emanating from NBS and the need for continuing dialogue.

(5) North American Rockwell - Autonetics Metrology Laboratory, Anaheim, California. It has recently been designated as one of the official State Laboratories of the California Calibration Service and is responsible for the calibration of all industry standards within their assigned area of the state. It maintains standards which are calibrated and certified by NBS. It calibrates and certifies those standards and instruments which are used by the laboratories of Autonetics divisions in the calibration of test and measuring instruments. Autonetics is a major supplier of inertial guidance systems for the DoD and NASA. The accuracy requirements for the rotor in their gyro, 20 microinches on the diameter and 5 microinches on roundness, is probably the tightest in industry for a production item.

A supervisor of the Metrology and Calibration Laboratory says that there is no need for greater accuracy in their measuring equipment or standards at the present time. Fabrication techniques and technology must improve before any significant change in measuring equipment or techniques is required.

(6) Navy Standards Laboratory, Pomona, California, provides calibration and special test/evaluation services for other Navy Standards and Calibration Laboratories, other government activities, Navy contractors, and other DoD contractors within the Eleventh Naval District. Calibration services are also provided to participants of the NAVELEX and NAVSHIP Calibration Programs in the Pacific area as directed. In addition, calibration and special test services are provided to the participants of the Fleet Ballistic Missile Weapons System Calibration Program within the Continental United States as directed by the Strategic System Project Office. These functions consist of direct and indirect fleet support to insure traceability to standards maintained by NBS and/or the Navy.

This facility is a secondary laboratory whose prime function is the support, calibration and test of the metrology equipment used in the US ship yards and aboard the various naval vessels. One of its major activities is the design and fabrication of special gages for use with the Polaris and Poseidon missile systems. These gages are used during the assembly and installation of these missile systems aboard the ship.

The director of the laboratory states that they have no particular problems and that the services provided by NBS are quite satisfactory for their present needs and those of the foreseeable future. He did complain of the extremely long "turn around" time for calibrations at NBS several years ago which forced them to send their standards to the Navy Primary Standards Laboratories, ESL, in Washington, D.C., or WSL in San Diego, California, for calibration and traceability to NBS. He requested that they be made aware of any new process or technique developed at NBS that may help them. He welcomed the idea that NBS was trying to assess the requirements of the various agencies and industry and the willingness of NBS to improve its capability where necessary.

(7) Moore Special Tool Company of Bridgeport, Conn., sells approximately 12 measuring machines per year, total cost approximately $500,000. These machines have greater accuracy than the coordinate measuring machines, consequently, they are primarily used in the various research laboratories rather than the metrology laboratories of industry. The chief engineer of Moore Special Tool said that they are continually upgrading the accuracy of the lead screws that are used in their measuring machines and jig grinders. The accuracy of the lead screws used in the jig grinders and jig borers is guaranteed to be within 90 microinches per axis. This is a factor of 3 better than the measuring capability of most coordinate measuring machines. The Moore measuring machine is capable of measuring to the required accuracy, but it is relatively expensive, rather time-consuming to operate and must be in a controlled environment to obtain this type of accuracy and precision. It is doubtful if better accuracy can be obtained by using a precision lead screw without some type of automatic correction feature to compensate for pitch and lead errors.

Accurate line scales, Moiré scales and linear inductosyns are presently being used and appear to be the best choice for greater accuracy in measuring machines as well as machine tools. At present Moore Special Tool has no plans to incorporate any of these devices in their machines.

(8) In recent months we have visited or have been visited by representatives of the

following:

Agriculture, Department of - Maryland State Office of Weights & Measures, discussing needs of state labs for dimensional and length measurements.

Army Metrology and Calibration Center

Autonetics

BAI Corporation

Battelle Pacific Northwest Lab

Bausch & Lomb Inc.

Bendix Corporation

Canada Wire & Cable Co.

Commerce, Department of, Scientific & Technical Instrumentation, discussing trends in new devices and instrumentation.

Deltronics Gage Corporation - discussing measurement problems in general with particular emphasis on thread wires and plug gages.

Eastman Kodak Co.

General Dynamics (Convair) discussing measurement problems in general.

IBM Corporation (San Jose)

K & E - discussing the future of Electronic Distance Measuring Devices and the possibility of cheaper units replacing many steel tapes on the market now.

Moore Special Tool Company

National Machine Tool Builder Association

National Bureau of Standards - Office of Weights & Measures, discussing needs of state labs for dimensional and length measurements.

Navy - ESL, becoming familiar with the calibration programs and problems of the Navy.

Navy Standards Lab (Pomona)

NOAA, National Geodetic Survey, discussing ranging problems which NOAA is currently facing and will be facing in the future.

Sandia (Physical Standards Lab) discussing implementation of Measurement Assurance Program (MAP) processes to thread wires and other artifacts.

Union Carbide Corporation.

### 4.4.4 Exhibit in the International Machine Tool Show 1974

In view of improving ties with industry and publicizing the capabilities to some extent, we had for the first time, a manned exhibit at the International Machine Tool Show (ITMS) in Chicago, September 1974. The ITMS is the largest industrial show held in the USA. There were over 300 machine tools in operation; computer and control equipment; inspection, gaging, and testing equipment; material handling equipment, etc.; equipment from 30 nations and 78,151 registered visitors.

NBS had an attractive display manned by qualified personnel experienced in the field of dimensional measurements, surface roughness measurements, and optical instrumentation, since these are the areas of most interest to the machine tool industry.

An estimate of 4000 people stopped at the booth to pick up various NBS publications. Four hundred and sixty-one stopped to talk, some about their particular problems and others to learn more about NBS activities. These 461 people requested a total of 1300 copies of the Dimensional Technology and Optics and Micrometrology reports. The majority of these reports are "how we do it." They describe in detail how we measure or calibrate industry standards. Because of the many requests we have compiled a list of all these reports which are available to those who need or request them.

The response to the NBS exhibit was so satisfactory that we plan a repeat performance at the next ITMS in September 1976.

### 4.4.5 High Efficiency Methods for Dimensional Calibrations

A two-day seminar on High Efficiency Methods for Dimensional Calibrations was held in June 1974. Approximately 20 people from industrial and military standard laboratories attended. Knowledgeable personnel from the Dimensional Technology and other sections described how the efficiency (cost/unit calibration at fixed accuracy) of dimensional calibrations could be improved by appropriate use of experimental design and time shared computer data processing. The practical application of these methods, as applied to gage blocks, thread wires, and two-dimensional ball check-out plates for coordinate measuring machines was discussed and demonstrated in the laboratory and at the computer terminals. Programs written in BASIC and FORTRAN for these calibrations were furnished to each participant. The general comment at the conclusion was that this type of seminar be conducted at least once a year.

### 4.4.6 Analysis of Data Base

It is evident from looking at the results of some recent "round-robins" that the claims of industry to measure accurately objects other than simple end standards are optimistic. Even though gage blocks are available in accuracies of a part in $10^6$, not many industrial labs have the capability to transfer these measurements to other artifacts with any great precision and accuracy.

The precision of instrumentation today far outpaces the capability of personnel to utilize these devices fully in accurate dimensional measurements. In many cases accurate dimensional measurements are needed to satisfy functionality requirements.

In many cases the industrial contacts which we made yielded no earth-shattering news concerning needs for more accuracy. The main area of concern was need for more help with the day-to-day mundane problems. One solution seems to be a concerted effort to publish more articles in journals to describe our philosophies of measurement and also various processes.

The main area of impact which new instrumentation is having in dimensional measurements is in the surveying field. Tapes are still used quite extensively in the industry, mainly by private individuals, but in the past year low cost electronic distance measuring devices have been revolutionizing the surveying industry. With these devices many surveyors have ranges of over one kilometer with accuracies limited only by atmospheric corrections. It has been predicted by one tape manufacturer that sales and production of tapes might possibly see a sharp decline in two to seven years because of these devices. There is probably a residual beyond which tapes will be safe but it should be interesting to watch the developments.

The computer has proven to be a valuable tool in the area of inspection and quality control. If tied into an automatic gaging system, the computer can print out the inspection result of every part. The computer is also a valuable tool for sampling and control. The process can be set up so that if the production process is under control, no action will be taken, but if a parameter changes, corrective action may be taken.

The computer can also be a vital tool in the use of coordinate measuring machines. As the artifact is probed, the computer can compare the dimension measured against a nominal dimension and record the deviations.

Many manufacturers claim that the resolution of their units may be within 50 or 100 microinches. Not many machine tools can produce to these accuracies. There are screws, lead screws, beds, ways, spindles, and columns made of metal and subject to tolerances. All of these play a role in determining the final machining capability which is the one parameter of primary concern. Thus it behooves the user to know what can be obtained from his machine.

From communication with various industrial concerns we have seen that the need of industry for the next three to seven years in dimensional measurements is in the area of better measurements in three dimensions. There are many measuring machines now on the market today but most of them have the fault that inaccuracies are defined in terms of one axis. There is no assurance that if you start at point (1,1,0) and terminate at point (0,0,1) in a working volume that your inaccuracy can be expressed as linear combinations of the individual axis errors. What is needed are methods to characterize these errors. This is under development now at NBS with the 3-Dimensional facility. One of the main purposes of the study of the National Measurement System is to find efficient means to disseminate our work to the people who need it as our project progresses.

## 4.5 The Future

Central to the NBS program in length and related dimensional metrology is the provision of adequate calibration services to the national measurement system. We view the term *adequate* as the principal challenge. We must be aware of the changing needs of our customers and support sufficient development effort to be prepared to meet new needs as they occur while at the same time we must continue to supply the traditional services as long as a real need exists. Continued self-education in our specialties is also a major goal.

To deal with this dichotomy, we have structured the section into a series of interwoven service and development tasks so that the expertise of all is available for both service and research functions. We hope in this manner to avoid the intellectual stagnation of the "test house" as well as the ivory tower mentality that can plague a research elite.

### 4.5.1 Current Major Technical Projects

One of the major programs underway is the development of a 3-dimensional measurement capability. The best three axis measuring machine available was purchased and interfaced with a minicomputer; the necessary software is being developed. To eliminate machine errors due to structural bending as the table moves, five channels of laser interferometers are used as the readouts instead of relying on the machine screws. To reduce errors due to thermal effects, all heat producing elements such as the motors and clutches are water cooled. A sophisticated temperature measuring system is being installed to monitor the temperature of various parts of the machine as well as the item being measured. It is estimated that this capability will be completed during 1975.

A long range (0 - 4 inches) gage block comparator has been developed which uses a laser interferometer as the read-out device. This instrument has the advantage that only one master block is required to calibrate a complete set of gage blocks.

A similar measuring instrument has also been developed using the same principle to measure balls and thread wires. Both machines are operational.

A non-contacting gage block comparator has also been developed but at this time is still under test.

### 4.5.2 Distribution of Effort

The current and projected distribution of effort for Length and Related Dimensional Measurements is depicted in figure 4-20. Our inputs are broadly classified into four areas:

(1) Intellectual - The reason for our being (Definition of Meter).
(2) Internal NBS - These are areas within NBS with which active cooperation is necessary.
(3) External Customer Requirements - Includes all users of our routine calibration services as well as users of our specialized measurement capabilities.
(4) External Information - Comes in the form of society interaction, publications, trade journals, personal visits, and participation in standards organizations.

The outputs are broadly broken into three areas and "loose" percentages have been applied to indicate how these areas relate to the total output of Length and Related Dimensional Measurements.

(1) Calibrations - One of our functions is the providing of services to external and internal customers for fee. The factor of 25% is an average and may fluctuate from time to time. By looking at funding and spending for FY 1974 we see:

In the area of Length

| | |
|---|---|
| 4-1/4 man-years Research & Technical Support | \$154.4 K |
| 3-1/2 man-years Calibration effort | \$ 73.0 K |

In the area of Dimensional Technology

| | |
|---|---|
| 8 man-years Research & Technical Support | \$242.4 K |
| 2 man-years Calibration effort | \$ 37.0 K |

(2) Information - The area of providing information through publications, membership in societies, attendance at various meetings, etc. constitutes approximately 15% of our output currently.

(3) Specialized Measurement Capability - Most of our time is devoted to development, construction, and check-out of new instrumentation for furthering the state-of-the-art and increasing efficiency at NBS for making measurements. We also spend a great deal of time in the design and implementation of measurement algorithms to enhance the systems approach to making measurements. (Many of these have and will find increasing use in the industrial community.) A current project underway with university/government/industry cooperation is an R & D study of the dimensional stability of optical materials over a long period of time. Several spin-offs from this project such as more sensitive interferometers are expected to emerge.

It is expected that inputs in the areas of external information will be increased substantially in the future. We expect to develop better contacts with various societies, publications, and research and standards organizations. This fact will be mirrored in our output percentages for information because the Section plans to develop more publications in the areas of dimensional measurements and to disseminate them more efficiently. Continued stronger interactions with industry will be developed.

Calibrations will no doubt remain reasonably stable with the exception of some increase in workload due to the metric conversion by the nation. It is not known what effect the current energy crunch will have upon the ability of industry to send items in for calibration, but it should be interesting to observe for the next few years.

Our future, however, appears to lie predominantly in the area of specialized measurement capability. Since industry is converting to numerically-controlled machines and automated measuring machines for inspection and quality control, it seems our current work of pushing algorithm development may be expanded in the next few years. It seems imperative that we keep current by continued interactions with industry, government, and universities.

### 4.5.3 Time Table for Continuing Analysis and Acquisition of Data for the National Measurement System

Plans for the future include the following:
(1) Further acquisition of the data base through customer interchanges either by letter, personal visit, or telephone.
(2) General interest paper to be presented to the Inspection and Quality Control Division of SME on National Measurement System in either first or second quarter.
(3) Continued interaction with the Aerospace Industries Association and preparation of a questionnaire to be circulated within their membership by third quarter.
(4) Continued interaction with Metrology Division of the American Society for Quality Control.
(5) Preparation and submission of an overview article for trade journals such as *Quality Management & Engineering*, *Manufacturing Engineering & Management*, or *American Machinist* (McGraw-Hill) to be completed by second or third quarter.

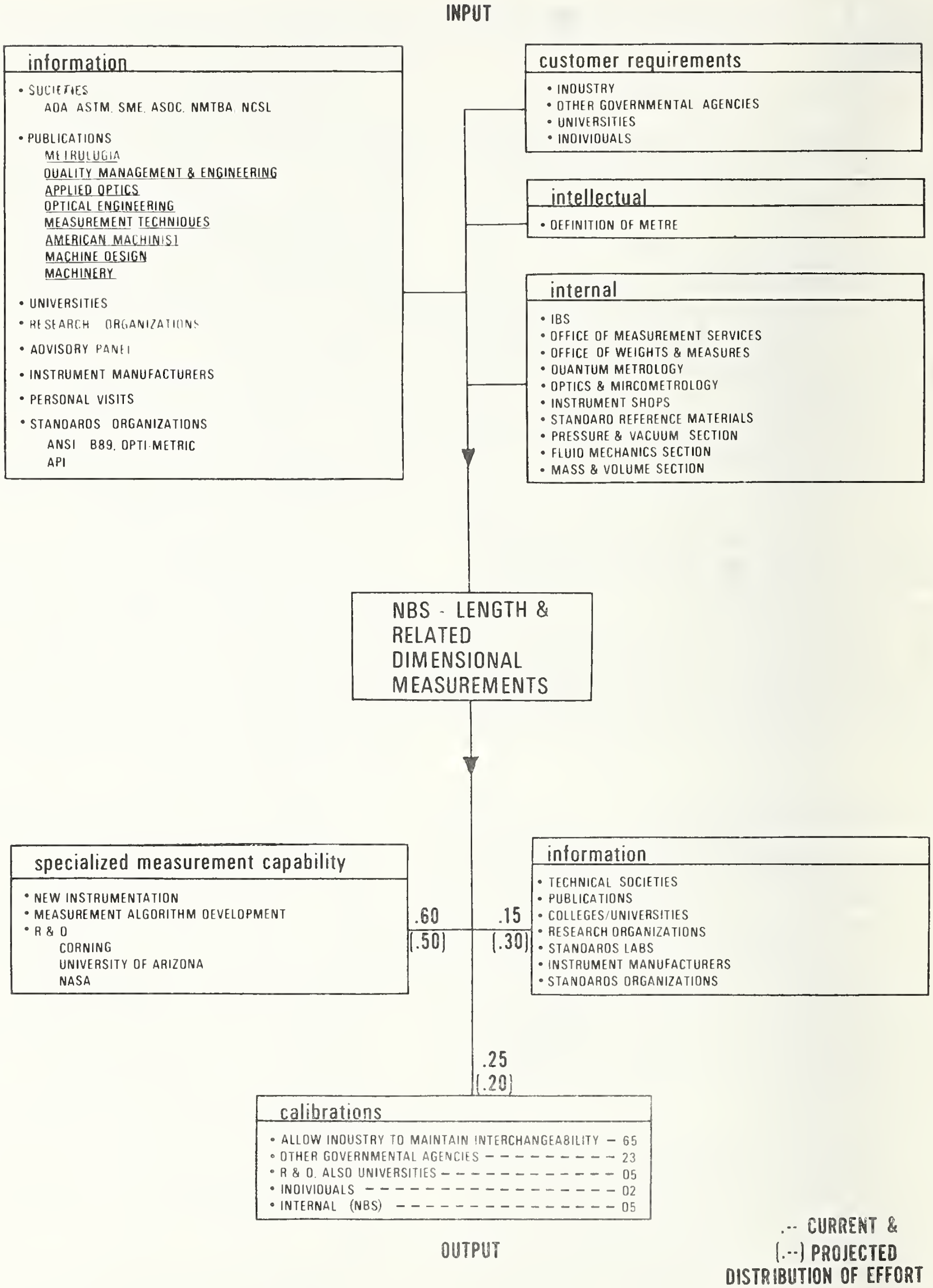



Figure 4-20. Input-output for NBS-length and related dimensional measurements.

## 5. SUMMARY AND CONCLUSIONS

The determination of length and related dimensional measurements constitute the largest group of measurements made in science, manufacturing and technology. We have shown that length and related dimensional measurements have impact upon many areas of the economy. We have also shown that the National Measurement System is viable and is adaptable in conforming to the changing requirements of industry. The greater accuracy requirements of some industries brought new measurement techniques into use, e.g. the fringe counting laser interferometer systems now used in many tool rooms and metrology laboratories. We have found no deficiencies in the system but only in the knowledge and capabilities of individuals or the measurement technique that they use, as shown in the comparison measurement on audit packages that were made by the various standards laboratories.

Through the Measurement Assurance Program (MAP) NBS is playing a vital role in monitoring government, industrial, and commercial standards laboratories measurement systems and techniques to keep their measurement precesses in control. The increasing use of the computer aided three dimensional (3D) measurement facility has reduced the calibration cost of some of the services. Of equal importance, it has reduced the "turn around time" of the physical standard and returned it to the National Measurement System with minimum inconvenience to industry.

Our contacts with industry at the International Machine Tool Show, 1974, only reverified our position that the publication of NBS calibration procedures written at the technician level is the type of document most useful to the metrology community that we serve. We will continue to publish our existing calibration procedures for all the length and related dimensional measurements that we offer. Since NBS does not have a formal mailing list of interested parties, we intend to publish a list of the available papers in the various trade magazines with information on how and where to obtain them.

Plans for the immediate future call for adapting more of our standard calibrations to our 3D facility. A short range, (0-4in.) gage block comparator was recently designed and at present is under evaluation. Another long range (4-24in.) comparator is in the preliminary design stage. This instrument will be in operation in late 1976. Since the instrument makers are reluctant to invest their research funds in new measurement techniques because of the limited demand and the old adage of metrologists "but we've always done it this way," NBS must lead the way in developing new measuring instruments using the most recent discoveries of the scientific community.

## APPENDIX A. METHODOLOGY OF THE STUDY

Four primary categories of contact mechanism were used to develop our knowledge and understanding of the National Measurement System:

(1) An industry canvass and also telephone interviews with selected people,
(2) Contacts with technical societies and/or publications in the area of interest,
(3) "Outreach" Porgram,
(4) Literature search for pertinent "round-robin" or audit packages.

A(1) - The canvass of industry was an attempt to establish a preliminary data base to answer a few of our basic questions concerning the importance of dimensional measurements. The canvass consisted of two parts: first, an informal question letter and/or telephone interviews with responsible individuals within an organization. In all cases no formal questionnaire was sent "blindly" into an organization. A high-ranking contact within a company was first established within our area of interest (sometimes requiring several iterations); a preliminary telephone interview was conducted; and second, if the need existed, a letter outlining other questions was subsequently sent to the interviewee for his consideration. By adopting this system, it appears we may achieve 95-100% participation with the industries we contacted.

We took an objective look at our NBS Customer Profile to select the SIC categories which could be interpreted to imply "first-order measurement-intensive" industries. By selecting companies which then possessed these SIC codes for their products or services rendered, we were able to develop a systematic "sample" of the users. However, the resulting list does not lend itself to conventional statistical analysis because: (1) that was not the original purpose, and (2) the size of the population cannot be proven to be a random sampling of the overall distribution.

The size of the companies represented range from a low of less than $1 million to a high of $9.4 billion in value of shipments in 1972. Figure A-1 shows the cross-section profile of the participating companies in terms of two-digit SIC codes. These companies represent total sales of over $15.2 billion. The codes are:

Table A-1. SIC codes of canvassed companies.

| Frequency | SIC Code | Description |
|---|---|---|
| 1 | 35 | Machinery, except electrical |
| 2 | 36 | Electrical machinery, equipment, and supplies |
| 3 | 28 | Chemicals and allied products |
| 8 | 37 | Transportation equipment, Ordnance & accessories |
| 4 | 34 | Fabricated metal products |
| 4 | 39 | Misc. manufacturing indust. |
| 5 | 38 | Professional, scientific, & controlling instruments, photographic & optical goods, watches & clocks. |

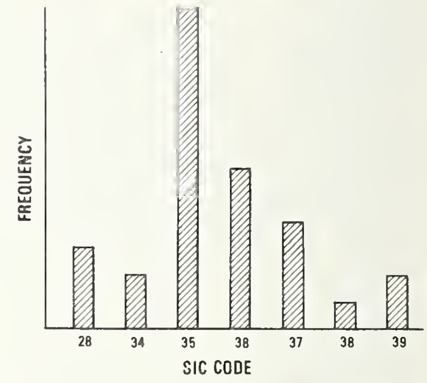



Figure A-1. Cross-section of industry canvass on dimensional measurements from companies with 1972 sales of $15.2 billion total.

A comprehensive listing of representatives from companies we have contacted by these methods is given at the end of this appendix.

The form of the survey was standardized to some extent to facilitate easy interpretation of the results. Questions were changed if they were not appropriate to the interviewee's particular case. For the most part, the interview (letter and/or telephone) was conducted as follows:

(1) Introduction of person or persons
(2) Purpose of study of National Measurement System
(3) Inquiry as to the nature of the company
(4) Economics of performing dimensional measurements accurately
(5) Types of personnel and instrumentation involved in dimensional measurements
(6) Any foreseeable problems in dimensional measurements
(7) Opinion of NBS and how you think NBS can better serve the system
(8) Thanks and expression of desire to continue dialogue.

In some cases where we wanted more information a formal letter was sent to incividuals already contacted (see fig. A-2).

A(2) - Contacts with Technical and Trade Societies and Journals. The methodology was simply to telephone, write or meet the re-

Dear ________:

We wish to thank you for your willingness to provide data for our assessment of the National Bureau of Standards' role in the National Measurement System. As we mentioned before, our main area of focus is the subject of length and length measurements. A few of the questions we are attempting to answer are:

Do NBS measurement services meet the needs of US industry? If not, where and how can these services be improved?

Are there predictable developments that would create a need for standards and/or services not now available?

To obtain a focal point, we have assembled a questionnaire which will serve for the development of a more in-depth probe of your needs. We would ask that you assemble various individuals within your organization-from management to technicians-to discuss the various questions and obtain a spectrum of answers. Please answer and comment on as many of these questions as possible. Your answers may be very informal - use a pencil if you'd like, and add any additional information that you feel might be helpful. We assure you that all your answers and comments will be strictly confidential.

If you have any other comments on problems associated with dimensional measurement, please write them down. We asked for your help and you are entitled to ours.

QUESTIONS

(1) Explain the nature of your business in terms of products and services rendered.
(2) How much money and/or man-years is expended annually by your company in the measurement of some facet of length? Can you give a rough estimate of the amount of money invested by all companies in the measurement of length?
(3) What types of length instrumentation are used in your plant? How do you proceed in the calibration of these instruments?
(4) What type of personnel do you have involved in length measurements? Is there any type of additional training you would like these personnel to receive and in what area?
(5) If you had unlimited funds for development of new instrumentation, what precision and accuracy range would you be interested in achieving?
(6) Do you find pneumatic gaging adequate for certain applications in your plant? In what areas is this form suitable and in what areas is it not?
(7) If you use the services of NBS, please state in what way? Why do you use these services? Do you find these services adequate or inadequate? Please tell how you feel these might be improved.
(8) Do you feel that NBS gives enough assistance to various manufacturers around the country? Please explain how you think this situation might be improved.
(9) Are there any problems in your manufacturing processes where an improvement in the accuracy or precision or method of length measurement might help raise productivity? Do you think consultation with NBS could help? If not, why not?
(10) In what areas do you find foreign competition? What are their most interesting products and what do you foresee as their most innovative products in the future?
(11) If some of your personnel attended the NBS Dimensional Conference in 1972, what were their impressions? How could the conference have been improved? Would you like to see such a conference repeated every few years? Why?
(12) What type of training seminars and/or publications would you like to see emanate from NBS? In what areas of interest? Toward what level of personnel should these be geared? Where do you feel would be the most effective and efficient place to publish our work?
(13) Do you feel that if you had to "prove" to accuracy of your measurements in a court of law, you would have sufficient evidence to convince the jury? What type of evidence would you present for your defense? Is this type of proof important to you?
(14) What is your current concept of NBS (please include different views of your people)? How do you visualize NBS as you think it should be?

FINAL - On the scales below, rank the dimensional measurements you perform with the following symbols: X - CURRENT (what you can now do) O - FUTURE (what you will need in 5-10 yrs.)

| | 1-Dimension Precision | 1-Dimension Accuracy | 2-Dimension Precision | 2-Dimension Accuracy | 3-Dimension Precision | 3-Dimension Accuracy |
|---|---|---|---|---|---|---|
| Not Impor- | ______ | ______ | ______ | ______ | ______ | ______ |
| tant | ______ | ______ | ______ | ______ | ______ | ______ |
| | ______ | ______ | ______ | ______ | ______ | ______ |
| Very | ______ | ______ | ______ | ______ | ______ | ______ |
| Impor- tant | ______ | ______ | ______ | ______ | ______ | ______ |

Figure A-2. Canvass cover letter and questionnaire.

sponsible officials or editors. Results have been reported in section 4.4.2.

A(3) - "Outreach" Program. In the past few years, the management of the Dimensional Technology Section at NBS started to "reach our" to the outside world by sending personnel on fact-finding missions to various companies around the country. Anytime someone visits a part of the country on either personal or business reasons, the area is usually searched to find any interesting visits that might be made. We have a colored map in our Section Office with the places visited depicted by colored pins so that one can easily see the far-reaching results of this program.

A(4) - Literature Search. One way of assessing the needs of industry in terms of dimensional measurements is to look at the results of surveys which are conducted periodically by interested indiviudals. When the surveys are in the form of audits, i.e., artifacts which are sent to various laboratories and companies to be measured, then much more information is gained.

We have found three pertinent surveys which tell us some things concerning the ability of industry to measure dimensional objects.

(a) A survey conducted in 1958 and 1959 by the Aerospace Industries Association.

(b) A survey conducted in 1961 by the National Physical Laboratory, which included artifacts sent to more than 40 companies in England.

(c) A current NCSL Audit Package sent to more than twelve of the best laboratories around the United States: Results of this survey have been presented in section 2.3.

Personal and Corporate Contacts

Mr. Ernest Weber
Micro-line Inc.
Division of Bausch & Lomb
Box 938
Jamestown, New York 14701
(716) 483-7182

Mr. Conrad Fahlman, Director Quality Con.
Brown & Sharpe Manufacturing Company
Industrial Products Division
North Kingston, Rhode Island 02852
(401) 884-3000

Mr. Ed. Clincher
Metrology and Primary Standards Lab.
Chrysler Corporation
Highland Park, Michigan 48203
(313) 956-6672

Mr. R. R. Sandman, Mgr., Physical Stds.
Mr. Paul Ackermann, Mgr., Engrg. Stds.
Mr. C. Carter, Director, Mach. Tool R&D.
all with the
Cincinnati Milacron Corporation
4701 Marburg Avenue
Cincinnati, Ohio 45209
(513) 841-8409

Mr. Fred Hutcherson & Mr. Hugh Turnball
Continental Machines
Savage, Minnesota 55378
(612) 890-3300

Mr. William Bauer, General Manager
Deltronic Corporation
929 Baker Street
P. O. Box 2155
Costa Mesa, California 92626
(714) 545-0401

Mr. Calep Hathway
Scientific, Electrical, Optical Ins rs.
Department of Commerce
Washington, D.C. 20230
(202) 967-2312

Mr. Bob Hunsburger
Department of Commerce
Transportation and Capitol Equip., Div.
Metalworking Machinery & Machine Tools
Washington, D.C. 20230
(202) 967-5611

Mr. John Musgrave & Mr. Bob Wasson
Department of Commerce
Bureau of Economic Analysis
Washington, D.C. 20230
(202) 967-3230

Mr. Thomas Gray
Federal Products Corporation
1144 Eddy Street
Providence, Rhode Island 02901
(401) 781-9300

Mr. Lyman W. Higgins, Director of Mktg.
Gaertner Scientific Company
1201 Wrightwood Avenue
Chicago, Illinois 60614
(312) 281-5335

Mr. Max Unis
Gage Lab Corporation
Philadelphia, Pennsylvania 19115
(215) 355-5420

Mr. George E. Nateau
General Electric
Aircraft Engine Operations Division
1000 Western Avenue
Lynn, Massachusetts 01905
(617) 594-0100

Mr. A. J. Woodington, Chief, Meas. Con.
General Dynamics
Convair Aerospace Division
P. O. Box 1128
San Diego, California 92112
(714) 277-8900

Mr. J. Rochette
General Motors
New Departure Hyatt Bearings
Bristol, Connecticut 06010
(419) 626-2120

Mr. Joel D. Gruhn, Physicist
Hutchinson Industrial Corporation
40 West Highland Park
Hutchinson, Minnesota 55350
(612) 879-2371

Mr. W. N. Clausen, Reg. Sales Engr.
Keuffel & Esser Company
1521 North Danville St.
Arlington, Virginia 22201

Mr. Marshal Brown, Director of Engr.
Laser Systems, Inc.
Tullahoma, Tennessee 37388
(615) 455-0686

Mr. Ferris S. Chandler
Lufkin (Div. of Cooper Industries)
Box 728
Apex, North Carolina 27502

Mr. Ed. Hagel, Manager
National Astro Labs
2201 North Hollywood Way
Burbank, California 91504

Mr. Coleman
Navy Western Standards Laboratory
Pomona, California 91766
(714) 437-6991

Mr. Charles Muirhead
National Ocean Survey
Oceanographic Division
6001 Executive Blvd.
Rockville, Maryland 20852
(301) 496-8501

Mr. Nelson Wilkins
Oak Ridge National Laboratory
P. O. Box X
Bldg. 2525
Oak Ridge, Tennessee 37809

Mr. C. G. Erickson, Manager of Engrg.
Pratt & Whitney Small Tool Division
Charter Oak Boulevard
West Hartford, Connecticut 06101
(203) 233-7591

Mr. J. C. McKinney, Jr., Chief
Army Standards Laboratory
U.S. Army Metrology and Calibration Ctr.
U.S. Army Missile Command
Redstone Arsenal, Alabama 35809

Mr. Hugh Collins, Manager of Engrg.
Webber Gage Division
L. S. Starrett Co.
24500 Detroit Road
Cleveland, Ohio 44145
(216) 835-0001

Mr. Richard A. Newton, Chief Inspector
L. S. Starrett Company
104 Crescent Street
Athol, Massachusetts 01331
(617) 249-3551

Mr. Doug Garside, Manager of Engrg.
Mr. Robert Lamport, Head of Q.C.
The Van Keuren Company
176 Waltham Street
Watertown, Massachusetts 02172
(617) 926-1450

## APPENDIX B. SUMMARY OF BACKGROUND DOCUMENTS

1. Title: Federal Specification - Gage Blocks and Accessories
By: Federal Supply Service, General Services Administration
Published: Fed. Spec. GGG-G-15B, November 6, 1970.
Results or Key Findings:

1.1 Scope. This specification covers precision gage blocks up to and including 20 inches (500mm) in length, and accessories, in either the inch or metric system for use by laboratories, inspection shops or as work gages for high accuracy machining operations. Notes for usage and definitions of terminology may be found in section six.

1.1.1 Federal specification coverage. Federal specifications do not include all types, classes, and styles of commodity indicated by the titles of the specifications, but are intended to cover only those used by the Federal Government.

1.2 Classification.

1.2.1 Style, grades, classes and types. The gage blocks shall be of the following styles, grades, classes, and types, as specified:

Styles (shapes): Style 1. Rectangular.
Style 2. Square, with center accessory hole.
Style 3. Other shapes as specified.

Grades: Tolerance grades: Grade 0.5 (formerly grade AAA).
Grade 1 (formerly grade AA).
Grade 2 (formerly grade A+).
Grade 3 (compromise between former grades A and B).

Accuracy level grades: 1 microinch (25 nanometres).
2 microinch (50 nanometres).

Classes and types (material): Class I. Steel.
Class II. Faced blocks, steel.
Type (1) Chromium plated.
Class III. Carbide.
Type (1) Chromium carbide.
Type (2) Tungsten carbide.
Class IV. Other material (as specified).

Effect: The preceding material is quoted directly from page 1 of a 28 page specification. The effect of this specification is to assure the quality of all gage blocks purchased by the Federal Government. The specification is available from Business Service Centers at the General Service Administration Regional Office in Washington, DC.

2. Title: NBS Handbook 44, Fourth Edition
By: As adopted by the National Conference on Weights and Measures
Published: U.S. Government Printing Office, for Department of Commerce, NBS.
Approach Used: Committee consensus within National Conference on Weights and Measures, with staff support from NBS.
Scope: This handbook covers the specifications, tolerances, and other technical requirements for commercial weighing and measuring devices. The publication may be purchased from the United States Department of Commerce, Washington, DC.
Effect: Provides the technical "bible" for the state and local weights and measures officials.

## APPENDIX C. MANUFACTURERS OF DIMENSIONAL ARTIFACTS**

FLATS, optical
- AGA Corp
- Acme Scientific Co, Div. of Acme Ind.
- American Gage, Sub. of Katy Ind.
- Ash Mail Order System, Inc.(d)*
- D.I.L., Inc.(d)
- Davidson Optronics, Inc.
- DoAll Co.
- Ealing Corp. The Optics Div.
- Edmund Scientific Co.
- Gaertner Scientific Corp.
- Group 128, Inc.
- Infrared Industries, Inc.
- International Micron Optics, Div. Charvoz-Carsen Corp.
- Itek Corp.
- Jodon Engrg. Assocs., Inc.
- Katy Industries
- Laser Technology, Inc.
- Ledford Machine & Gage Lab., Inc.
- Lenox Instr. Co., Inc., Unit of Esterline
- Opto-Metric Tools, Inc.
- Owens-Illinois Inc., Fecker Systems Div.
- Perkin-Elmer Corp., The Laser Products Div.
- Perkin-Elmer Corp., The Instrument Div.
- R.I.S. Inc.(d)
- Radiation Equipment Co.
- Rank Precision Inds., Inc.
- Shumway Optical Instruments Corp.
- Speedlap Supply Co.
- Starrett Co., The L.S.
- Swiss Precision Inst., Inc.
- Van Keuren Co., The
- Webber Gage Div. of The L.S. Starrett Co.
- Zeiss Inc.
- Zygo Corp.

GAGE BALLS
- AA Gage Div. US Industries, Inc.
- American Gage, Sub. of Katy Industries
- Ash Mail Order System, Inc.(d)
- Bendix Corp., The Automation and Measurement Div.
- D.I.L., Inc.(d)
- DeKalb Precision Inds.,Inc.
- Deltronic Corp.
- Dorsey Gage Co., Inc.
- Ind'l. Tectonics, Inc., Ball Div.
- Katy Industries
- Micro Surface Engineering Co.
- Penniman Inc., Elisha
- Precision Industries, Carbide Div.
- Ralmike's Tool-A-Rama
- Schmitt Co. Inc., R.I.
- Siber Precision Inc.(d)
- Size Control Co. a Katy Industries Co.
- Swiss Precision Inst. Inc.
- Tietzmann Tool Corp.
- Van Keuren Co., The

*(d) designates distributor.

GAGE BLOCKS
- Alina Corp.(d)
- Ash Mail Order System, Inc.(d)
- Boice Div. Mechanical Technology Inc.
- Brown & Sharpe Mfg. Co., Ind. Prod. Div.
- CEJ Gage Co.(d)
- Carey Machy & Sup. Co., Inc.(d)
- Collins Microflat Co. Inc.
- Colt Inds. Pratt & Whitney Small Tool Div.
- Custanite Corp., The
- D.I.L., Inc.(d)
- DeKalb Precision Inds.,Inc.
- Dearborn Gage Co.
- Detroit Testing Lab.
- DoAll Co.
- Fowler Co., Fred V.
- International Micron Optics, Div. Charvoz-Carsen Corp.
- Jonard Industries Cor.
- Julie Research Labs., Inc.
- Kuroda Precision Ind. Ltd.
- Ledford Machine & Gage Lab., Inc.
- MTI Corp.
- Montgomery & Co. Inc.(d)
- Pacific Gage Co., Inc.
- Precision Devices, Inc.
- R.I.S. Inc.(d)
- Ralmike's Tool-A-Rama
- Rank Precision Inds., Inc.
- Rutland Tool Supply Co., Inc.(d)
- Siber Precision Inc.(d)
- Starrett Co., The L.S.
- Swiss Precision Inst., Inc.
- Van Keuren Co., The

POLYGONS, optical
- AA Gage Div., U.S. Industries, Inc.
- Bailey Meter Co., Sub. of Babcock & Wilcox
- D.I.L., Inc.(d)
- Davidson Optronics, Inc.
- Ehrenreich Photo Optical Inds. Nikon Instrument Div.
- Ledford Machine & Gage Lab., Inc.
- Starrett Co., The L.S.
- Statham Instruments, Inc., Industrial Div.
- Webber Gage Div., The L.S. Starrett Co.
- Zygo Corp.

RULES, measuring (also see Tapes, measuring)
- Ash Mail Order System, Inc.(d)
- Brown & Sharpe Mfg. Co., Ind. Products Div.
- Brunson Instrument Co.
- Carey Machy. & Sup., Co., Inc.(d)
- Coastal Abrasive & Tl. Co., Inc.
- Colt Inds., P&W Small Tool Div.
- Custanite Corp., The
- D.I.L., Inc.(d)
- DoAll Co.
- Edmund Scientific Co.
- Fowler Co., Fred V.
- General Hardware Mfg. Co., Inc.,Div. of General Tools Corp.
- Ledford Machine & Gage Lab., Inc.
- MTI Corp.
- Metra-Tech Inds., Inc.

Millers Falls Co.,Ingersoll-Rand Co.
Pacific Gage Co., Inc.
Panelgraphic Corp.
Pi Tape
Picker Industrial, Div. Picker Corp.
Proto Tool Co.
Rank Precision Inds., Inc.
Snap-on Tools Corp.
Starrett Co., The L.S.
Yuasa International Inc.

TAPES, measuring (also see Rules, measuring)
Ash Mail Order System, Inc.(d)
Carey Machy. & Sup. Co. Inc.(d)
Comparator Chart Engineering
Custanite Corp., The
D.I.L., Inc.(d)
Ledford Machine & Gage Lab.Inc.
Micro Metrics, Inc.
Millers Falls Co., Ingersoll-Rand Co.
Pi Tape
Proto Tool Co.
R.I.S. Inc.(d)
Rank Precision Inds., Inc.
Rolatape Corp.
SOS Photo-Cine-Optics, Inc.
Snap-on Tools Corp.
Starrett Co., The L.S.
Yuasa International Inc.

TAPES, precision calibrated
Custanite Corp., The
Panelgraphic Corp.
Pi Tape
Rank Precision Inds., Inc.

SQUARES, cylindrical
AA Gage Div., U.S. Industries, Inc.
Ash Mail Order System, Inc.(d)
Busch Co., Inc., J.C.
CEJ Gage Co.(d)
Carey Machy. & Sup. Co., Inc.(d)
Collins Microflat Co. Inc.
D.I.L., Inc.(d)
DeKalb Precision Inds., Inc.
DoAll Co.
Federal Products Midwest Davis Gage & Engrg. Co., A.G.
Fowler Co., Fred V.
Int'l. Machine & Tool Corp.
Ledford Machine & Gage Lab. Inc.
Mahr Gage Co., Inc.(d)
Montgomery & Co., Inc.(d)
Moore Special Tool Co., Inc.
Pacific Gage Co., Inc.
R.I.S. Inc.(d)
Rank Precision Inds., Inc.
Rutland Tool Supply Co., Inc.(d)
Siber Precision Inc.(d)
Taft-Peirce Mfg. Co., The
Van Keuren Co., The
Yuasa International Inc.

WIRES, thread measuring
Alina Corp.(d)
American Gage, Sub. of Katy Industries
Ash Mail Order System, Inc.(d)
Bendix Corp., The Automation & Meas. Div.
Bendix Corp., The Industrial Tools Div.
Colt Inds. P&W Small Tool Div.
D.I.L., Inc.(d)
DeKalb Precision Inds., Inc.
Deltronic Corp.
Katy Industries
Kromhard Twist Drill Co.
Ledford Machine & Gage Lab., Inc.
Montgomery & Co., Inc.(d)
O-Vee Gauge Co.
Precision Devices, Inc.
R.I.S. Inc.(d)
Ralmike's Tool-A-Rama
Siber Precision Inc.(d)
Size Control Co., a Katy Industries Co.
Southern Gage Co.
Swiss Precision Instr., Inc.
Taft-Peirce Mfg., Co., The
United Gage Co.
Van Keuren Co., The

**Some manufacturers of dimensional artifacts may have been inadvertently omitted.

APPENDIX D. TYPICAL INDUSTRY SPECIFICATIONS FOR RULINGS

## SPECIFICATIONS OF RONCHI RULINGS AT 68° F

| | COMMERCIAL GRADE | | INSPECTION GRADE | |
|---|---|---|---|---|
| PITCH LINES PER INCH | ACCURACY FORMULA Maximum Error From Any Group of Lines to any other Group L inches away | MAXIMUM PERIODIC ERROR PEAK TO PEAK | ACCURACY FORMULA Max. Error From Any Group of Lines to Any Other Group L Inches Away | MAXIMUM PERIODIC ERROR PEAK TO PEAK |
| 200 | .0005 " + .00002" L | .000125" | .00025" + .00001 " L | .000050" |
| 250 | .0004 " + .00002" L | .0001" | .0002 " + .00001 " L | .000050" |
| 500 | .0002 " + .00001" L | .00005" | .0001 " + .00001 " L | .000015" |
| 1000 | .00015" + .00001" L | .00003" | .0001 " + .000005" L | .000015" |
| 1250 | .00015" + .00001" L | .000025" | .0001 " + .000005" L | .000015" |
| 2500 | .00015" + .00001" L | .000020" | .0001 " + .000005" L | .000012" |

| METRIC PITCHES LINES PER MM | Maximum Error From Any Group of Lines to any other group L mm away | MAXIMUM PERIODIC ERROR PEAK TO PEAK | Max. Error From Any Group of Lines to Any Other Group L mm Away | MAXIMUM PERIODIC ERROR PEAK TO PEAK |
|---|---|---|---|---|
| 8 | 12.5 μm + .01 L μm | 4 μm | 6 μm + 0.01 L μm | 1.2 μm |
| 10 | 10 μm + .02 L μm | 2.5 μm | 5 μm + 0.02 L μm | 1.2 μm |
| 20 | 5 μm + .015 L μm | 1.2 μm | 2.5 μm + 0.01 L μm | 0.6 μm |
| 40 | 4 μm + .01 L μm | 0.75 μm | 2.5 μm + 0.005 L μm | 0.4 μm |
| 50 | 4 μm + .01 L μm | 0.6 μm | 2.5 μm + 0.005 L μm | 0.4 μm |
| 100 | 3 μm + .01 L μm | 0.5 μm | 2 μm + 0.005 L μm | 0.3 μm |
| 200 | 2.5 μm + .01 L μm | 0.4 μm | 1.5 μm + 0.005 L μm | 0.25 μm |

MOIRE FRINGE PATTERN USING 500 LINE/INCH RONCHI RULINGS

## APPENDIX E. STATE LABORATORIES AND CAPABILITIES (PHYSICAL DIMENSIONS)

| Laboratories | ** | *** |
|---|---|---|
| ALABAMA DEPT OF AGRI & INDUST | X | S |
| ALASKA STATE | X | S |
| ARKANSAS WEIGHTS & MEASURES LAB | X | S |
| CALIFORNIA BUREAU OF WTS. & MEAS | F | B |
| COLORADO DEPT OF AGRICULTURE | X | S |
| CONNECTICUT STATE OFFICE BLDG | X | S |
| DELAWARE DEPT OF AGRICULTURE | X | S |
| GEORGIA DEPT OF AGRICULTURE | X | S |
| STATE DEPT OF AGRI, HAWAII | X | B |
| IDAHO DEPT OF AGRICULTURE | X | S |
| ILLINOIS STATE | X | S |
| INDIANA STATE BOARD OF HEALTH | X | S |
| KANSAS DEPT OF AGRICULTURE | X | B |
| MAINE DEPT OF AGRICULTURE | F | S |
| MARYLAND OFFICE OF WTS. & MEAS. | F | S |
| COMMONWEALTH OF MASSACHUSETTS | X | S |
| MICHIGAN DEPT OF AGRICULTURE | X | S |
| MINNESOTA DEPT OF PUBLIC SERV | C | S |
| MISSOURI WEIGHTS & MEASURES | X | B |
| NEVADA DEPT OF AGRICULTURE | C | S |
| NEW HAMPSHIRE BUR OF WTS & MEAS | F | S |
| NEW JERSEY STATE | X | S |
| NORTH CAROLINA DEPT OF AGRI | X | S |
| NORTH DAKOTA PUBLIC SERV COMM | F | S |
| OREGON AGRICULTURE DEPT | F | S |
| COMMONWEALTH OF PENNSYLVANIA | | S |
| S. C. DEPT. OF AGRICULTURE | X | B |
| TENNESSEE DEPT OF AGRICULTURE | X | B |
| UTAH DEPT OF AGRICULTURE | X | S |
| VERMONT DEPT OF AGRICULTURE | F | S |
| *VIRGINIA DEPT OF AGRI & COMMERCE | X | |
| WISCONSIN DEPT OF AGRICULTURE | X | B |
| WYOMING DEPT. OF AGRICULTURE | F | |

*Indicates NCSL member

** O Service to Parent Organization ONLY
C Available to Customers in SPECIAL CASES
F Calibration Services Available on a FEE BASIS
X Calibration Services Available on a NO FEE BASIS

*** (P) for primary standards only
(S) for secondary and/or test instruments only
(B) for both levels of work.

## APPENDIX F. GOVERNMENT AND INDUSTRIAL LABORATORIES AND CAPABILITIES (PHYSICAL DIMENSIONS)

| Laboratories | ** | *** |
|---|---|---|
| *AEROJET ELECTRO SYSTEMS CO. | O | S |
| *AEROJET NUCLEAR CO. | C | S |
| WILLIAM AINSWORTH, INC. | F | |
| *ALLIS CHALMERS MFG. CO. | F | B |
| AMERICAN ELECTRONIC LABS., INC. | F | P |
| AMERICAN GEOPHYSICAL & INSTR. | F | B |
| AMERICAN INSTRUMENT SERVICE, INC | F | B |
| *AMP, INC. | O | |
| *APPLIED PHYSICS LAB./JHU | O | S |
| *ARGONNE NATIONAL LABORATORY | O | |
| *ARIZONA STATE UNIVERSITY | O | |
| *AUDIO DEVICES, INC. | O | |
| *AVCO CORP. | F | B |
| AVCO CORP. LYCOMING DIV. | F | B |
| AVCO CORP. | F | |
| *BAILEY METER CO. | O | B |
| *BALL BROS RESEARCH CORP | F | S |
| BATH IRON WORKS CORP. | F | |
| *BATTELLE, COLUMBUS LABS. | O | S |
| *BECKMAN INSTRUMENTS., INC. | F | B |
| *BEECH AIRCRAFT CORP. | C | B |
| *BELL AEROSPACE CO. | C | B |
| *BELL & HOWELL RESEARCH LABS. | O | |
| *BENDIX CORP. | F | P |
| *BENDIX CORP. | O | S |
| *BENDIX CORP. | F | P |
| *BENDIX CORP., KANSAS CITY DIV | O | B |
| *JAMES G. BIDDLE CO. | F | |
| B & K INSTRUMENTS, INC. | F | |
| *BLANCHETTE TOOL & GAGE MFG CORP | F | B |
| *BOEING CO., AEROSPACE GP | F | B |
| BOEING CO., WICHITA DIV. | F | S |
| *BRUSH INSTRUMENTS DIV OF GOULD | O | B |
| BURROUGHS CORP. | F | B |
| *CAL TECH | O | |
| *CAL TECH, JPL DSN | O | B |
| *CANNON INSTRUMENT CO. | F | |
| *CERTIFIED CALIBRATION LABS., INC | F | |
| *COLLINS RADIO CO. | F | B |
| COLORADO ENGINEERING EXPERIMENT | F | |
| *COMMUNICATION SATELLITE CORP. | C | |
| *COMPUTER DIODE CORP. | C | |
| *COMSAT LABORATORIES | O | S |
| *COX & COMPANY, INC. | C | B |
| *CUMMINS ENGINE CO. | O | |
| *DALMO VICTOR CO. | C | S |
| *DAYTON T. BROWN, INC. | F | B |
| *DETROIT EDISON CO. | C | S |
| *DOW CHEMICAL CO. | C | S |
| *DUPONT DE NEMOURS, E. I. | C | B |
| E G & G, INC. | F | |
| *E G & G, INC. | C | S |
| *E G & G, INC. | F | |
| *EIL INSTRUMENTS, INC. | F | B |
| *ELECTRICAL INSTRUMENT SERVICE | F | |
| *ELECTRICAL TESTING LABS., INC. | F | S |
| *ELECTRO-SCIENTIFIC INDUSTRIES | F | S |
| *ENDEVCO | F | |
| EPPLEY LABORATORY, INC. | F | |
| *E-SYSTEMS, INC. | F | B |
| *FAIRCHILD CAMERA & INSTRUMENT | O | S |
| *JOHN FLUKE MFG. CO., INC. | F | S |
| *FOXBORO CO. | F | S |
| *GAGE LAB CORPORATION | F | S |
| *GARRETT CORPORATION | O | |
| GAUGE REPAIR SERVICE | F | |
| GEN. DYNAMICS, QUINCY SHIP DIV. | F | S |
| *GENERAL DYNAMICS CORP. | C | B |
| *GENERAL DYNAMICS CORP | F | B |
| *GENERAL DYNAMICS CORP. | F | B |
| *GENERAL DYNAMICS | O | B |
| *GENERAL ELECTRIC CO. | F | B |
| *GENERAL ELECTRIC CO. | F | S |
| *GENERAL ELECTRIC CO. | F | |
| *GENERAL ELECTRIC CO. | O | S |
| *GENERAL ELECTRIC CO. (NASA) | C | B |
| GENERAL ELECTRIC CO. | F | |
| GENERAL ELECTRIC ICSS | F | S |
| GENERAL ELECTRIC INSTRUMENTATION | F | |
| *GENERAL RADIO CO. | F | |
| GRUMMAN AEROSPACE CORP. | O | B |
| *GUILDLINE INSTS., INC. | F | |
| HAMILTON TECHNOLOGY, INC. | C | S |
| *HARRIS-INTERTYPE | F | B |
| HEATH CO. | O | |
| *HERCULES INC. | F | S |
| HEWLETT-PACKARD CO.; MICROWAVE | F | |

| Laboratories | ** | *** |
|---|---|---|
| HEWLETT PACKARD CO. | F | S |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| *HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| *HONEYWELL INC. | C | S |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| *HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| HONEYWELL INC. | F | |
| *HUGHES AIRCRAFT CO. | O | B |
| HUGHES AIRCRAFT CO. | O | S |
| *IIT RESEARCH INSTITUTE | F | |
| *INLAND TESTING LABS., INC. | F | |
| *INSTRUMENTS EAST | F | |
| *INTERNATIONAL TELEPHONE & TELEG | O | |
| ITEK CORPORATION | O | S |
| *KAISER AEROSPACE & ELECTRONICS | O | S |
| KOLLSMAN INSTRUMENT CORP. | O | O |
| *KOPPERS CO., INC. | O | S |
| *LAKE CENTER INDUS. | O | |
| *LEAR SIEGLER, INC. | O | B |
| *LEEDS & NORTHRUP CO. | F | |
| *CLIFTON OF LITTON INDUSTRIES | F | S |
| LOCKHEED AIRCRAFT CORP. | C | B |
| *LOCKHEED-CALIFORNIA CO. | F | B |
| *LOCKHEED ELECTRONICS CO., INC. | F | B |
| *LOCKHEED ELECTRONICS CO. (HASD) | O | B |
| *LOCKHEED MISSILES AND SPACE CO. | F | B |
| *L T I RESEARCH FOUNDATION | F | S |
| MANCIB CO. | F | |
| MARTIN MARIETTA CORP. | O | B |
| *MARTIN MARIETTA CORP. | F | B |
| *MARTIN MARIETTA CORP. | C | B |
| *MASS. INST. OF TECHNOLOGY | O | S |
| *MCDONNELL AIRCRAFT CO. | C | B |
| *MCDONNELL DOUGLAS ASTRONAUTICS | F | B |
| *MCDONNELL DOUGLAS ASTRO. WEST | F | B |
| *METTLER INSTRUMENT CORP. | O | |
| *MICROWAVE ASSOCIATES, INC. | O | S |
| *MIDWEST GAGE LABORATORY | F | B |
| *3M COMPANY--3M CENTER | F | B |
| *MONSANTO RESEARCH CORP. | O | S |
| *MOTOROLA INC. | O | |
| NAR, ROCKETDYNE DIV. | F | B |
| NATIONAL ASTRO LABS | F | B |
| NATIONAL CASH REGISTER DPD | O | S |
| *NEWPORT NEWS SHIPBUILDING & DRY | C | S |
| NIAGARA MOHAWK POWER CORP. | O | S |
| NORTH AMERICAN ROCKWELL | O | |
| *NORTH AMERICAN ROCKWELL | C | B |
| NORTHROP, ELECTRONIC DIV. | O | B |
| *PAN AM WORLD AIRWAYS, INC. | C | S |
| PAN AMERICAN WORLD AIRWAYS | | B |
| *PERKIN ELMER CORP. | O | S |
| *PHILCO-FORD CORP. | O | B |
| *QUALITY CONTROL CO. | O | S |
| RCA | O | |
| *RCA | O | S |
| *RCA INTERNATIONAL SERVICE CORP. | C | |
| RANK SCHERR-TUMICO. INC. | F | |
| *RAYTHEON CO. | O | S |
| RAYTHEON CO | O | |
| RAYTHEON CO. | O | B |
| *RAYTHEON.SUB. SIG. DIV. | F | S |
| *ROCKWELL INTERNATIONAL | F | B |
| *RUSKA INSTRUMENT CORP | F | |
| *SANDERS ASSOCIATES, INC. | F | B |
| *SANDIA LABS. | O | B |
| *SCHLUMBERGER WELL SERVICES | O | S |
| *SINGER CO KEARFOTT DIV. | F | B |
| SPERRY ELECTRONIC TUBE DIV. | F | S |
| SPERRY RAND CORP | O | B |
| *SPERRY RAND CORP. | O | B |
| SSCO STANDARDS LAB. | F | S |
| *STANFORD RESEARCH INSTITUTE | O | |
| *SWEETMAN CALIBRATION SERVICES | F | |
| *SYBRON CORP | O | |
| *SYSTRON-DONNER | C | S |
| TEKTRONIX, INC. | O | S |
| TELEDYNE MCCORMICK SELPH | F | S |
| *TELEDYNE-RYAN AERONAUTICAL | O | S |
| *TELEDYNE SYSTEMS CO | F | B |
| *TELEX COMMUNICATIONS DIV | O | S |
| TEXAS METROLOGY LAB | F | B |
| *TIMKEN CO. | O | P |
| TRANSITRON ELECTRONIC CORP. | O | B |
| *TRW SYSTEMS GROUP | F | B |
| *TUCKER ELECTRONICS CO. | F | |
| *TURNER BALANCES AND WEIGHTS | F | |
| *UNION CARBIDE CORP | C | B |
| *UNITED AIRCRAFT CORP | O | B |
| *UNIVAC | C | |
| *UNIVAC | O | S |
| *UNIVERSITY OF CALIFORNIA | O | B |
| *VARIAN | F | S |
| *VITRO LABORATORY | O | S |
| VOLUMETRICS | F | |
| *WESTERN ELECTRIC CO., INC. | O | B |
| *WESTERN ELECTRIC CO., INC. | O | P |
| *WESTERN ELECTRIC CO. | O | S |
| *WESTINGHOUSE ELECTRIC CO. | F | |
| *WESTINGHOUSE ELECTRIC CORP | F | B |
| *WESTINGHOUSE ELECTRIC CORP. | O | S |
| *WESTON INSTRUMENTS. INC. | C | |

## U.S. Government Laboratories

| Laboratories | ** | *** |
|---|---|---|
| *ABERDEEN PROVING GROUND | F | B |
| *AEROSPACE GUIDANCE & METRO. CENT | O | P |
| DEPARTMENT OF THE ARMY | O | |
| U.S. ARMY METRO & CALIB CENTER | C | P |
| *U.S. BONNEVILLE POWER ADMIN. | O | |
| *U.S. BUREAU OF MINES | O | |
| *FEDERAL AVIATION ADMIN. | C | |
| *FRANKFORD ARSENAL | O | S |
| *HARRY DIAMOND LABS | O | S |
| LEXINGTON-BLUE GRASS ARMY DEPOT | O | S |
| *U.S. MARINE CORPS | C | S |
| *NASA | C | B |
| *NASA | C | B |
| *NAVAL AIR REWORK FACILITY NORFOL | F | S |
| NAVAL AIR REWORK FACILITY | O | B |
| NAVELEXSEDIV NAVAL ELECTRONIC | | |
| US NAVAL ORDNANCE LABORATORY | O | |
| *NAVAL UNDERWATER SYSTEMS CENTER | C | B |
| *NAVY CALIBRATION LAB. | C | S |
| *NAVY EASTERN STDS LAB | F | P |
| *USN METROLOGY ENGINEERING CENTER | | |
| NORFOLK NAVAL SHIPYARD | O | S |
| *USAF TYPE II A STANDARDS LAB. | O | S |
| TYPE II STDS. LAB. PENSACOLA | C | P |
| *UNDERWATER SOUND REFERENCE DIV. | F | |
| *WESTERN STANDARDS LAB | O | P |

*Indicates NCSL member

** O Service to Parent Organization ONLY
C Available to Customers in SPECIAL CASES
F Calibration Services Available on a FEE BASIS
X Calibration Services Available on a NO FEE BASIS

*** (P) for primary standards only
(S) for secondary and/or test instruments only
(B) for both levels of work.

APPENDIX G. NORTH AMERICAN DATUM

I. PURPOSE

This report was prepared to present the need for a new general adjustment of the horizontal control system of North America in order to bring it up to modern standards as an effective reference datum for present and future surveying and mapping. The report provides background information, identifies and describes the requirements, and shows the benefits of an updated National Network. This report also discusses the work activities required to update the network and recommends a procedural plan to accomplish the job within a reasonable time frame.

II. BACKGROUND

A. Terminology

The National Network of Horizontal Geodetic Control is composed of monumented points derived from the accumulated geodetic surveys made by NOAA, its predecessors, and other Federal and local agencies since 1816. Some of the terminology which will be used throughout this paper is explained in the following paragraphs:

1. Horizontal Geodetic Surveys - Horizontal Geodetic Surveys are conducted primarily to provide measures of the interrelationships of distance, direction, and location of monumented points. The location of the points are expressed in terms of latitude and longitudes. The national system of interrelated points is called a "horizontal control network" because the correlation of other surveys is derived from and controlled by the network. The illustration below shows a brass disk monument, inscribed with its identifying station name, which is used to mark a control point.

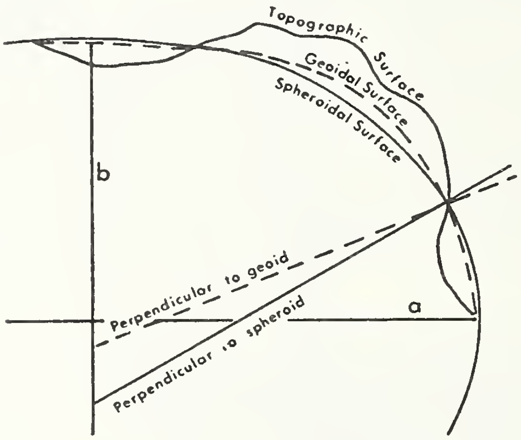
Horizontal Control Station Monument.

2. Datum - A Geodetic Datum is the base of reference for the computation of horizontal control surveys in which the curvature of the earth is considered. It consists of five quantities: the latitude and longitude of an initial point, the azimuth of a line from this point, and the two constants (polar and equatorial radii) necessary to define the terrestrial spheroid.


GEODETIC CONTROL FOR 1901 ADJUSTMENT
THE NORTH AMERICAN DATUM

3. The North American Datum - The North American Datum (NAD) is the base of reference on the North American Continent to which all geodetic control surveys of the United States, Canada, and Mexico are related. Collectively, these National Network surveys are commonly referred to as the North American Datum. The geodetic datum, or starting point, for the North American Datum is a monumented point in Kansas called Meades Ranch. The latitude and longitude for Meades Ranch are referenced to the semiaxes of the Clarke Spheroid of 1866. The Clarke Spheroid of 1866 mathematically defines the spheroid which most closely fits the geoid (the actual shape of the earth) in North America.

4. Geoid and Spheroid - The geoid is the actual shape of the earth described by an equipotential surface, or a surface that is everywhere perpendicular to the direction of gravity. Because the surface of the earth (the geoid) is irregular, and surveys must be made on this irregular surface, it is necessary to transform the surveys to a regular surface (the spheroid) to provide a uniform system of reference. The North American Datum is referenced to the spheroidal surface by geographic coordinates calculated from the dimensions of the equatorial and polar semiaxes, a. and b. These relationships are shown in Figure 1.



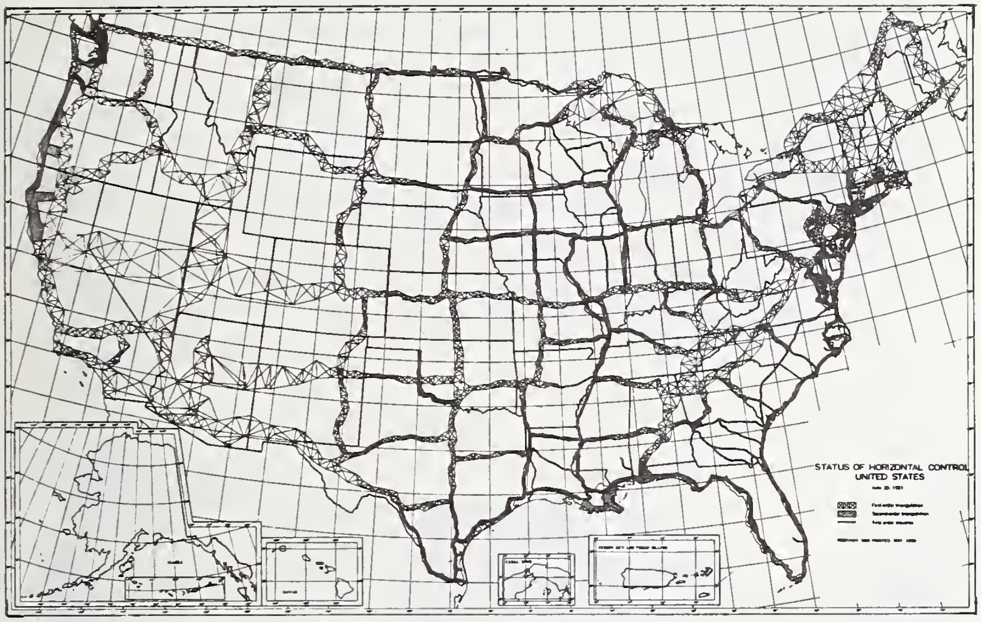

| | Clarke Spheroid 1866 (Meters) |
|---|---|
| a. Equatorial semiaxis | 6,378,206.4 |
| b. Polar semiaxis | 6,356,583.8 |

FIGURE 1.

B. Evolution of North American Datum

Incorporating surveys made for over a century and a half, the geodetic reference systen of the United States has evolved in a dynamic manner, both technologically and physically. Like any engineering creation, the structure requires timely maintenance throughout its life, and occasionally, a major overhaul.

1. Historical Development - The first official geodetic datum in the United States was the New England Datum, adopted in 1879, based on an adjustment of surveys in the eastern and northeastern states and referenced to the Clarke Spheroid of 1866, with triangulation station Principio, in Maryland, as the origin. The first transcontinental arc of triangulation was completed in 1899, connecting independent surveys along the Pacific Coast. In the intervening years, other surveys were extended to the Gulf of Mexico. The New England Datum was thus extended to the




· Geodetic control used for the 1927 adjustment.


Adjustment loops and closures for the North American 1927 Datum. Loop closures are expressed as the ratio of the distance around the loop; i.e., 1:299,000 - one part in 299,000.

Figure 2.

south and west without major readjustment of the surveys in the east. Following a new adjustment in 1901, this expanded network was officially designated the United States Standard Datum, and triangulation station Meades Ranch, in Kansas, was the origin. In 1913, after the geodetic organizations of Canada and Mexico formally agreed to base their triangulation networks on the United States network, the datum was renamed the North American Datum.

2. North American Datum of 1927 - By the mid-1920's, the problems of adjusting new surveys to fit into the existing network were acute. Therefore, during the five-year period 1927-1932, all available primary data (approximately 25,000 monumented control points) were adjusted into a system now known as the North American 1927 Datum. The extent of the horizontal control used at that time is shown in Figure 2. The skeletal-like framework formed 41 loops ranging in circumference from a few hundred to 3,000 kilometers. The average closure of these large loops, after adjustment, was in the order of one part in 300,000, which was considered satisfactory to provide basic control across the Nation for dependent surveys of that period. The loops of the framework in the 1927 adjustment confined coverage of North America to the conterminous U. S. excluding a large part of the southeastern United States, Canada, Alaska, and all of Mexico. Shortly after the eastern part of the adjustment was completed, and before the results were published, a discrepancy of approximately 10 meters in latitude along the United States border in northern Michigan was noted. The U. S. portion of the network in Wisconsin and Michigan was subsequently readjusted to absorb this discrepancy.

3. Present Status - As the years passed, the geodetic control in the United States, Canada, and Mexico has been extended and more than 100,000 monumented control points have been added to the network since 1927 as shown in Figure 3. The new surveys

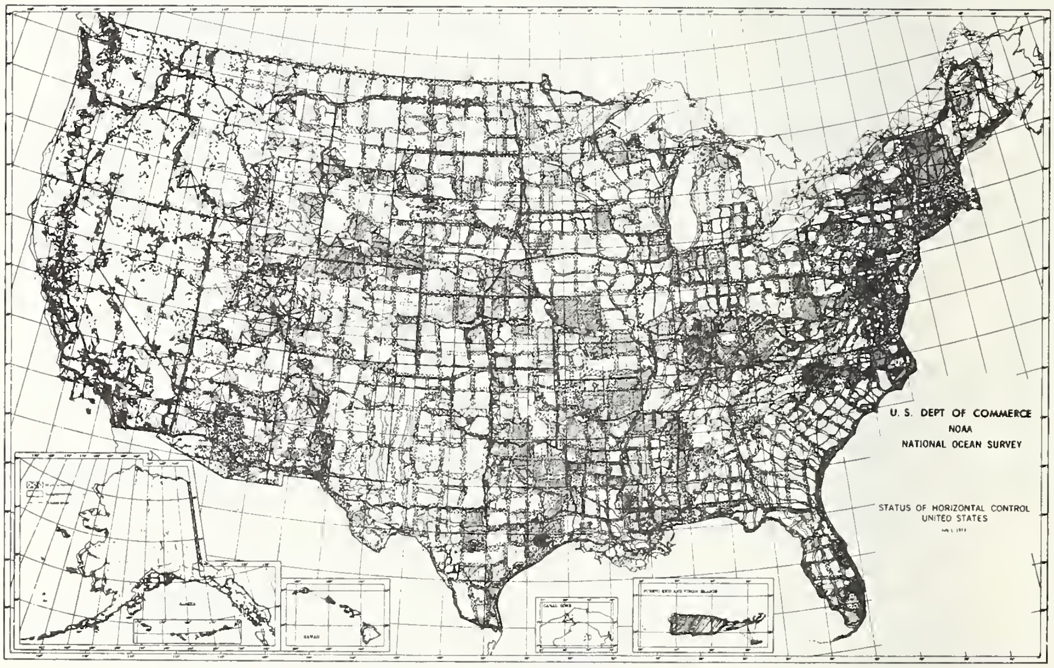



Figure 3. Status of Horizontal Control – United States, July, 1973.

divide the large loops into smaller ones and cover the interior area of some of the loops. These surveys were fitted and adjusted to the 1927 framework for a number of years without undue difficulty. But later surveys have had to be distorted by as much as one part in 15,000 (one foot in 3 miles) to fit within the loops. Analysis showed that errors and discrepancies had accumulated to as much as 10 meters and then compensated by other discrepancies of similar magnitude over the long distances in the loops.

These discrepancies went undetected until they were finally isolated through the process of fitting and adjusting. Regional readjustments were then made to distribute discrepancies over larger areas so that distortion could be minimized. These regional readjustments are a patching process that does not eliminate errors, but rather distributes and minimizes the impact (see Figure 4.).

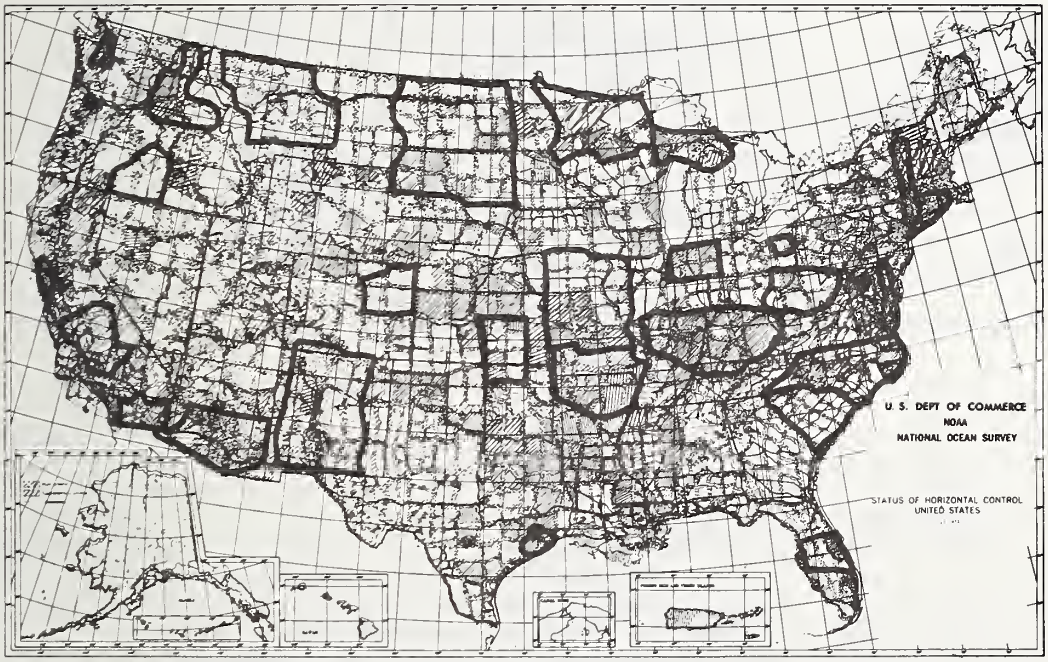



Figure 4 Regions of the United States that have required major readjustments

Other weaknesses of the 1927 adjustment include:

1. The old adjustment did not include the Atlantic Seaboard control.

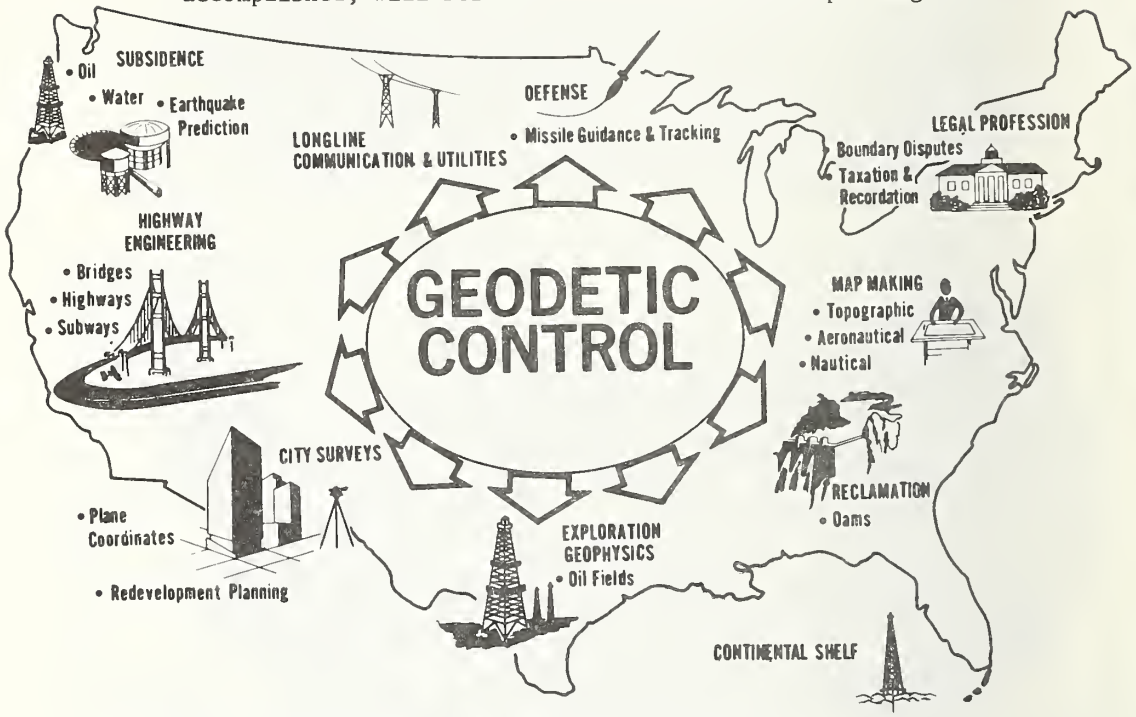
2. Length control was significantly deficient for the 1927 adjustment.

3. A number of azimuths used in 1927 have been found to be of inferior accuracy.

4. The control in Alaska was connected to the Datum during World War II by means of a single arc of triangulation along the Alaska Highway.

5. In some areas of North America, relative horizontal tectonic movements as great as 5 cm. per year have been observed.

This last point is supported by enough evidence to evoke the suspicion that many geodetic reference points move relative to each other, in addition to the probable movement of the continent as a whole. Thus, it is obvious that a geodetic reference system cannot be considered as something that, once accomplished, will serve for all time without updating.




Public Affairs Benefiting from a New North American Datum.

## III. REQUIREMENTS FOR NEW ADJUSTMENT

Since the adjustment of 1927, requirements for the fundamental network have changed, users of geodetic data and accuracy needs of the users steadily increased. A recent study of an interagency task force on Mapping, Charting and Surveying (MCS) by the Office of Management and Budget (OMB), has determined that 39 Federal agencies now conduct sizeable MCS programs which are dependent on the NAD.

Technology has introduced new and improved measuring tools to the surveyor so that the increased accuracy needs of today, which approach an order of magnitude greater than those of 1927, can be met. One of the engineering principles governing the accuracy of horizontal surveys is that the accuracy of the basic control system must be at least an order of magnitude greater than the dependent survey. Over the years, the accuracy requirements of many users have increased from one part in 25,000 to one part in 100,000. The 1927 NAD generally will support the one part in 25,000 requirements, but the one part in 100,000 control is available only in limited portions of the network.

### A. Network Users of the 1970's

The North American Datum has become truly a National base of reference in the 1970's. The range of activities that depend upon or benefit from the accuracy and reliability of these data is great. The following simple listing of activities and users that benefit from accurate geodetic information is intended to give a qualitative glimpse of their extent:

- Rural, urban, city, and regional engineers; planning, construction, and surveying groups; and related data banks
- Nationally coordinated transportation systems and other activities using geodetically controlled coordinates
- All surveys and negotiations for boundary definition, national or international - including, in the United States, the individual states and their political subdivisions
- Surveys and planning for water resources, highways, and utilities
- Mining and related engineering surveys
- Siting and national and international navigation systems
- All large-scale mapping and charting work
- Scientific users

  Federal work; Federal agency control requirements assembled by the Federal Coordinator for Geodetic Control and Related Surveys exceeded 270,000 square miles in area for FY 1975. These requirements are listed in Table 1., and they are all dependent on the NAD.

TABLE 1. FEDERAL AGENCY REQUIREMENTS
NORTH AMERICAN DATUM HORIZONTAL CONTROL
F. Y. 1975

| Dept. | Agency | Program Requirements | Area of Control (Square Mile) |
|---|---|---|---|
| DOI | Geological Survey | National Map Series | 23,600 |
| DOI | Bureau of Land Management | Land and Resource Management | 67,400 |
| | Tennessee Valley Authority | Power Plant Siting; Crustal Movement | 15,750 |
| DOA | U.S. Forest Service | Forest Management and Conservation | 68,000 |
| DOC | Soil Conservation Service | Agricultural Program Monitoring & Admin. | 7,000 |
| DOC | National Oceanic and Atmospheric Administration | Marine Surveys & Charts; Aeronautical Charts; North American Datum Maintenance & Update | 33,600 |
| HUD | | Urban Development and Renewal | 600 |
| DOD | Corps of Engineers | Public Works | 54,300 |
| | | TOTAL | 270,950 Sq. Miles |

Many of these new demands on the NAD stem from urban area expansion and renewal, extension of national and international transportation and navigation systems, land use changes and jurisdiction, etc., all of which have caused an expansion of Federal programs such as those of the Departments of Housing and Urban Development, and Transportation.

Advanced earth science studies have led many scientists to believe that we are on the verge of understanding fundamental earth processes that relate to mountain building, volcanism, and earthquake mechanisms. Historically, periodic updating and evaluation of the geodetic datum have provided the only measurements of physical changes in the earth's crust in North America. New measurements and a new adjustment of the NAD will provide updated and new information necessary for the furtherance of these studies.

B. Economic Considerations of a New Adjustment

The economic ramifications for a new adjustment of the North American Datum have increased just as the number of agencies, programs, engineers, surveyors, and scientists who depend upon the datum as a base of reference have increased since 1927.

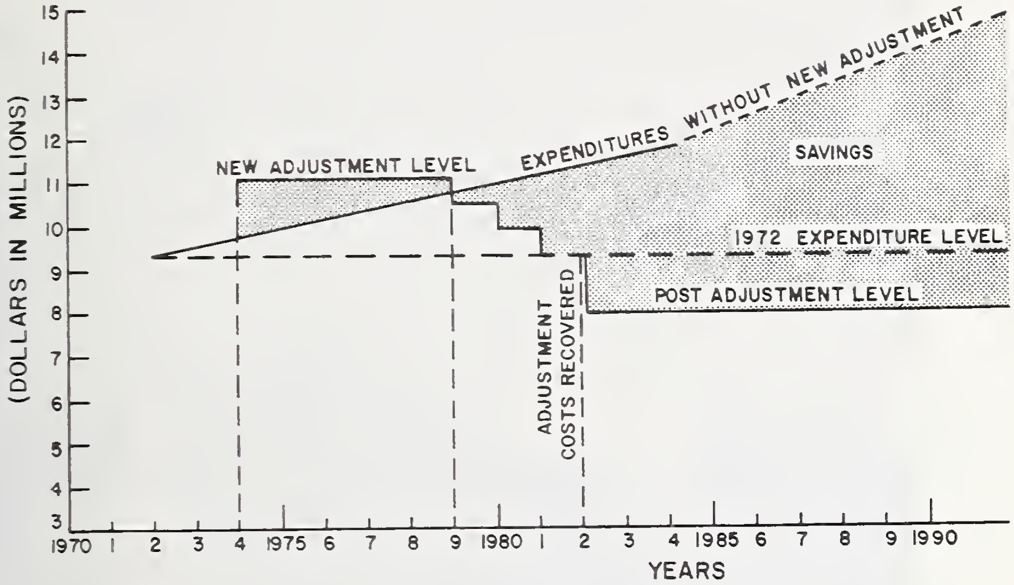
The cost of heavy construction, modern highway systems, communication networks, working satellites, urban renewal, complex record manipulation systems, etc., has greatly advanced requirements for assurance and reliability in the datum. Electronic distance measuring equipment, optical reading theodolites and both small and large electronic computers are commonly used by surveyors, engineers, data managers, and decision-makers. This relatively new technology is providing necessary accuracy and capability for the increased utilization of the National Datum by users, both new and traditional.

An estimate of the benefits from more accurate and more dense control can be derived by analyzing the costs associated with actual use of the control. The cost of new construction in the United States is something in excess of $80 billion annually. Control surveys of some type are required for all construction. Ratios derived from exerpience in engineering and land survey expansion show that 10 percent of new construction requires precise control and that one percent of the construction costs would be charged to the survey activity. Thus, of the $80 billion now spent annually for construction, $80 million is spent on survey work. Improved accuracy and increased density of the Federal Control Net would reduce these costs by 25 to 50 percent and an estimated annual benefit of $20 to $40 million would be realized. This is more than 10 times the estimated annual incremental cost of the proposed new adjustment.

The recently completed OMB Task Force report on MCS activities states that Federal agencies expend more than $300 million annually for civilian MCS products. About $75 million of this amount is for surveys which are affected by the accuracy and reliability of the National Network, and $9.4 million of that amount was spent in 1972 for horizontal control surveys that would benefit directly from a new network adjustment. Figure 10 from the OMB report shows an approximation of the benefits to be derived to the Federal agencies by increasing the expenditure level in order to complete a new adjustment in the next five years. The OMB report indicates a $1.2 million increase level between 1974 and 1979 would complete an adjustment of 90% of the conterminous 48 States, whereas NOAA's new adjustment plan provides for completion of 100% of the 48 states with an increase level of $1.5 million between 1975 and 1980.

FIGURE 10

SAVINGS
from a
NEW ADJUSTMENT OF HORIZONTAL CONTROL




C. Conclusions and Recommendations

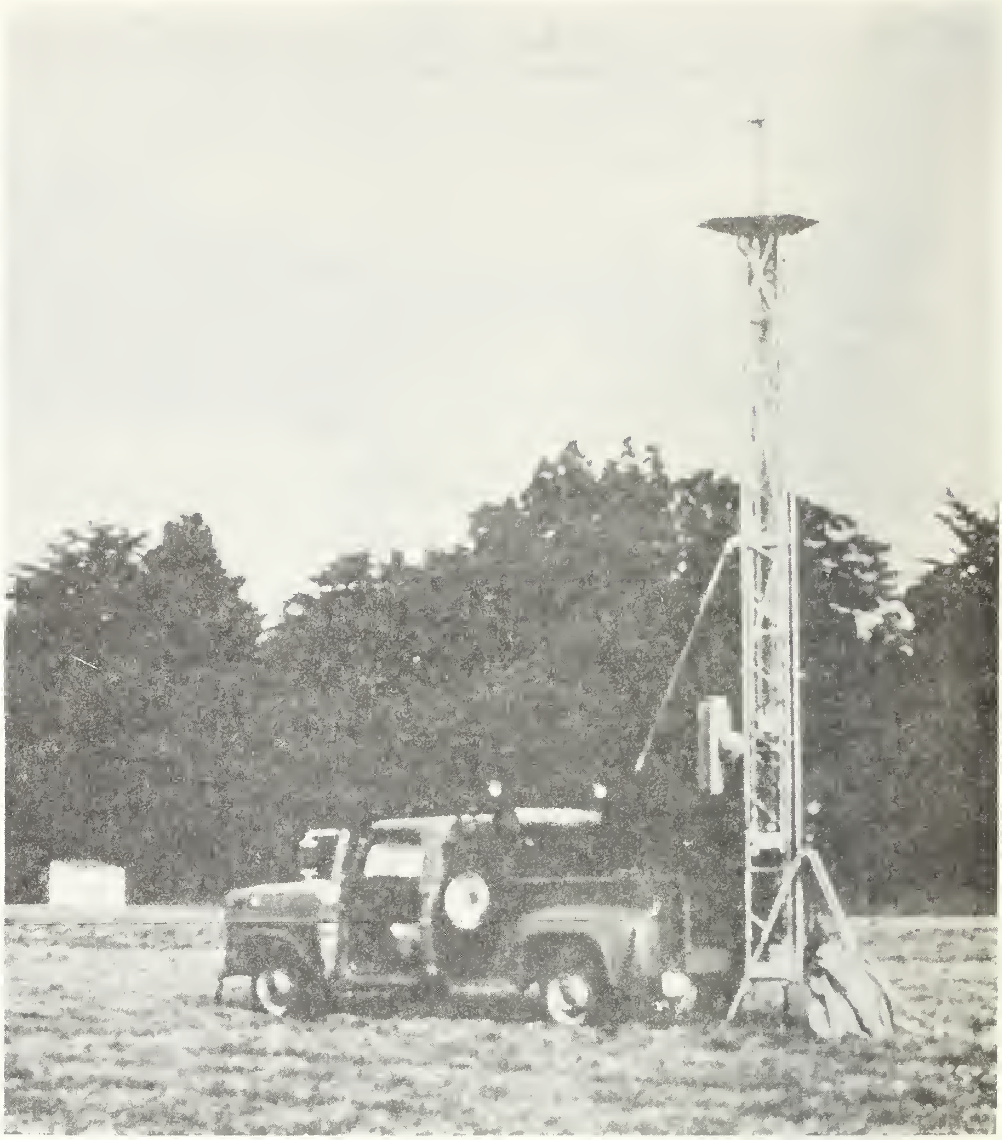
The overall conclusion is that a new general adjustment is necessary; indeed, it is overdue. Such an adjustment would provide benefits to the Nation that would be more than commensurate with the costs.

NOAA endorses the 1971 NAS/NAE report which concluded that "a new adjustment of North American Geodetic Control is necessary." -- and summarized, -- "it is clear that a new adjustment will have to be made in the next decade or half-decade." Additionally, the OMB Task Force on Mapping, Charting and Survey Activities in Federal civil agencies concluded that a new general adjustment should be completed as soon as is practicable, and the reliability afforded by updating the network will reduce the cost of mapping and surveying operations throughout the Nation.

The concern and interest of other agencies in updating the North American Datum is demonstrated by their participation in contributory studies, symposia, and field operations. The Worldwide Satellite Triangulation Network was accomplished by the Departments of Commerce, Defense, and NASA. Likewise, the DoD has performed segments of the Precise Transcontinental Traverses and the Geoceiver (Doppler) measurements, necessary for a new adjustment.

Since the Canadian and Mexican National Geodetic Networks are connected to the North American Datum, the new adjustment is also an international concern. Both bordering governments cooperated in the Worldwide Satellite Triangulation project and Canada provided manpower and transportation for observation teams. Moreover, the University of New Brunswick in Canada is sponsoring an International Symposium on the Redefinition of the North American Geodetic Network in May, 1974.

In view of the overwhelming support documented by the NAS/NAE report, the OMB study and testimony voiced by professional and scientific communities, NOAA recommends that a new general adjustment over all the conterminous states be completed by 1980.



Electronic Distance Measurements from a Portable Tower.

Recent studies by NOAA show that a new adjustment could be completed by 1980 if the work were accelerated with new resources starting in 1975. Completion of the tasks involved in the new adjustment will require an investment of approximately $16 millions over the next five years, of which $7.5 million new money is required. The major tasks involved in an adjustment are:

1. Field surveys and new distance and azimuth measurements necessary to correct known weaknesses in the North American Datum.
2. Conversion of all survey measurements and listings to automated computer format.
3. A new mathematical adjustment of the North American Datum.

## IV. ELEMENTS OF A NEW ADJUSTMENT

The task of performing a new adjustment begins with the referencing of geodetic surveys to an ellipsoid of revolution, as defined in Section II, A, using the dimensions of the earth as a frame of reference. Traditionally, these dimensions have been hypothesized from indirect measurements, but with earth orbiting satellites, we have measured directly the size and shape of the earth. In addition to providing a measure of the size and shape of the earth, the satellite triangulation also provides orientation of the continental network in the 48 conterminous states and a direct measurement and orientation to Alaska and Hawaii. Figure 5 shows a diagram of the Worldwide Satellite Triangulation Network which was completed in 1971.

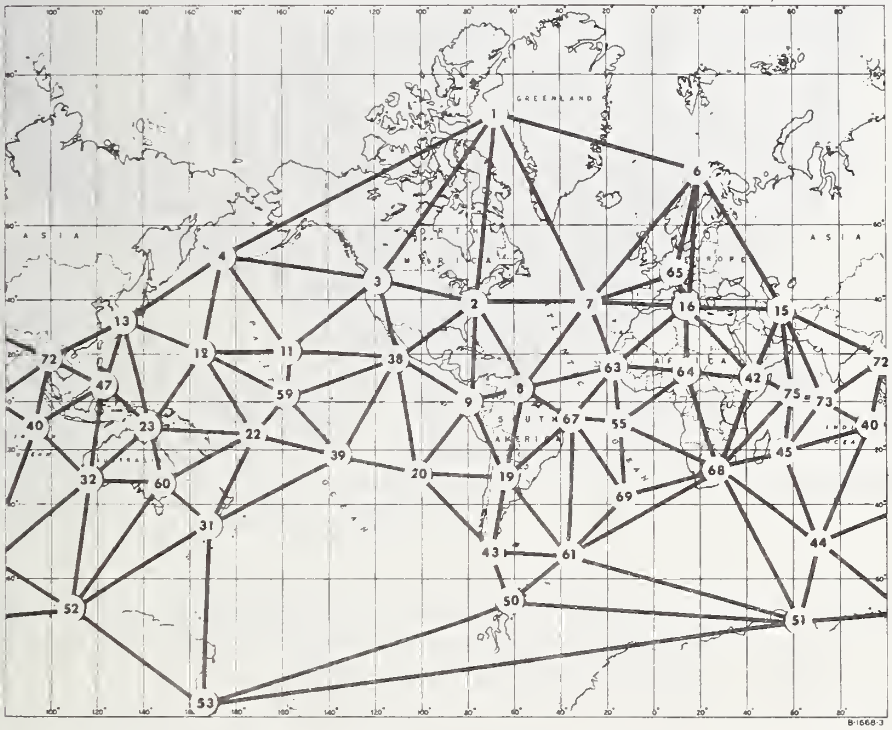



Figure 5 Worldwide geometric satellite network

Additional satellite triangulation locations have been determined to provide direct measurements over continental North America and adjacent locations to frame the North American Datum within the worldwide network. These locations are shown in Figure 6.

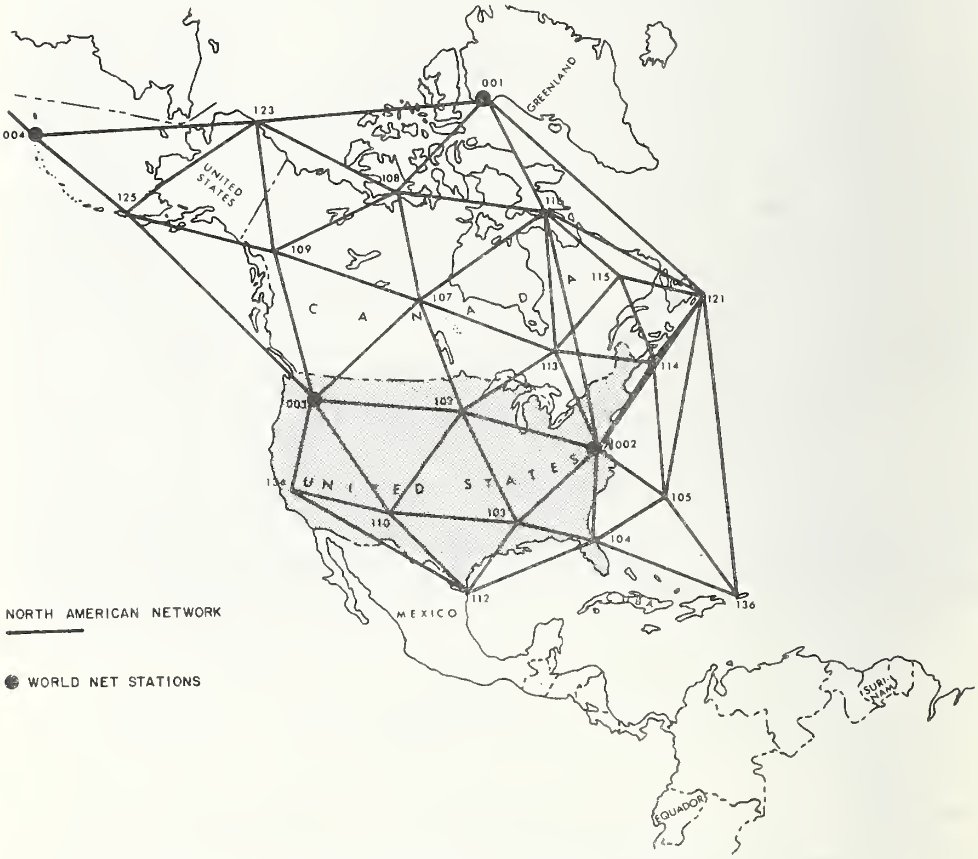



Figure 6 Satellilite triangulation in North America

A. Adjustment of the Framework

The adjustment involves dividing the United States into regions and framing the North American Datum on the surface of the continent. The partitioning and framing of the NAD is accomplished by means of precise transcontinental traverses which separate the Nation into ten regions. Geoceiver (Doppler) measurements reinforce the traverses in framing the datum for a new adjustment. The precise traverses and the geoceiver measurement locations are depicted in Figure 7.

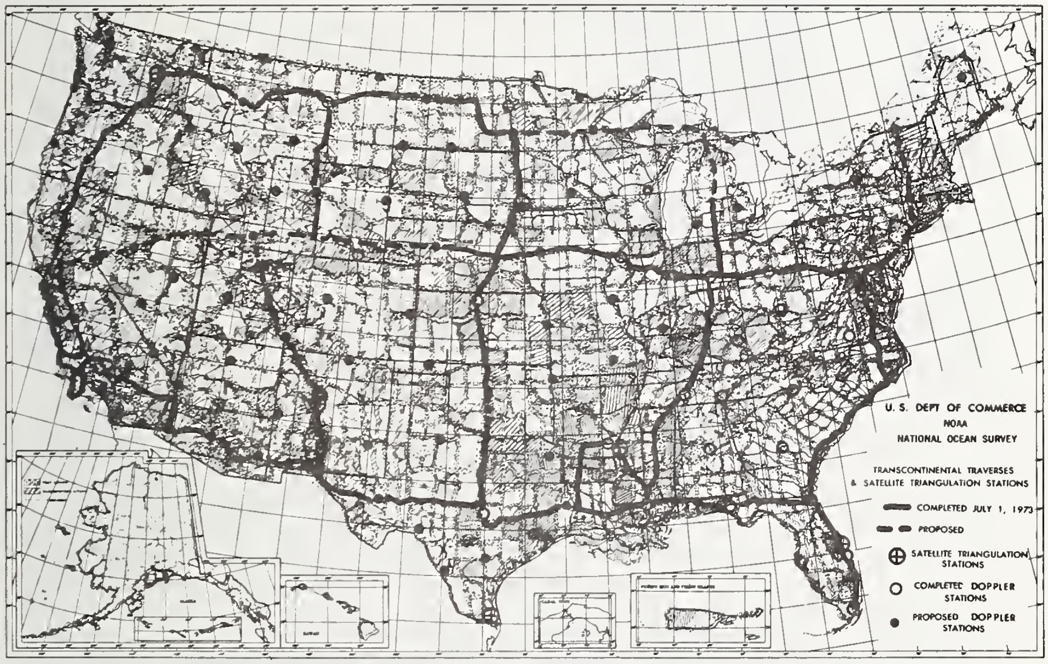



Figure 7 Triangulation, traverses, doppler and satellite triangulation stations in the United States in 1973

More than 10,000 miles of 13,000 miles of traverse depicted have been completed as have 40 of the 140 geoceiver locations.

## B. Mathematical Adjustement of the Framework

The adjustment of the framework is simply the mathematical process of manipulating the geoceiver, precise traverse, and satellite triangulation measurements in such a way that divergences in the various measurements are optimally distributed. The framework is fitted to the shape of the earth in the same process. Preliminary studies and evaluation are now in progress using the measurements that have been completed to date.

## C. Data Conversion to Automated Format

It will be necessary to convert all the pertinent information of the horizontal control network to a single automated computer format to facilitate a new general adjustment. The kinds of information pertinent to a new adjustment which must be converted to a single format for computer processing include the survey measurements of record, lists of directions, lists of locations, and descriptive information for the more than 125,000 monumented points in the network at this time.

The initial steps to convert the data are in progress. Computer programs are being prepared and key punching of basic information is underway. Other forms of data are being assimilated for the conversion.

## D. New Measures for the Adjustment

The new surveys required to facilitate a new adjustment of the network are essentially distance and direction measurements. The measurements will provide direct connections between key parts of the network and new baselines and azimuths in known weak areas, as illustrated in Figure 8.

The new measurements will involve approximately 600 baselines and azimuths and 5300 miles of new surveys in the 8 regions of the conterminous United States. New measurements are being made in Regions 1 and 2 to accommodate the scheduling priorities set forth later in the study.

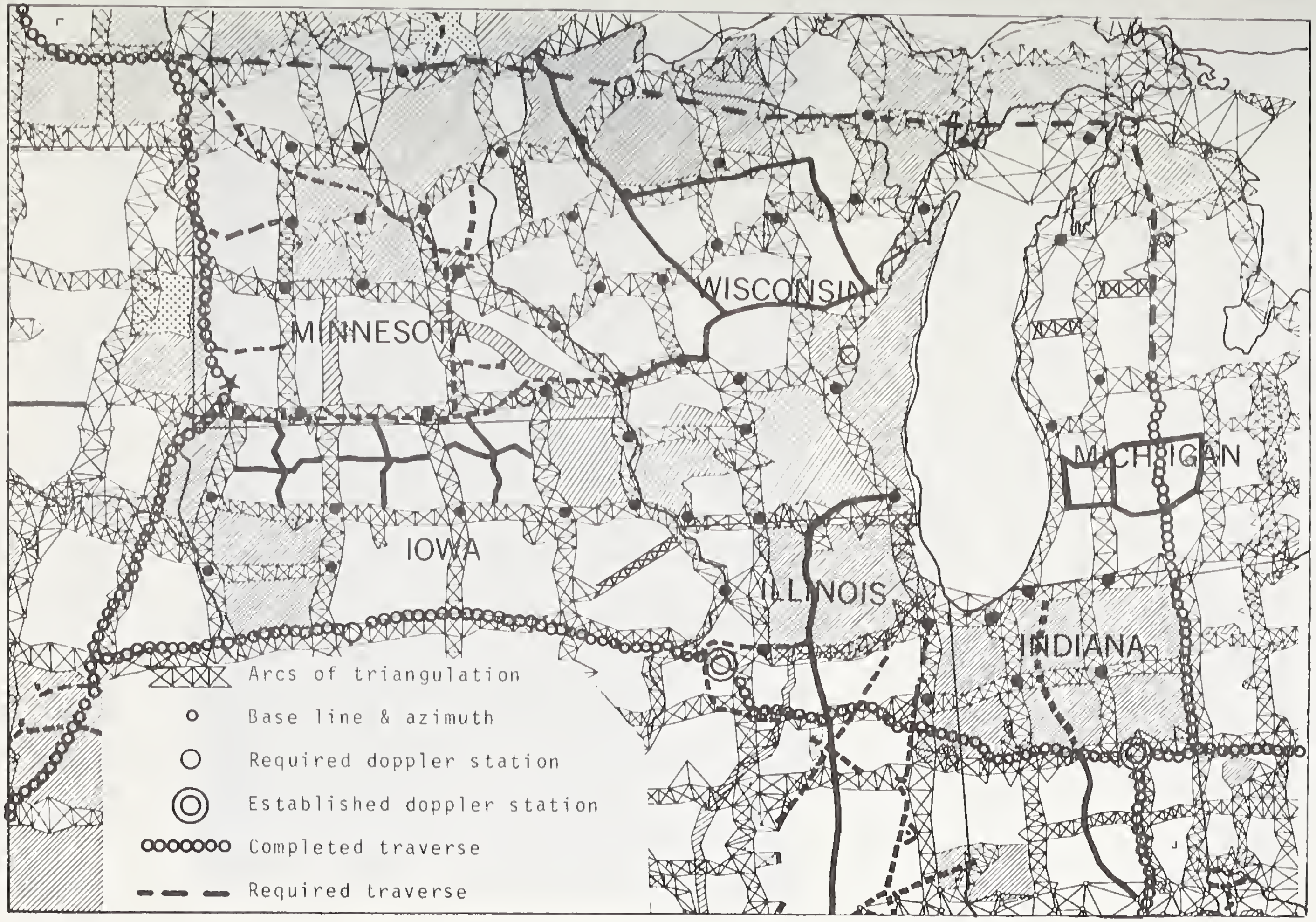



Figure 8 New measurements required for new adjustment

## E. Adjustment for a New North American Datum

The actual mathematical adjustment will involve a number of steps summarized briefly as:

1. Computer analysis of network surveys

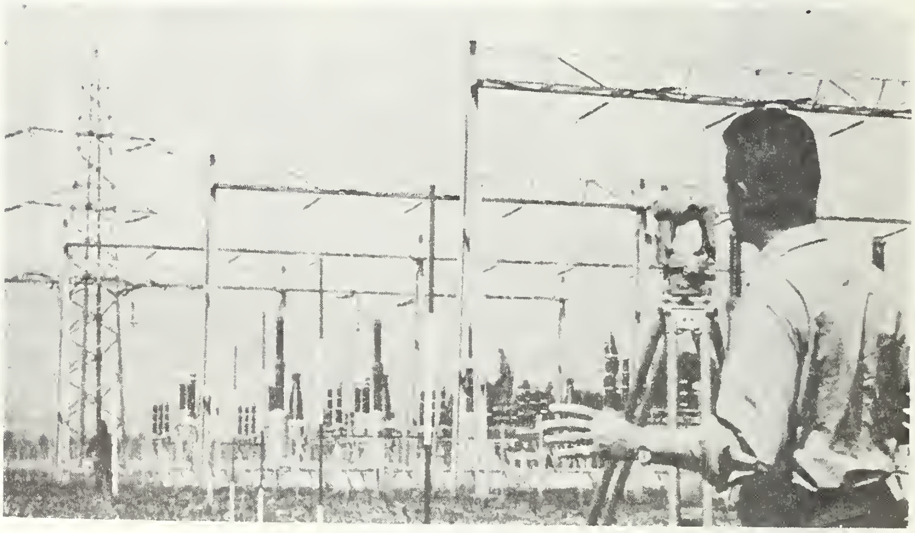
2. Computation of sections of the network within a region

3. Preliminary adjustment of the network by region

4. Final mathematical adjustment of network in each region

5. Assimilation of final data and publication of the new North American Datum.

Computer analysis of network surveys in Region 1 have been initiated.



Survey and Development Engineering Dependent on the North American Datum.

## V. OPERATIONS PLAN

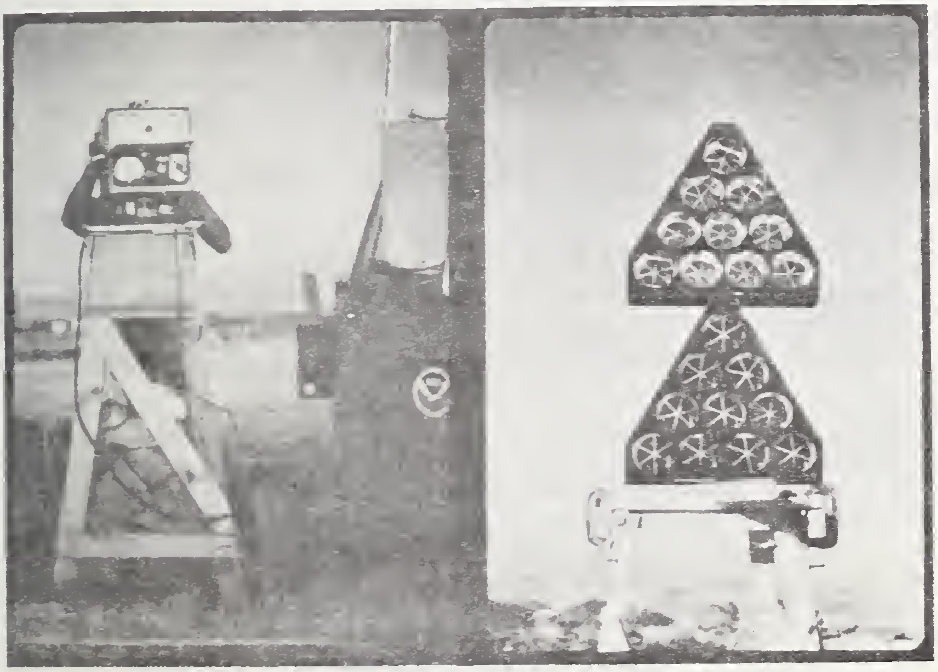
The tasks outlined in the preceding sections must be accomplished systematically and undertaken in a coordinated manner to accommodate sequential integration as the work proceeds. The operational plan which follows is recommended for implementation, and provides for:

a. Completion of a general adjustment and new North American Datum by 1980.

b. Publication of the new datum for all conterminous states by 1980.

c. Maximum and efficient utilization of base program resources and facilities.

d. The beginning of benefits returned to the public by July, 1978.



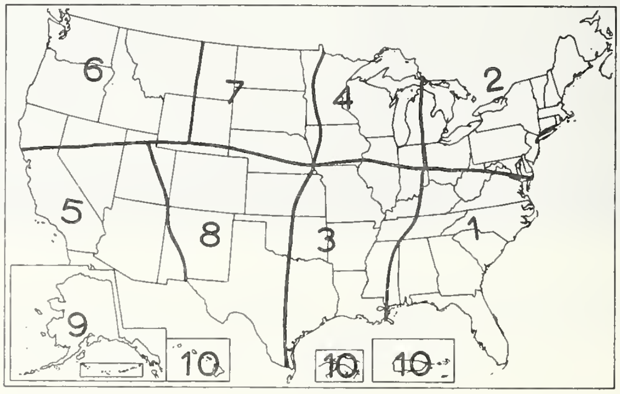
Light wave distance measuring on the Precise Traverses in the Framework.

The plan to achieve a new adjustment of the North American Datum is relatively straightforward. The tasks to be performed have been sequentially scheduled and milestones to mark significant events have been established. Table 2 shows the schedule of milestones to be completed during the five-year (1975-1979) period and the regions in the Table are outlined on the accompanying diagram of the United States.

TABLE 2.

OPERATIONS SCHEDULE-NEW ADJUSTMENT NORTH AMERICAN DATUM

| MILESTONE | FISCAL YEAR 1 1975 | 2 1976 | 3 1977 | 4 1978 | 5 1979 | 6 1980 |
|---|---|---|---|---|---|---|
| Perform field surveys forming a framework for updating the North American Datum. | Doppler & TCT. Regions 1-4 | Doppler and TCT Regions 5-8 | Framework completed, Jan. 1977. | | | |
| Perform an adjustment of the framework for updating the North American Datum | Analyze Framework Data Regions 1 - 8 | | Adjust Framework. | | | |
| Perform the new measurements required and final adjustment of the network in Regions 1 & 2 of the 10 Regions of the country | Azimuth and Distance Measurements and Network Analysis. Regions 1 & 2. | | | Adjustment Completed. | | |
| Convert all survey measurements and listings to automated computer format. | Regions 1 &2 | Regions 3 &4 | Framework and Regions 5 and 6. | Regions 7 and 8 | Final Revision to Format. | |
| Perform the new measurements required, final adjustments for Regions 3 - 8, -- the finish of the new adjustments in the 48 conterminous States. | New Azimuth and Distance Measurements and Network Analysis. Regions 3 - 8. | | | | Final Adjustment Regions 3 - 8 | Publish North American Datum |
| Initiate the area Adjustments in Regions 9 & 10 (Alaska and Hawaii). Distribution of the new North American Datum. | | | | | Framework and Data Conversion. Regions 9 and 10. | |



The first main milestone will be reached in FY 1977 upon completion of the remaining 4500 kilometers of precise transcontinental traverses and 100 Doppler (Geoceiver) measurements which form the framework for updating the North American Datum. This framework will be fitted to the Worldwide Satellite Triangulation Network and thereby relate North America to other continents as well as to the shape of the earth. In addition, the traverses will provide the framework with a uniform standard of accuracy in all regions of the country. The Doppler measurements will reinforce the precise traverses and extend uniform accuracy into the interior of the regions.

The second milestone involves combining the Doppler, precise traverses, and satellite triangulation measurements into cohesive mathematical relationships, resulting in a mathematical adjustment of the framework for the new datum. It will be accomplished in 1977, immediately after all measurements for the framework are completed.

Milestone 3 will be reached when final adjustment is completed for Regions 1 and 2 in 1978. This means that all survey listings will have been converted to computer format, the network surveys analyzed, and new measurements to correct discrepancies and strengthen weak areas finished prior to the final adjustment which will provide cohesive mathematical relationships between all network control points in Regions 1 and 2.

Milestone 4 marks the finish of the conversion of the North American Datum records to automated computer format so that the listings of geographic positions, survey measurements and descriptive information for all 48 conterminous states will be accessible by computer for final adjustment of remaining Regions 3 - 8. The conversion of data is a major task which must be carefully coordinated in the earlier stages to facilitate the adjustment of the framework, analysis of survey network and systematic final adjustment beginning with Regions 1 and 2.

Milestone 5 marks the completion in 1979 of the new horizontal control network adjustment in the 48 conterminous states. It means that after all data have been converted in format, the network surveys analyzed, and required new measurements made, the final adjustment makes an updated North American Datum a reality, after approximately 50 years since the 1927 adjustment.


Geodetic control in North America in 1973 which will be updated by the new adjustment.

## VI. RESOURCE REQUIREMENTS/SCHEDULE

The operations schedule covers a six-year period, extending one year beyond the five years required to complete the new datum for the 48 conterminous states. Implementation of the tasks, which are outlined will require resources in excess of those which are available from base program funding during the course of the project.

Resources required to produce the new NAD will total $15.7 million during the five-year course of the project. Of this amount, $8.2 million will be made available from base program funding and additional new funding amounting to $7.5 million ($1.5 million in each of the years), will be required.

Resource requirements for the sixth year (FY 1980) to extend new NAD adjustment operations into Alaska, Hawaii and our Caribbean Islands (Regions 9 and 10) amount to $0.2 million.

Table 3 lists the total resource requirements and the application of base program and new funds which will be applied toward completion of the milestones in the operations schedule.

TABLE 3.
SCHEDULE OF RESOURCE REQUIREMENTS

| | FUNDING IN $ (Thousands) | | | | | |
|---|---|---|---|---|---|---|
| MILESTONES | FY 75 | FY 76 | FY 77 | FY 78 | FY 79 | FY 80 |
| PERFORM FIELD SURVEYS FORMING A FRAMEWORK FOR UPDATING THE NORTH AMERICAN DATUM. | 426 (497)* | 765 | 576 | | | |
| PERFORM AN ADJUSTMENT OF THE FRAMEWORK FOR UPDATING THE NORTH AMERICAN DATUM. | 133 ( 26)* | 141 | 108 | | | |
| PERFORM THE NEW MEASUREMENTS REQUIRED AND FINAL ADJUSTMENT OF THE NETWORK IN REGIONS 1 AND 2 OF THE 10 REGIONS OF THE COUNTRY. | 470 (488)* | 1130 | 329 | 155 | | |
| CONVERT ALL SURVEY MEASUREMENTS AND LISTINGS TO AUTOMATED COMPUTER FORMAT. | 327 (180)* | 507 | 497 | 428 | 243 | |
| PERFORM THE NEW MEASUREMENTS REQUIRED, FINAL ADJUSTMENTS FOR REGIONS 3-8, -- THE FINISH OF THE NEW ADJUSTMENTS IN THE 48 CONTERMINOUS STATES. | 368 (309)* | 677 | 1711 | 2816 | 2485 | |
| INITIATE THE AREA ADJUSTMENTS IN REGIONS 9 AND 10 (ALASKA AND HAWAII). DISTRIBUTION OF THE NEW NORTH AMERICAN DATUM. | | | | | 91 | 140 |
| BASE PROGRAM FUNDS TOTAL | 1724 | 3220 | 3161 | 3399 | 2819 | 140 |
| NEW FUNDS* TOTAL | (1500) | | | | | |
| GRAND TOTAL | 3224 | 3220 | 3161 | 3399 | 2819 | 140 |

The project will involve 564 man-years of effort over the five-year period as shown in Table 4. Four new positions will be required to initiate the acceleration of effort with new FY 1975 funds. The remaining personnel requirements will come from base Geodetic Surveys and Services programs. Contract efforts will be used to the maximum extent possible for the new surveys and data conversion for machine processing.

TABLE 4.

PERSONNEL REQUIREMENTS FOR NEW ADJUSTMENT
(MAN-YEARS OF EFFORT)

| FY 75 | FY 76 | FY 77 | FY 78 | FY 79 | TOTAL |
|---|---|---|---|---|---|
| 98 | 108 | 118 | 136 | 104 | 564 |

## APPENDIX H. THE ANSI OPTIMUM METRIC FASTENER COMMITTEE

The ANSI Special Committee to Study Development of an Optimum Metric Fastener System was appointed by the American National Standards Institute in April, 1971. Briefly stated, its purpose and objectives are:

Develop a system of mechanical fasteners, to be stated in metric units of measure:

(1) To incorporate into the design of each fastener technical refinements contributing to improvement in performance capability.

Object -- cost reduction through technical improvement.

(2) To simplify to the absolute degree possible the number of items recognized as standard in the system.

Object -- cost reduction through simplification.

More specifically, the committee is developing a total system of mechanical fasteners with dimensions and properties stated in metric units. In its work, it is exploring all opportunities to improve the design of each fastener in every way which will enhance its performance capability. It is limiting to the fewest possible, the number of different sizes, series, types and styles, and grades of fasteners to be recognized as standard. The new system will take full advantage of all new ideas, and modifications in product design. It will be as non-disruptive of existing metric practice as possible.

Target completion date for basics of the system is the spring of 1974.

Scope - The scope of the OMFS study extends to the entire mechanical fastener field with priority given to threaded fasteners and associated specifications such as screw threads, material and performance, quality assurance and product design.

NBS has participated in this study through one of its staff who is a member of this committee. At their request, NBS has gaged several hundred screws and nuts, of various sizes, selected randomly from several screw manufacturers to determine if the thread elements of these samples were within the limits specified by Handbook H28, Screw-Thread Standards for Federal Services. The data from this sampling will be used by the Committee to determine the thread tolerances for the proposed Optimum Metric Screw Thread System.

Organization and Membership - Committee relationships to the USA, Canadian, and international standards groups are shown in figure 1. The chart shows the relationships between the worldwide organization (International Organization for Standardization-ISO)

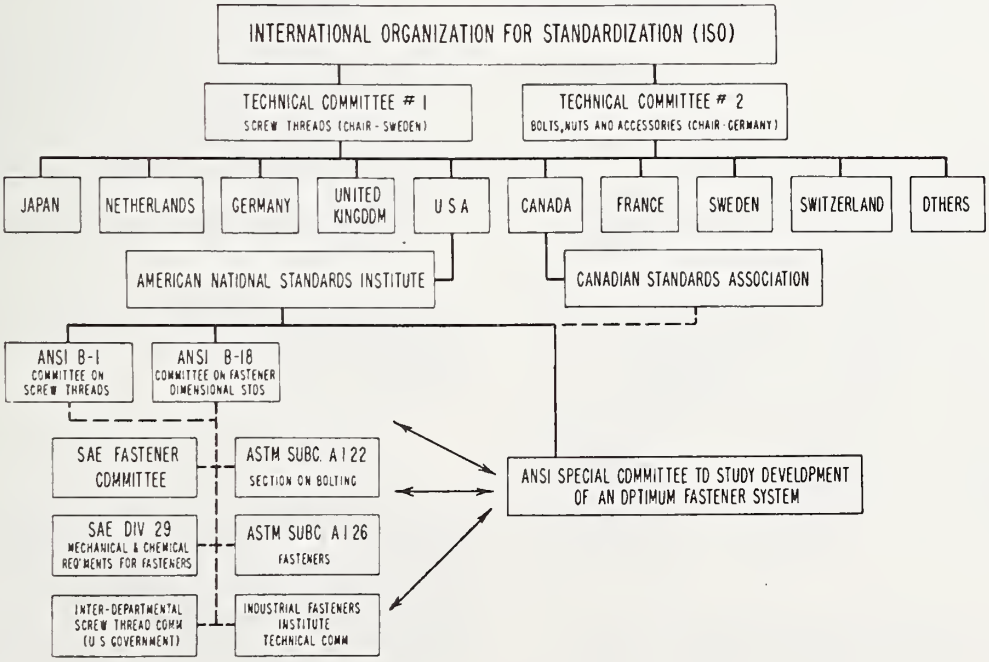



Figure H-1. Committee relationships.

with its two major technical committees (screw threads and fasteners) and the standing committees affiliated with American National Standards Institute. The ANSI Special Study Committee was created as an agency serving all of these USA committees to avoid duplication of effort and to assure a prompt and thorough study.

Because of the mutual interests of USA and Canada, this special committee is maintaining liaison with the Canadian Standards Association, as well as ANSI. Several special subcommittees have been created within the Committee to define, more specifically, the task, recommend priorities, and to conduct the extensive technical investigations.

Committee membership is limited to assure that the effort does not become cumbersome, but, at the same time, assure that adequate expertise representing all disciplines is available. Approximately 40 percent of the members represent users of fasteners, 40 percent represent producers, and the remainder represent U.S. government, Canada, aerospace, and overseas interests as shown below:

Member Affiliation Summary

| | |
|---|---|
| User-Industrial, Auto & Agricultural | 11 |
| Government | 2 |
| Manufacturer - U.S. | 8 |
| - Canada | 2 |
| Total Members | 23 |
| Technical Consultants, Aerospace, and Europe | 5 |
| Total | 28 |

A membership roster and how the OMFS is organized into six subcommittees is shown in figures 2 and 3.

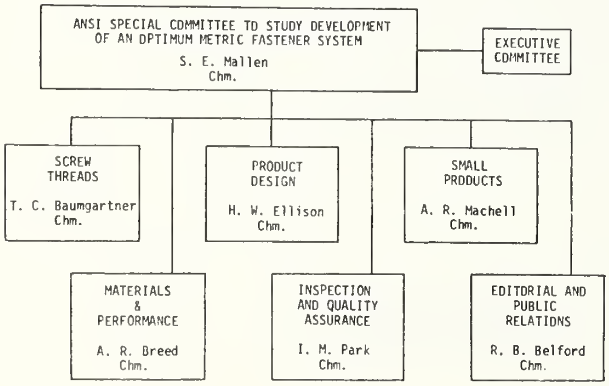



Figure H-2. The six subcommittees of the organization Optimum Metric Fastener System.

- MEMBERSHIP ROSTER -

Stanley E. Mallen, Chm., Ford Motor Co.
Arthur R. Breed, Vice Chm., The Lamson & Sessions Company
John J. Artman, Department of Defense
John W. Axness, Deere & Company
Donald N. Badgley, Clark Equipment Company
Thomas C. Baumgartner, Standard Pressed Steel Company
Richard B. Belford, Industrial Fasteners Institute
Geoffrey Dreger, P. L. Robertson Manufacturing Company, Ltd.
H. William Ellison, General Motors Corp.
Norman B. Johnston, Intl. Harvester Co.
Rudy C. Kozlik, National Lock Fasteners, Div. of Keystone Consolidated Ind.
Frank V. Kupchak, Westinghouse Electric Corp.
Jack B. Levy, General Electric Company
Arthur R. Machell, Xerox Corporation
John C. McMurray, Russell, Burdsall & Ward Bolt and Nut Company
Herman G. Muenchinger, Continental Screw Co.
Joseph S. Orlando, ITT Harper Inc.
Ian M. Park, The Steel Co. of Canada, Ltd.
Jack Shugart, Rockford Products Corporation
Arthur G. Strang, Natl. Bureau of Standards
Louis R. Strang, Caterpillar Tractor Co.
William M. Thatcher, US Steel Corporation
David W. Vial, Chrysler Corporation
C.J. Wilson, (Secy), Ind. Fasteners Inst.

European Liaison Representative

Peter J. Gill, GKN Screws & Fasteners Ltd.

Technical Consultants

Robert M. Byrne, U. S. Screw Bureau
Ernest J. Heldmann, Holo-Krome Company

Aerospace Technical Consultants

Lloyd W. Justice, General Electric Company
B. H. Beal, Grumman Aerospace Corporation

Corresponding Liaison for Australia

J. R. Paton, Standards Assoc. of Australia

Figure H-3. ANSI Special Committee to study development of an optimum metric fastener system.

## INTERNATIONAL PROCEEDINGS

Background - The ultimate objective of the ANSI Special Committee is to design a metric fastener system sufficiently attractive technically and economically that it will become the single internationally accepted system of mechanical fasteners. Very early the Committee recognized that success in achieving this goal depended largely on establishing a close and continuing liaison with fastener producing and using industries in other principal industrialized countries of the world. The Committee fully appreciated that all recommendations and proposals originating from its studies would eventually have to be channeled through ISO procedures. Consequently, one of its first efforts was to arrange a working two-way information exchange.

ISO - the International Organization for Standardization - is a federation of the national standards bodies of the countries of the world. The responsibility for development and issuance of international standards is assigned to Technical Committees. Technical Committee 1 (TC1) on Screw Threads and Technical Committee 2 (TC2) on Fasteners are the two Committees sharing responsibility for standards relating to threaded fasteners. Both Committees have functioned for over 20 years, both have accomplished a great deal, and both are still extremely active with the pace of accomplishment, particularly TC2, accelerating dramatically during the past five years.

Official contact between the ANSI Special Committee and ISO was not possible until such time as specific proposals were ready for submittal to TC1 or TC2. However, "unofficial" contact was not only desirable but viewed as mandatory by the ANSI Special Committee.

Immediately after its appointment in April 1971, the Committee made its first international overtures. In May, six of its members visited with industry representatives in Sweden (the Secretariat of TC1), France, Germany (the Secretariat of TC2), and England. The purpose of these four meetings was to describe the new activity, to explain why this program of study was being undertaken, to suggest the potential benefits which could be shared by all countries of the world, and to invite participation and technical input from all interested sources. In July, two fastener experts from England met in the USA with several of the Committee members to gain a fuller understanding of the Committee's intentions and plans. Shortly after their return to Europe, a request was received and quickly accepted that a European Liaison be appointed to membership on the ANSI Special Committee.

In May 1972, the Committee, again represented by a six-man delegation, presented an in-depth report in London, England describing progress of its first year of study.

In January 1973, it was apparent that studies on screw threads, diameter-pitch series, and strength grades for ferrous fasteners would be finalized within a few weeks and that it was now an appropriate time to formalize contact between the Committee and the ISO Technical Committees. However, before submitting specific and detailed proposals, the Committee felt it would best serve all interests if some preliminary discussions could be arranged to informally explore the possibility of merging OMFS proposals into existing and planned ISO standards.

In early February, one of the Committee members met with representatives from Germany, Sweden and England to plan the most suitable means for bringing the principal ISO interests together for an exploratory discussion of OMFS proposals.

Shortly after this meeting, the Chairman of TC1 and TC2 jointly announced appointment of an ISO/TC1/TC2 Ad Hoc Advisory Panel and extended invitations to 29 fastener experts from 14 countries to serve as members. A first meeting of the Panel was scheduled for May 28-30 in Frankfurt, Germany with the main agenda item being discussion of OMFS proposals. This Engineering Report was then prepared by the Committee and sent to all members of the Ad Hoc Advisory Panel in late April.

Ad Hoc Advisory Panel Meeting - Attending the Frankfurt meeting were 38 representatives from 12 countries - Austria, Canada, France, Germany, Hungary, Italy, Japan, Netherlands, Sweden, Switzerland, United Kingdom and USA. The ANSI Special Committee was represented by nine of its members. The only members of the Panel not attending were those from Russia and Czechoslovakia; however, the latter communicated their comments through the Hungarian member. It was fully understood that commitments were neither being sought nor would any be given. The prime objective was to review progress of the OMFS studies and comment on the possibility of ISO acceptance of OMFS proposals already completed and predictable recommendations which might originate from other areas of study still underway. A report of the Panel's views follows:

Screw Threads - The Panel accepted the OMFS statistical evaluation which proves the improbability of interference occurring when internally threaded fasteners having ISO metric screw threads are mated with externally threaded fasteners having OMFS threads. There was no fear that mated fasteners with the two thread systems would not function safely and without noticeable strength-of-connection difference. The Panel expressed no criticism of the OMFS contention that a more generous radiusing of external thread roots enhances a fastener's fatigue resistant properties.

There were no technical criticisms of the OMFS recommended profile, however, the majority of the Panel opposed any change to the ISO basic thread profile - the reason offered was a general reluctance to change from a profile adopted by ISO in 1958, one which has necessitated major manufacturing change by most metric countries and one which has so far proven satisfactory. The Panel appreciated that the principal reason for the reduced thread height of the OMFS basic thread profile was to accommodate a larger root radius on the external thread. It pointed out the possibility of achieving an increase in root radius without an accompanying change to the ISO basic profile by adjusting minor diameter tolerances. The Panel urged the ANSI Special Committee to consider this possibility, accept the ISO profile and then work cooperatively with other countries in TC1 to achieve the desired larger root radiusing of external threads.

There was little discussion of the OMFS proposals to define thread limits of size using the boundary method and also using basic major diameter rather than pitch diameter as the dimensioning reference datum. The Panel noted the simplicity of this concept and anticipated no problem affecting interchangeability of product if it is used.

The Panel was extremely complimentary of the new gaging system. It viewed the double NO-GO gaging concept as a significant technical advance and predicted favorable consideration by TC1. It was suggested the technique might be best suited for acceptance gaging of only those products intended for high-fatigue service because of a suspected higher gaging cost. In reply, the OMFS representatives reported work is underway to evaluate gage wear, gaging time, and other expense items occurring during routine production and receiving inspection. They expressed an opinion that results would be favorable and that in North America, the new gaging practice would not be limited in its application.

The Panel expressed concern with the OMFS proposal to reduce screw thread tolerances and allowances from those now specified for the current ISO grade 6g/6H. It urged the ANSI Special Committee to reconsider and hopefully accept the ISO tolerancing system.

In summary, the Panel was generally complimentary of the proposed OMFS screw thread system. It agreed there should be little, if any, problems in mismatching of fasteners if the OMFS system was introduced as proposed and the ISO system was continued without revision. It asked, however, that the ANSI Special Committee review its recommendations with respect to the basic thread profile and to tolerances and allowances and learn if some modifications could be accepted to bring the two systems into conformance.

Diameter-Pitch Series - It is interesting to note that of the 25 diameter-pitch combinations, 20 are ISO standards. The five combinations that deviate were proposed for two separate reasons: (1) The Committee was genuinely concerned that the fineness of ISO thread pitches for the 3, 3.5, 4 and 5mm sizes could cause installation problems during high-speed driving on fast-moving assembly lines. Such troubles have been experienced when using fine thread fasteners in sizes No. 4 thru No. 8, and the Committee was fearful of a reoccurrence particularly as ISO metric coarse pitches in these sizes are as fine or finer than inch series fine threads, and (2) The Committee's proposal that a new size, 6.3mm, be introduced was warranted by the favorable results of both technical and economic studies.

The Ad Hoc Panel was very much opposed to recommending ISO recognition of the OMFS slightly coarser pitches for the 3, 3.5, 4, and 5mm sizes. The principal concern was the chance of mixing and mismatching fasteners having OMFS pitches with those having ISO. Several members of the Panel disputed that problems would occur during high-speed assembly and stated their own industries' experiences have been entirely satisfactory. On this basis, the OMFS representatives offered to recommend to the ANSI Special Committee that the ISO coarse pitches for these four sizes be provisionally accepted and that actual assembly line testing be conducted to verify that the ISO pitches would be suitable. If such research indicated that a legitimate problem existed, then the ANSI Special Committee would return to the Panel with the technical evidence to support the need for a coarser series of thread pitches for the four sizes 3 thru 5mm.

There was general agreement by the Panel that the economics favored a single intermediate size between the sizes 5 and 8mm. Optimism was expressed that TC1 would act favorably in giving ISO recognition to such a new diameter-pitch combination. The OMFS simulation studies showed the economics strongly support the 6.3 x 1 size.

The ANSI Special Committee has still much work to do. However, the principal features influencing interchangeability between systems - screw threads, diameter pitch series, strength grade properties - are not reasonably finalized and have been explored internationally. Based on the co-operative spirit evidenced at the Frankfurt meeting, it now appears that a single internationally acceptable system of fasteners can become a reality.

## REFERENCES


[1] 43rd Australian-New Zealand Association for Advancement of Science Congress, 1971.

[2] Quality Management & Engineering, July, 1973.

[3] Correspondence with Mr. J. C. McKinney Chief of the Army Standards Lab.

[4] Hughes Research Laboratories, Malibu, California

[5] NBS Technical News Bulletin, March 1967, p.43.


## BIBLIOGRAPHY


Publications

Standard & Poor's Corporation Reg. 1974.

Standard & Poor's Yellow Sheets.

Value Line Investment Survey, 1974.

Moody's Handbook of Common Stocks, 1973.

Annual Survey of Manufacturers 1970-1971, US Dept. of Commerce, Bureau of Census.

US Industrial Outlook, 1974, US Dept. of Commerce.

NBS SP329, An Index of U.S. Voluntary Engineering Standards.

U.S. Department of Defense, Index of Specifications and Standards, May, 1973.

General Services Administration, Index of Federal Specifications and Standards, (FPMR 101-29.1), Jan. 1, 1973.

NBS SP375, An Index of State Specifications and Standards.

Specifications and Tests of Metal Cutting Machine Tools, University of Manchester Institute of Science and Technology, Machine Tool Engineering Division, April 30, 1970.

Lane, Donald L., Method for Evaluation and Certification of the Moore No. 3 Universal Measuring Machine, Report UCRL 50679, Lawrence Radiation Laboratory, June 1969.

Census of Manufacturers, US Dept. of Commerce, Bureau of the Census, 1967, 1963.

US Dept. of Commerce, social and Economic Statistics Administration, Bureau of the Census, Preliminary Reports, 1972 Census of Manufacturers, Industry Series, MC72(P)-35C-4, Machine Tool Accessories, SIC 3545, issued March 1974.

US Dept. of Commerce, Bureau of the Census, Annual Survey of Manufacturers, 1971, M71(AS)-2.

Predicasts, April 27, 1973.

Selected Electronic and Associated Products, Series MA-36N(71)-1, 1971, US Dept. of Commerce

Mechanical Engineering and Management, (trade journal), August 1972.

Iron Age (trade journal), Oct. 25, 1973.

American Machinist, (trade journal), Oct. 15, 1973.

Bendix Technical Journal, (trade journal), Summer/Autumn 1972.

Laser Focus, (trade journal), Jan. 1973, Oct. 1973.

Optical Spectra, (trade journal), May 1973.

Hewlett-Packard Journal, August 1970.

North American Datum, report from National Academy of Sciences and National Academy of Engineering.

American Machinist, (trade journal published by McGraw-Hill), Oct. 29, 1973.

Petroleum Facts and Figures, American Petroleum Institute, 1971.

NBS Handbook H28, Screw Thread Standards for Federal Services.

NBS-114A (REV. 7-73)

| U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET | 1. PUBLICATION OR REPORT NO. NBSIR 75-926 | 2. Gov't Accession No. | 3. Recipient's Accession No. |
|---|---|---|---|
| 4. TITLE AND SUBTITLE<br>THE NATIONAL MEASUREMENT SYSTEM FOR LENGTH AND RELATED DIMENSIONAL MEASUREMENTS, PART I | | | 5. Publication Date<br>August 1976<br>6. Performing Organization Code |
| 7. AUTHOR(S) J. W. Lazar and R. L. Bach | | | 8. Performing Organ. Report No. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>NATIONAL BUREAU OF STANDARDS<br>DEPARTMENT OF COMMERCE<br>WASHINGTON, D.C. 20234 | | | 10. Project/Task/Work Unit No.<br>11. Contract/Grant No. |
| 12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* | | | 13. Type of Report & Period Covered<br>14. Sponsoring Agency Code |

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*


The determination of length and related dimensional measurements constitute the largest group of measurements made in science, manufacturing and technology. We have shown that length and related dimensional measurements have impact upon many areas of the economy. We have also shown that the National Measurement System is viable and is adaptable in conforming to the changing requirements of industry. The greater accuracy requirements of some industries brought new measurement techniques into use, e.g. the fringe counting laser interferometer systems now used in many tool rooms and metrology laboratories. We have found no deficiencies in the system but only in individuals or the measurement technique that they use as shown in the comparison measurement on audit packages that were made by the various standards laboratories.


17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Dimensional; gage; instrument; laser; length; machine; measurements; standard.

| 18. AVAILABILITY ☐ Unlimited | 19. SECURITY CLASS (THIS REPORT) | 21. NO. OF PAGES |
|---|---|---|
| ☒ For Official Distribution. Do Not Release to NTIS | UNCLASSIFIED | |
| ☐ Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 | 20. SECURITY CLASS (THIS PAGE) | 22. Price |
| ☐ Order From National Technical Information Service (NTIS) Springfield, Virginia 22151 | UNCLASSIFIED | |

USCOMM-DC 29042-P74