Introductory Remarks

HISTORICAL ACCOUNT OF THE SYMPOSIUM

It is not my duty to inform you in detail of the objectives and specific format of the Symposium; I will leave that to the Organizing Committee and others. For now, just let it suffice for me to tell you that the objectives are different and the format is different from any other Fatigue Symposium which you may have attended or experienced.

Regardless of the specific objectives, however, the underlying purpose of this and any symposium is interchange of ideas, and we trust that this purpose will be served in exemplary fashion. As part of my message to you today, I wish to trace the history of ASTM Committee E-9 on Fatigue, which is the sponsor of the symposium.

The Committee, as it is now constituted, has been in existence for nearly 40 years; however, its roots trace back much farther than that. In 1928, the ASTM Research Committee on Fatigue was formed under the leadership of Professor H. F. Moore. This Committee served the Society until 1946 at which time it was dissolved and its duties were transferred to the ASTM Committee E-9 on Fatigue, which was formed at the ASTM Annual Meeting 1946 in Buffalo, New York.

The membership of the first Advisory Committee, now called the Executive Subcommittee, was comprised of individuals whose names will be familiar to all of you who are familiar with the fatigue literature. The Chairman was R. E. Peterson; the Secretary was O. J. Horger; other members were M. A. Grossman, J. M. Wassels, H. F. Moore, and R. L. Templin. From an initial membership of 53, Committee E-9 has now grown to its current membership of 378; this is a very current figure, among which are included many international members.

Since 1946, the Committee which meets twice annually has been sponsor or co-sponsor of 60 or more fatigue symposia, as well as many, many workshops and less formal technical meetings. Sponsorship of this current symposium and other fatigue symposia is quite consistent with the overall scope of the Committee. Bear with me while I read verbatim the scope of our Committee E-9 on Fatigue.

"The formulation of methods for the determination of the fatigue characteristics of simple and composite materials, the promotion of research leading to the determination of the nature of fatigue, and to methods for determining fatigue characteristics and the coordination of society activities in these areas conducted by other committees."

Now, I underscore the words, *Promotion of Research Leading to Determination of the Nature of Fatigue* because this is exactly the underlying purpose of this Symposium. Fulfillment of this purpose moreover is entirely consistent with the other elements of the Committee's scope. In particular, we view the maintenance of a continuing research forum within the Committee as a most instrumental and necessary precursor to the creation and advancement of standard methods for fatigue testing and evaluation, this being the consummate function of our Committee.

Now, the credit for creating this Symposium and the immediately-preceding workshop, which was held in Arlington, Texas, last week, must go to the Symposium Organizing Committee, the Program Committee, and the International Advisory Board. There are many names—too numerous to cite here, however, I would be remiss not to mention the names of Dr. Jeffrey Fong, Professor Robert Wei, and Dr. Louis Coffin, for their considerable efforts in this regard.

I also cite the generous financial contributions of the following organizations which have provided travel grants which have helped many of you to attend this Symposium. They are the U.S. Army Research Office; the U.S. Office of Naval Research; Alcoa Laboratories of the Aluminum Company of America; the Boeing Commercial Airplane Company; Exxon Research and Engineering Company; General Dynamics Corporation; Corporate Research and Development Laboratory of the General Electric Company; Lockheed California Company; McDonnell Douglas, and MTS Systems Corporation.

Unquestionably, I must also cite the considerable contributions of the National Bureau of Standards in terms of personnel staff time in the organization of this Symposium. I also must cite the personal commitment to this field of fatigue by all of you, and your employers in providing the funds to send you here because without you, there would be no Symposium.

John T. Cammett
Vice president, Metcut Research Associates, Inc., Cincinnati, Ohio; past chairman of ASTM Committee E-9 on Fatigue.

The International Role of ASTM

The topic I will address with you this morning is the general issue of standards organizations in the international arena. For the past several years, we have all struggled with economic problems; it certainly has been true in the United States, and I believe it is true in every one of the countries that is represented at this gathering. Here in the United States there has been mounting concern over the last several years about our balance of trade with other countries. There has been also concern about the fact that the dollar is extraordinarily strong. I am sure that any of you who have come into this country in the last few days and had to exchange your money for dollars are aware of the problem. It is a problem that affects us in many ways. The strong dollar makes it more difficult to sell American products abroad because the costs associated with the manufacture of those products in the United States, by the time they are converted into other currency, cause our products to be priced high. On the other hand, it tends to make the United States a lucrative marketplace for our colleagues from other countries.

I think all of us in the standards business have wondered what we can do to help. That has certainly been the case at the National Bureau of Standards (NBS) and, in fact, in nearly every standards organization that I know of. We deal with many standards organizations at NBS and nearly every one is considering what an appropriate role should be in the international arena. Certainly, ASTM is no exception to that. There has been considerable discussion for an extended period of time within ASTM about international activities and about the proper role of ASTM. The issue of determining the proper role for an organization like ASTM is really what I want to address. It is not an easy matter, and I think in the end, not everyone is going to agree that the right direction is chosen.

I think that it has become clear from the discussions within ASTM and within many other standards organizations in the United States, that there are certain basic facts that must be established. To use Jeffrey Fong's terms, there are certain questions that must be answered. Questions such as, what kind of credibility does ASTM have in the international arena? You can substitute other words for credibility here: What kind of recognition . . . what kind of clout does ASTM have? What we are after is some assessment of the ability of the organization to follow through with what it proposes to do. Perhaps credibility is the best word to choose, to get a sense of ASTM's goals. How much recognition does the organization have? Does it have name recognition in Europe, for example? Can it compete favorably with the other well-established standards writing organizations in Europe?

Yet another question, and a question that is a fundamental one is, what is the purpose of ASTM and who does it serve? You might say that answer is simple. The purpose of ASTM is to write voluntary standards. ASTM is a voluntary standards or concensus standards writing organization. I think that is generally well understood and well accepted. But when one begins to think about alternative activities in the international arena, one begins to expand upon that writing of standards theme and add other things. I think one has to focus sharply on what the purpose of the organization is.

You might ask questions such as, who are the customers of ASTM? How can you define the customers of ASTM? Who is ASTM here to serve? ASTM is a private sector organization in the United States. It is clearly not here to serve the U.S. Federal Government. From the discussions we have had at the ASTM Board of Directors, I think the general concensus is that the primary clientele, as represented by the majority of membership, is North American industry; not just U.S industry, but Canadian industry and Mexican industry as well. On the other hand, ASTM is also well represented by members from Europe and Asia, and certainly, they have interests that must be considered. So, I think the issue of, who does ASTM serve?, is not an easy one; and it is an issue that is going to require considerable discussion.

The last issue that I feel needs to be addressed is the question of what resources are available to implement any programs that are planned in the international arena? Here is an area where ASTM as an organization has great riches. There is a strong management team at ASTM; a good, strong headquarters staff located in Philadelphia. ASTM is a healthy organization financially. The annual budget for 1984 will be approximately $15 million. The sources of income for ASTM are strong and well established. The membership of ASTM is strong; nearly 30 000 members this year. So, it is an organization with great resources, which can be brought to bear on the international problems.

With these questions in mind, a thorough examination of the whole subject of ASTM in the international arena was initiated about 1980, begun with an international symposium, where the general issues were aired. Then a special committee was established. That special committee was chaired by a long-term ASTM member, Frank LaQue, and was charged with the responsibility of trying to determine what was really fact and what was just folklore as far as ASTM's reputation was concerned. The LaQue Committee carried out a number of studies. Some of those studies were carried out on contract for the Committee; other studies carried out by the ASTM staff.

There is one study that I would like to highlight for you, as an example. It is a study carried out by Keith Gorton from Humberside College in England, and the use of ASTM standards in Europe. This is called the Humberside Study and has been reported in great detail in the *Standardization News*, the ASTM magazine. If you have not read the reports in Standardization News, I urge you to do so. But now I will just touch on some of the basic facts that are involved.

The study involves three commodities (*a*) iron and steel, (*b*) plastics and resins, and (*c*) bulk chemicals. It involves four countries: Great Britain, West Germany, the Netherlands, and Sweden. It was carried out with a total of 202 so-called belly-to-belly interviews, direct interviews of people who would be involved in the use of ASTM standards. These are people who run industrial organizations that use standards; they are people who are involved in the purchasing and the procurement side of the standards business.

I am just going to summarize a couple of the key results because I want to make a point here. There is a great deal of detail on how the countries were selected; how the companies within those countries were selected. I also should make it clear that at the beginning it was understood that the interviewers were to address the questions in a general sense and to not divulge the fact that this was an ASTM sponsored investigation. We were interested here in getting as even-handed and balanced a view as possible.

I think there are two results among the many that probably indicate most clearly how ASTM is viewed. One of those came from the first question that was asked by the interviewers: what kinds of books of standards do you keep on your premises? The results are shown there: DIN, ASTM, BSI, and ISO standards are kept by the vast majority of the people interviewed. The other standards systems are used significantly less. It is clear just in terms of the standards kept on the shelf that the top four overshadow the others. If we explore further and we ask, which standards are used? ASTM Standards has been normalized at 100, and again, you will notice, that ASTM, BSI, DIN, and ISO win out. You can explore more detailed questions here and ask, why particular standards are being used? You can ask, who makes the choice of a standard? And I think you can reach some general conclusions.

First of all, concensus standards are a preferred means of communication in world markets. Essentially, every individual who was interviewed in this study made that point. Concensus standards are the common meeting ground in foreign trade. They form the basic understanding of any kind of contractual arrangement. A conclusion that came from the study that I think is perhaps most significant is that the customer is the one who usually specifies the standard to be used; not the seller, but the buyer. That means that if you are an exporter you must have available to you several different books of standards so that you can meet whatever terms your customers specify.

We have found in this study that customers specify ASTM standards as frequently as they do British Standards or DIN Standards in the European system, perhaps more frequently than ISO. You might ask, why more frequently than ISO? The usual answer to that question is that ASTM standards are more quickly updated; they are more quickly modified than ISO standards and they tend to be more readily available. The last point here, which is one of the major issues that we were exploring, is that ASTM is viewed as a major supplier of standards worldwide. The conclusion one has to reach is that ASTM is credible; that it does have clout in the standards writing arena; it is important to world trade.

The next questions to ask are, what can we do about that? What kind of program can we implement at ASTM which will provide an expanded role in the international arena?

There are several ways that we could go. One of the major operating functions of ASTM is to publish books of standards. Certainly, wider distribution of those standards documents would further goals in the international arena. ASTM is in the process of developing a technology training program, aimed at training individuals in the use of ASTM standards; not necessarily training ASTM members, but rather training individuals who use ASTM standards at the bench—technicians, draftsmen, procurement agents, and the like. Certainly, taking training programs of that kind into other countries would further the use of ASTM standards in those countries.

There is also the issue of laboratory accreditation. Accrediting laboratories so that those laboratories can certify products that will be sold internationally is another worthwhile goal. All three of those areas could have significant impact on the posture of ASTM internationally.

The remaining issues that are now being heavily debated at the Board are related to implementation. How should we go about dealing with each of the three areas mentioned previously? One can certainly take extremes. For example, if you view the results of the Humberside Study to mean that ASTM has a well recognized name and reputation in Europe, then one might assert that the organization has a responsibility to provide a certain level of service to our European clients and colleagues. This assertion would lead to a view of ASTM as a worldwide organization responsible for the standards needs of people in all countries. Logically one would then aim a distribution program at getting the widest circulation of ASTM documents possible.

On the other hand, one could take the opposite extreme, an extreme that Jeffrey Fong tells me is a protectionist view. You could assert that the purpose of ASTM is to write voluntary standards; the clientele of ASTM is North American industry and that any distribution of documents in the international market should be focused on those areas where North American industry wants to market. For example, if the plastics industry in the United States wants to sell plastic pipe in Argentina, it would be appropriate for ASTM to distribute standards documents related to ASTM Standards for plastic pipe as completely as possible in Argentina. One could expect those documents to contribute to specifications in requests for bids, allowing U.S. companies an advantage in sale in that market. That is a protectionist view and one that is certainly extreme.

I think you can see that there are arguments that can be made either way: the United Nations of International Voluntary Standards on one hand and the extreme protectionist view on the other. One can make the same kind of arguments with technology training and laboratory accreditation. These are the kinds of issues that are being debated by the ASTM Board of Directors at the present time.

It is clear that we are reaching decision points; we are looking at implementation of programs, but the final strategy, the final approach has not been decided upon. My guess, and I am giving a personal comment now, is that we will end up somewhere in the middle with some moderate position, which tries to take the balanced view that I think is appropriate for this organization.

Donald R. Johnson
Director of National Measurement Laboratory, National Bureau of Standards, Gaithersburg, Maryland; past member of the Board of Directors at ASTM.

EXPERIMENTATION AND MEASUREMENT

The title of this remark, "Experimentation and Measurement," was that of a book written by Dr. William J. Youden in 1962. That book was one of a series of Vistas of Science books published by the National Science Teachers Association for the purpose of the "improvement of the teaching of science." The original version has been out-of-print for many years. Recently, we at the National Bureau of Standards have reprinted a limited number of copies for use in our statistics-related workshops and courses.[1]

[1] *Experimentation and Measurement,* W. J. Youden, NBS Special Publication 672, National Bureau of Standards, Gaithersburg, MD, March 1984.

I was fortunate to be associated with Dr. Youden at the National Bureau of Standards for a decade or so before his death in 1971. He was unsurpassed in his skill in communicating sophisticated ideas in simple language, and throughout his statistical consulting career his main aim was to make the life of engineers and scientists easier. There are three experiment designs that bear his name:

The Youden Square, which are rectangles, the *Youden diagram*, or plot, for interlaboratory tests, and the *Youden ruggedness test* for checking on test methods. These designs are widely used by various ASTM committees.

An experiment has been defined as "a considered course of action aimed at answering one or more carefully framed questions" by Youden. I like this definition: it is general enough to cover all types of experiments, yet it is specific enough to make one think through what we intend to do and how to do it. By "carefully framed questions" we tend to sharpen the objectives of the experiments; by "considered course of action" we would avoid confounding of experimental factors, introduce planned grouping of data prints, and provide realistic estimates of variabilities. Above all, at the end of the experiment, the result should answer the questions asked. If not, we can usually trace the failure to two main causes: first, the question was too ambitious for the resources available, and secondly, the experiment as designed and performed has inherent weaknesses that makes a meaningful interpretation of the result difficult if not impossible, no matter how meticulously the measurements were made.

My favorite example of an interesting design is provided in Chapter 7 of the book *Experimentation and Measurement* with the title Experiment with Weighing Machines. Here Youden used 16 measurements on four men to assess the performance of four weighing machines found in corner drug stores. As common with all good designs, he used as few measurements as possible, arranged them in patterns that are easily interpretable, took care of all the possible side issues, and yielded useful, defensible results for the purpose intended.

Admittedly not all experimental design problems can be resolved so neatly. Youden used a standard Latin square design, which is one of many standard designs available in the statistician's bag of tools. Other commonly used ones include: factorial and fractional factorial, block and randomized block designs, nested designs, response surface designs, and optimal designs. Hence even though we do not have a consultant as good or as sympathetic as Jack Youden, we still have a wealth of statistical designs to look over, to think about, and to select from, for the particular experiment we wish to perform. By going through this process there may be, or likely to be, questions raised the answers to which could determine the outcome, success, or failure of an experiment.

I hope that I have convinced most of you that planning and design of an experiment itself is an important, if not more important than the performance of the experiment. Once measurements are made and data taken, all the sophisticated method of analysis can only extract information from data, but cannot change or improve it. The foundation of an experiment is based on theoretical knowledge and the design. No enduring experimental results can be built on an inadequate foundation.

Let me be brave enough to suggest that there are three general types of experiments in fatigue testing:

1. Study of fatigue properties of a particular material.
2. Study of mechanisms underlying the fatigue phenomena.
3. Study of law-like relationship.

I will explain briefly what I include in each category:

For the study of fatigue properties of a particular material, we usually mean comparative studies of fatgiue life of different materials by certain prescribed tests methods. The result is usually represented by an S-N curve, and the value of interest is usually a lower limit of the safe stress that is suitable for comparison with an alternate material. These tests are costly and time consuming, with results depending on many factors. Your Committee E-9 is particularly interested in this type of activity and has produced a manual on fatigue testing, together with suggested statistical methods for the design and treatment of such data.

At this point I should like to jump to the category of "Law-like Relationship." By law-like relationship I mean a simple relationship stated quantitatively that is applicable to an enormous field without appreciable error. Our freshmen physics books are full of examples, such as Newton's laws of motion, Boyle's law, etc. We also have Gaussian law of errors. I do not know what to suggest to be successful in such undertakings, except to wish you luck and to have your name associated with such discoveries.

In looking over titles of experiments listed in this symposium, I believe most of them belong to the second class, that is, study of mechanisms underlying the fatigue phenomena. Those are controlled experiments. For example, the levels of temperature may be controlled, specimens may be prepared using the same or different techniques, sizes or shapes, levels of stress decided, and the crack lengths measured at different times. Suppose we select temperature at two levels, T and t; stress at two levels, S and s; and two frequencies F and f. The measurement of interest, let us say, is the rate of crack propagation. To find out the effect of temperature, stress and size we may perform four experiments:

$$\begin{aligned} TSF &\longrightarrow W \\ tSF &\longrightarrow X \\ TsF &\longrightarrow Y \\ TSt &\longrightarrow Z \end{aligned}$$

Thus, the effects of:

temperature	$W - X$
stress	$W - Y$
frequency	$W - Z$

This is traditional way of charging one variable at a time. It serves the purpose. But we can criticize the selection of experimental points on two counts: First, "W" has been used 3 times, whereas X, Y, Z each only once. Any error in W would affect all results. Secondly, if the measurement error has a standard deviation of σ then a difference of two measurements will have a standard deviation of $\sqrt{2}\,\sigma$. Thus the precision of a comparison is worse than a single measurement.

A better set of experimental points is, where we select

$$\begin{aligned} TSF &\longrightarrow W \\ Tsf &\longrightarrow X \\ tsF &\longrightarrow Y \\ tSf &\longrightarrow Z \end{aligned}$$

Thus, the effect of

Temperature	$\frac{W+X}{2} - \frac{Y+Z}{2}$
Stress	$\frac{W+Z}{2} - \frac{X+Y}{2}$
Frequency	$\frac{W+Y}{2} - \frac{X+Z}{2}$

Here we see the standard deviation of each difference is σ, and each result is used three times. If by chance, none of the variables has an effect, we can calculate a grand average where the higher level and lower level are equally represented. This cannot be done with the first arrangement. Moreover, we see that there are exactly two points on each of the six surfaces of the cube—balanced and satisfying to the aesthetic minded.

This simple design is a one half replication of three factors each at two levels, and belongs to the class of fractional factorial designs. When the number of factors and levels increase, the pattern gets complicated, yet the general principal is the same as in this example—to get the maximum useful information by carefully selecting the experimental points.

One of the main problems in the design of experiments is what to do with the large number of variables or factors that may have a bearing on the results. Take, for example, the life test of saucer-type springs in clutches in a car, we may have

A. Shape: 3 levels
B. Hole ratio: 2 levels
C. Coining: 2 levels
D. Tension stress: 3 levels
E. Comp. stress: 3 levels
F. Shot peening: 3 levels
G. Outside perimeter planning: 3 levels

There are altogether $2^2 \times 3^4 = 324$ combinations. To find out an optimal combination requires a tremendous effort, even without replication.

To concentrate only on a selected few factors is like drilling 100 holes within a square mile area to find oil, rather than drilling 1 hole each in 100 square miles.

A solution to this type of problem has been advanced by Genichi Taguchi of Japan using what are called "Orthogonal Array" designs. These designs are a class of super fractional factorial which Taguchi has used successfully in Japan. In 27 experiments using three springs each he pin pointed that $A_3\ C_2E_1\ D_2\ F_2$ and $A_3\ C_2E_1\ D_3\ F_2$ an optimal conditions, and give confidence limits to the estimates of average life.

I must admit that I know little about Taguchi's work since most of his publications are in Japanese. Taguchi teaches his design and analysis to engineers and uses signal to noise ratios as response. According to him, a 20 000 employee company, Nippon Denso, used the orthogonal array design 2700 times in 1976. You cannot argue with success!

Last May, a Conference on "Frontiers of Industrial Experimentation" was held in New York, sponsored by Bell Labs Quality Assurance Group. Taguchi was invited, and a number of papers were presented on his methods. A most readable reprint was by M. S. Phadke et al.[2] of Quality Assurance Center, Bell Labs, Holmdel, New Jersey.

How good is Taguchi's method? I cannot give you a definitive answer. Obviously some information in the full experimentation has been neglected. I like to make three points though. First, if one cannot possibly do the full experimentation, it would be better to follow a systematic approach like Taguchi's than select a subset based on instinct. Second, is the lost information really important for your purpose? If not, nothing is lost. Thirdly, the result of such an "exploratory" experiment can be always verified by confirmatory experiments.

[2] M. S. Phadke, R. N. Kackar, D. V. Speeney, and M. J. Grieco, "Off-Line Quality Control in Integrated Circuit Fabrication Using Experimental Design," *The Bell System Technical Journal*, Vol. 62, No. 5, May-June, 1983.

It appears to me that the design advocated by Taguchi can be of use to experimenters in fatigue test to deal with the larger number of factors and variables. It is worth looking into and trying out. I myself would like to learn more about it and study its properties.

H. H. Ku
Chief, Statistical Engineering Division, National Bureau of Standards, Gaithersburg, Maryland.