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January 18, 2012

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This letter serves as NIST's final response to your requests for DTIC Report AD-255023, DTIC Report AD-290128, DTIC Report AD-486987 and DTIC Report AD-B963237.

NIST has completed the review of the provided records and we are releasing in their entirety documents AD-2555023, AD-290128 and AD-86987.

Document AD-B963237 is being returned to DTIC for processing.

Sincerely,

Catherine S. Fletcher
Freedom of Information Act Officer

Enclosures

NIST

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THE STANDARDS LABORATORY AND ROCKET TESTING

by
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THE STANDARDS LABORATORY AND ROCKET TESTING

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Abstract

The responsibilities of the Standards Laboratory center on the following activities: 1. The development of a national system of standards of measurement under ideal, or "laboratory" conditions. 2. The furnishing of a calibration service which permits the transfer of the system of standards. 3. Collaboration with users of standards in the development of methods of measurement under "field" conditions. 4. Advising users on the best utilization of standards. 5. Getting advice from users about likely future needs for standards.

Several problems arise in the interaction between the Standards Laboratory and the user. These problems include the exchange of technical experience, the early and accurate identification of future standards needs, the establishment of a consistent set of relations of standards, traceable to the National Bureau of Standards.

A. Introduction

The present discussion will concentrate on the role of the National Bureau of Standards, the national standards laboratory, in the field of rocket testing. For this purpose we must consider not only what goes on at the test stand during a particular test, but also a great many things which lead up to this. Fundamentally, the problem is one of measurement. Every test of a rocket component, such as its motor, or its guidance system, or of the whole rocket in a test firing, comes down to a decision about adequacy of performance, and this decision is based on a series of measurements. It is possible to look on this problem as one involving the steps of sensing, transmitting, storing, processing, and analyzing large volumes of data. Such an approach has the advantage of presenting a "systems" approach to the problem of measurement. The "system" here is the totality of the steps referred to above. This whole system must perform adequately to achieve the basic task, i.e. to provide the data on which the decision about the adequacy of performance of the rocket must be based. We are actually dealing with the interactions of two complex systems: The rocket system and the measurement system. To this extent, the problem is one in communication theory and in operational analysis. Such an overall approach to the interactions and the performance of both systems is not yet feasible to carry through, though apparently some attempts are being made along these lines. In this paper we shall focus attention on parts of this complex interaction, principally those involved in sensing, transmitting, storing, and processing of data. We shall limit ourselves further to the highly specialized function of the NBS in this chain of steps.

B. The Mission of NBS

It may be useful to recall briefly the statutory function of the NBS. The chief functions are listed in the Organic Act[1] and they may be summarized as follows:

The NBS shall undertake the custody, maintenance and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards. The NBS shall test, calibrate and certify standards and standard measuring apparatus.

The NBS shall determine physical constants and properties of materials when such data are of great importance in science or technology, and are not to be obtained with sufficient accuracy elsewhere.

It is clear that this statutory mission is exceedingly broad, and that it must therefore be interpreted in practice in a manner consistent with limited resources. Concretely this means that the following tasks must be carried out[2].

1. The development of an integrated and coherent system of standards and methods for measurement, under ideal, or "laboratory" conditions.

2. The furnishing of calibration services which make possible the transfer of these standards to other laboratories.

3. Research and development leading to methods of measurement useful in non-ideal, or "field" conditions. (This must be done in collaboration with various "customers", because the NBS cannot usually duplicate the elaborate field facilities involved. This is a particularly severe problem in the field of rocket testing, and will be discussed below.)

4. Exchange of advice with users of the standards concerning best use of these standards, and also concerning present and future needs of users.

C. Rocket Testing and Precision Measurement

Problems of precision measurement enter into rocket testing in at least two ways. Obviously, the measurements being made at the test stand or on the firing range must be accurate enough to be able to decide whether or not performance criteria are being met, and the measurements must "tie in" with, or be clearly related to, the national system of standards. This means that the standards for these measurements must be traceable to NBS, through a chain of calibrated instruments. This requirement of traceability is easier to state than to fulfil, however, and it will be considered as a separate problem below. But the problems of precision measurement (and of traceability) arise well before the hardware reaches the test stage. Every piece of the hardware has been designed and manufactured using measurement techniques for specification and control, and therefore must rely on the national system for standards of measurement. Unless all the measurements involved are mutually consistent, the functioning of the hardware is jeopardized[3]. This problem is already a serious one, because of several difficulties. First, it is difficult to ensure traceability of all standards to NBS (more on this below). Second, modern requirements for accuracy in technology, and particularly in rocket technology, are extremely severe. There exist several cases where the factory working standard[4] for length, which is used on the assembly line to check every item which is produced, must be so accurate that it must be compared directly with the national standards, so as not to lose accuracy in the usual transfers of the calibration through a series of reference and working standards. In other words, the hardware requirements are beginning to push very seriously on the national standards of measurement. This trend will increase as hardware requirements become more severe. The consequences of this trend may be far reaching. A third difficulty arises from the fact that many design variables have to do with quantities which are as yet not susceptible to adequate scientific analysis, and therefore cannot be brought into the national standards scheme in a consistent way. One example of this will have to suffice. The behavior of the nose cone material at re-entry is difficult to describe. The relations of surface temperature, chemical reactions, ablation, interactions with the shock wave, etc., are only partially understood. Hence it is impossible to give a completely consistent description in terms of the usual variables of what is desired. As a consequence, only full-scale tests are really able to decide whether the basic design criterion (i.e. effective re-entry) has been met[5]. This difficulty also is likely to become more serious as time goes on.

It is, therefore, perfectly clear that precision measurement plays an essential role in rocket testing. On the other hand, it is also clear that there are large and important areas where the art of measurement has not sufficiently advanced to be able to play its role adequately.

There are a number of serious problems which must be overcome if the field of rocket testing is to be adequately served by the NBS. These problems are now being attacked in a variety of ways, and will no doubt be solved eventually. They may be grouped as follows. First, there are those problems which arise because the essential role of measurement is not being recognized in many quarters[6]. This means that standards programs generally lack the support and the glamor of other fields. This limitation operates within private corporations, universities, and the Federal and State Governments.

The second group of difficulties has to do with the technical problems associated with the science of measurement. The third group of difficulties consists of problems that are essentially administrative, and have to do with organizational and institutional matters. The second and third groups of difficulties are examined in some detail below.

D. Technical Problems in the Science of Measurement

It is obviously impossible to give here an exhaustive description of all major technical problems, or even to list all of them. A few typical examples must suffice.

The measurement of high temperatures, say above 5000°C in the laboratory, and typically above 1000°C in field applications presents some very difficult conceptual problems. These problems have to do with the fact that the concept of temperature becomes inexact in the absense of thermodynamic equilibrium[7]. At the temperatures mentioned this difficulty becomes serious, and it is not yet altogether clear what should be done about it. The whole complex of problems associated with "fast" temperature measurements, those carried out in a very short time, is tied in with this problem. Considerable basic and applied research is needed[8] before simple and useful standards can be defined. At the same time, problems of this sort must be attacked at a practical level by the designer and test engineer. Only close cooperation will lead to generally useful results.

Thrust must be measured accurately for the adequate prediction of rocket performance. Thrusts in the million pound range must now be determined with an accuracy of 0.1% or better[9]. New facilities for the accurate calibration of cells used in these measurements are being designed and will be constructed[10].

A vast array of standards in the radio and microwave region must be created to meet the demands of the industry. Frequency standards, power-, impedance-, and attenuation standards are required[11].

Better measurement of angles and lengths (including inside diameters of small holes) are typical of other requirements.

No field of measurement seems to be "immune" from the requirements of the rocket test engineer, and in most fields substantial progress must be achieved, and achieved quickly.

The basic national standards must be made more accurate in those fields where they already exist, and they must be created where none exist. To make the basic standards more accurate, more and more of them are being referred to atomic and molecular properties. This trend was advocated by the British physicist J. C. Maxwell 90 years ago[12](1) but only now are his recommendations being implemented. Thus length and time (frequency) will soon be defined in terms of atomic properties and temperature is defined in terms of the triple point of water (the fixed point of the Kelvin <u>thermodynamic</u> scale).

Another necessity is the following: In every calibration of an instrument in terms of a standard, some accuracy is lost, and the calibrated instrument will not be as accurate as the standard. This is a phenomenon inherent in the measurement process, and nothing can be done about it as such. The extent of the loss of accuracy can, however, be limited. Several approaches help in this regard. The more automatic the calibration process can be made, the less loss of accuracy there is. This is due to the elimination of human error, of psychological "noise" because of subjective human reactions, and because with an automatic system many more calibration points can be obtained in a given time, thus improving the statistics of the transfer. Another improvement is the processing of the data of the calibration by means of high speed electronic digital computers. This results in improvements similar to those just mentioned[13]. An additional important improvement which follows from automation of measurement and data reduction is to speed up the calibration process significantly[14].

E. Management Problems in the Science of Measurement

The problems of this type again fall into several broad categories. The first of these categories has to do with problems entirely internal to NBS. At NBS, we must understand our mission better and must do an ever improving job. The second broad category of problems has to do with the relations of the users of our product, i.e., standards, with NBS. The third category involves only the users. This paper will concentrate on the second of these, i.e., the relations between the users of standards and NBS. There are many such relations, as will appear shortly.

The first problem in order of priority is to find out at NBS what the needs for standards and calibrations are. This is less easy to achieve than it sounds. The problem has two parts: the short-range needs (present needs, and say, those for the next two years), and the long-range needs (two years and longer). The implied lead times may look unrealistically long, but it is an unhappy fact that it takes about half a year to set up a calibration laboratory if the basic science and measurement techniques are in hand and if the desired accuracy is only average, and that it takes one to two years to set up a calibration laboratory if the required accuracy is very high. It takes <u>at least</u> three years of basic work <u>before</u> the calibration laboratory can be set up if the basic science or the measurement techniques are <u>not</u> in hand. It is therefore absolutely essential to get indications of significantly greater requirements three to five years in advance of the need for calibration, if the needs are to be met.

It is relatively straightforward to discover present needs. Interest in this problem has grown very rapidly in recent years. Thus, a recent study by the Aerospace Industries Association, carried on in cooperation with the U. S. Air Force and the NBS, has given very valuable information on the measurement problems in the industry[15]. Such studies enable the NBS to tell what standards are needed, but at least as important, they make easier the setting up of some priorities among the many demands made upon NBS.

Studies of all types bring another difficulty to light. Occasionally requirements for accuracy are indicated which are completely unreasonable in terms of the state of the art. This leads to closer examination of the requirement, and it sometimes turns out that the supposed requirement was based on a fundamental misconception, or on an attempt to "play it safe" to an impossible degree.

Partly because of this type of difficulty, but more because of a general need, we have set up now, together with the AIA, a series of conferences at NBS, each of which concerns only one type of measurement, and to which are invited engineers and scientists from industry and NBS. At these conferences standards can be examined in detail, future possibilities explored, and much advice and stimulation given and received.

The problem to discover long-range needs for standards appears to be at present unsolved despite the urgent need to know future requirements. The chief difficulty seems to be that those who make long-range design studies usually do not attempt to estimate the probable implications in the area of measurement of various design requirements. Somehow we have "muddled through" with this difficulty in the past. But as time goes on, it seems to become increasingly important to solve this problem.

A problem of great urgency and complexity is that of traceability of all measurements to NBS. This is a fairly straightforward problem to solve if the measurement is something clear-cut such as length, time, etc., where good national standards and calibration methods exist. To say this is not to underrate the considerable practical problems involved in setting up and keeping "alive" such a calibration chain throughout so large an industry as the missile industry. Of course one must require more than a mere "pedigree" for a particular standard. What is needed most is "accuracy at the point of measurement". If this is achieved, then the basic requirement of consistency can be met. But at least the problem is conceptually fairly simple. On the other hand, what about standards of roughness, or "sphericity" of spheres, or of temperature in a rocket exhaust? What is to be done about traceability if no standard exists either because it is not yet possible to define an adequate one, or else because the technical problem is not clear enough conceptually? In some of these cases it is probably necessary to adopt interim standards of a quality inferior to that of those established in other fields. In other cases it may be necessary to adopt standard practices for a measurement in a complex and poorly defined situation, and hope that this will meet the practical need. The problem of traceability is enormous. Only a major effort by all concerned will make all measurements compatible.

Related to the problem of traceability is another one of great urgency and complexity. All industries use various practices which control the quality and performance of devices. Examples are tolerances, finish, etc. Many of these features must nowadays be made compatible, because of the greater demands made on devices. But most, if not all, of these do not correspond to standards in the sense in which we understand the word usually. Can one give a standard for sphericity, for example? It seems to me that there is a vast area of engineering where some standard techniques and practices would be highly desirable, but which cannot ordinarily be furnished by NBS. Who should do this? Can the various industry associations establish standards in this field? Recently an ad hoc committee has explored the possibility of forming a "Council of Standards Laboratories". Such an organization might well take the initiative to establish and promulgate "recommended practices", which might then be published as "standard practices" by the American Standards Association.

Another area of serious difficulties exists. The need for collaboration between NBS and industry to produce methods of measurement for non-ideal, or "field" conditions was mentioned above. For example, we wish to test some ideas on the measurement of temperatures in the exhaust gases of a rocket motor. But it is difficult to find an organization, which has realistic facilities, where some of these could be tied up in a "research" program. It is apparently true in most organizations active in this field, that the research departments do not have realistic facilities, and that the "hardware" departments have such strenuous test schedules that they cannot afford to use the facilities part-time for research. This case is typical of a general problem. There is at present no adequate effort going into attempts to translate refined methods of precision laboratory measurements into

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precise, but usable field measurements. Yet, it seems to me, if rocket testing is to become as effective as it needs to be, we shall have to find ways of bridging this gap. This can only be done by a cooperative effort. The facilities required for this are completely beyond the resources of NBS. Yet effective cooperation on this type of problem is, so far, the exception rather than the rule[16].

Finally, there are two problems which are serious, but are on the way to their solution. The first concerns the need for authoritative publications which describe in detail the "best" techniques for precision measurement. Of course NBS has published papers, circulars and reports on such matters since its formation, but it is realized now that this program needs to be stepped up significantly. This is being done now[17]. And last, but surely not least, is the problem of finding skilled personnel for precision measurement, both in industry and at NBS. A great step forward was taken recently toward a long range solution of this personnel shortage when the George Washington University, in Washington, began planning a curriculum for undergraduate and graduate work in precision measurement. This program will be carried on with the technical help of NBS and with the financial support of a private company, and should be under way early in 1961.

F. Summary

The problem of the relation of the standards laboratory to rocket testing is a complex one. Many scientific and engineering problems must be solved before adequate standards exist and can be disseminated adequately. Many administrative problems also remain to be solved. Most of these are complex, and do not admit of easy solution, partly because they are related to unsolved technical problems, partly because their solution requires active, even spirited, cooperation between many independent organizations. This paper has raised problems rather than attempted many answers because of the conviction that we must understand the full complexity of the over-all problem to take effective action.

Footnotes and References

1. Act of March 3, 1901 (31 Stat. 1449) as amended.

2. From here on we shall concentrate on the "measurement" aspects of the NBS mission. The "materials" aspects, while very important in the field of rocket technology in general, are related only indirectly to the subject of this paper.

3. It turns out that occasionally trouble develops because two subcontractors use different methods to calibrate instruments. For example, it has happened that two subcontractors calibrated their A.C. measurement equipment at quite different frequencies. This is an obvious example of a potentially troublesome situation. More subtle difficulties have also been found.

4. For a proposed system of nomenclature of standards of different "seniority", see McNish, A. G., "Classification and Nomenclature for Standards of Measurement", I.R.E. Transactions on Instrumentation, December, 1958, pp. 371-378.

5. The enormous cost of such an approach is evident. Less than ten test firings of large missiles cost as much as it costs to operate the whole NBS for a year.

6. Dr. A. V. Astin, Director, NBS, has often drawn attention to this phenomenon. See, for example, Astin, A. V., "Precise Measurement and the Race for Technological Supremacy", The Magazine of Standards, vol. 29, February 1958, pp. 37-40.

7. Herzfeld, C. M., "Incomplete Equilibrium and Temperature Measurement", J. Wash. Acad. Sci., vol. 46, no. 9, 1956, pp. 269-275.

8. Some of this work is now going on. See, for example, "Measurements and Standards in Plasma-Physics and Astrophysics", NBS Technical Note 59, Edited by Branscomb, L. B., July 1960.

9. Detailed studies have shown that enormous savings of resources and time could be accomplished in test firing programs, if this accuracy could be guaranteed in thrust measurement.

10. NBS Technical News Bulletin, vol. 43, December 1959, p. 240. This issue of the Technical News Bulletin contains a survey of many of the problems considered in this paper as well as valuable references to the literature.

11. Reference 10, pp. 226-233.

12. Maxwell, J. C., "Address to the Mathematical and Physical Sections of the British Association", Liverpool, September 15, 1870, published in "The Scientific Papers of James Clerk Maxwell", Dover Press, New York, 1956, vol. II, p. 225.

13. Reference 10, p. 245.

14. The cost per calibration is probably less for highly automated procedures than it is for manual procedures. It is, however, useful to remember the very large capital investment required to change from manual to automated procedures.

15. Reference 10, p. 222.

16. It should be pointed out that this problem is understood by most people active in the field. Certain well-established procedures of procurement, budgeting, and management stand, however, in the way of a satisfactory solution.

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This is a new type of problem (at least in the present context) and it will require new administrative approaches for a long-range solution.

17. NBS Handbook 77, "Precision Measurement and Calibration", vol. I, II, and III, compiled by Booth, Sherman F., in press.