OPENING REMARKS

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It is indeed a great pleasure and honor to welcome you to the Second Conference on Matrix Methods in Structural Mechanics. This second conference, like the first one in 1965, is being sponsored by the Air Force Institute of Technology and the Air Force Flight Dynamics Laboratory. The purpose of this conference is to provide a forum for discussions on the recent developments in matrix structural analysis and design of structural systems. Although the alleged object is to exchange ideas and technical information by means of lectures and discussions, I am convinced that the greatest value of this conference will be in seeing so many old friends again and having the opportunity of making new ones.

Our original plan for the conference was to restrict the participation to about 200, which represents the seating capacity of the AFIT auditorium; however, in response to the tremendous interest generated by this conference, we have, through the use of a closed-circuit television in the adjacent lecture room, made provision for 50 additional participants. Since there is never enough time for formal discussions following presentations of each paper at technical conferences of this type, the conference committee arranged for additional informal discussions in four separate conference rooms in this building. This will allow small groups of participants to meet the authors and discuss their specific topics of interest. The committee strongly believes that these informal discussions will contribute significantly to the greater exchange of ideas and information.

I would like to take this opportunity to thank all who worked so hard in organizing this meeting. My special thanks are extended to the conference committee consisting of Bob Bader, Les Berke (Chairman of the Technical Committee), Walt Mykytow, and Mike Shirk. Also I would like to thank Lisa Habib, AFIT protocol officer, and Al Cannon, Aeronautical Systems

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*Conference Cochairman

Division, for their assistance as conference coordinators. But above all, my appreciation and gratitude are extended to all authors for their untiring efforts in preparing such an excellent program for us. I am confident that our second conference will be as successful as the first one held in 1965 and that this conference will contribute much to the science and the art of structural design of aerospace systems.

After concluding his opening remarks, Dr. J. S. Przemieniecki read the following message from Maj. General Ernest A. Pinson, Commandant of the Air Force Institute of Technology.

TO: Delegates to the Air Force Second Conference on Matrix Methods in Structural Mechanics

I take great pleasure in extending my best wishes for the success of the Second Conference on Matrix Methods in Structural Mechanics sponsored jointly by the Air Force Institute of Technology and the Air Force Flight Dynamics Laboratory.

In these difficult times, when technological superiority plays such a dominant role in determining the course of world affairs, the free exchange of ideas and information between scientists and engineers is of paramount importance.

The Conference, I am confident, will do much to advance the science of structural mechanics and to further strengthen the bonds of friendship and understanding among the participants of your meeting.

The keynote address during the opening ceremony was delivered by Brigadier General Raymond A. Gilbert, Director of Laboratories, Air Force Systems Command. This distinguished guest speaker was introduced by the Conference Cochairman Colonel Joseph R. Myers, Director of the Air Force Flight Dynamics Laboratory.

KEYNOTE ADDRESS:

Brigadier General R. A. Gilbert
Director of Laboratories
Air Force Systems Command

To search, to find, to evaluate, to learn, to teach, to apply and to develop are the chosen goals of the community of scientists, engineers, and educators represented here today. It is fitting therefore that this second conference on matrix methods in structural mechanics should again be jointly sponsored by the Air Force Institute of Technology, an institution dedicated to higher education and research, and by the Air Force Flight Dynamics Laboratory, an organization charged with the responsibility for advancing the technology of flight vehicle structures, working with other government agencies, universities, and industrial organizations.

We are indeed honored that this conference is attended by educators and government and industry specialists from Belgium, Canada, France, Germany, India, Ireland, Japan, The Netherlands, Norway, Portugal, and The United Kingdom, as well as from the United States.

Today, while recognizing the achievements and progress in structural mechanics, I hope to challenge you and to stimulate you to pursue some complementary efforts.

Technological growth depends, first, upon a vigorous and imaginative research program in the basic and applied sciences and, second, upon a judicious but agressive application of the important results of this research. Furthermore, in the judicious application of important results, we must also recognize various constraints such as markets, economic feasibility, and perhaps, the development of complementary technologies.

Matrix algebra and structural mechanics are not new subjects. What is new and exciting is the development of modern, high-speed, large-capacity, electronic digital computers that have made it feasible to apply matrix methods to complex problems in structural mechanics on a much wider scale.

Modern high-performance aircraft demand much of the structural designer. As performance increases, so generally does the cost of design, fabrication, and testing. Matrix methods have already provided cheaper, lighter, and more efficient structures -- but much remains to be done.

Significant improvements are still needed in static and dynamic structural analysis, computer-aided design, and structural synthesis and optimization. We have already begun to apply modern matrix methods to the problems of flutter, structural response caused by sharply peaked loads, fatigue, and damage or partial failure of some elements. Although a significant development has taken place in the analysis of elasto-plastic and plastic stresses, this important and difficult area still presents a formidable challenge, particularly to aircraft designers.

Nonisotropic materials, such as fiber composite materials with either plastic or metal binders, that can be tailored to specific applications, offer great potential for lighter, more efficient structural designs. This potential may not be fully realized until analytical methods are developed that can adequately treat the more general structural configurations to permit comparisons and optimizations.

Fabricability is, of course, an important constraint. Depending upon how the composite is fabricated, new structural configurations not only may be possible but also may be necessary.

We might also note that, with adequate analytic design methods for dealing with composite materials, the engineer will have the somewhat unusual opportunity to design materials as well as structures.

Aircraft structures, however, do not offer the only opportunity for applying matrix methods. Better deep-submergence ships, lighter-weight launch vehicle motor cases and spacecraft, new types of buildings and prefabricated homes, and, hopefully, safer automobiles may result from your efforts.

In the aircraft industry alone, the number of computer hours devoted to structural design has increased by about a factor of ten in the past five years. This estimate is even more impressive when one realizes that computer speeds have also increased many-fold in the same period.

These great increases in computer usage speed could, in my view, be a mixed blessing. Those of you presenting papers at this conference are undoubtedly intimately familiar with all the details of your computer programs and have completely de-bugged them. As the use of these programs becomes more widespread, however, others less familiar with the details of particular computer programs and their limitations may attempt to apply them inappropriately or may not recognize incorrect answers that could result from numerous causes.

It would, I think, be appropriate for you gentlemen to develop some simple analytic or semianalytic methods that could provide both the engineering manager and the inexperienced design engineer a gross check on the computer results and, thereby, provide greater confidence in the use of matrix methods in structural mechanics.

Computers can perform many operations much more rapidly than humans, but computers and computer software have not reached the stage where we can blindly accept each computer result or ask a computer to do our thinking for us.

Computer graphics provides another method of checking computer results against our experience or intuition. Probably more important, however, is the fact that computer graphics can provide engineers the opportunity to interact more directly with the computer in such a way as to take much better advantage of the peculiar abilities of both man and computer. For these reasons I am particularly pleased to note the increasing use of computer graphics in structural design computer programs.

Another somewhat more dramatic demonstration of the utility of such a technique as matrix methods is the ability to design, build, and test a structure. Those of you gentlemen with an excellent appreciation of the greatest area of uncertainty in the matrix methods can play an important role in suggesting critical experiments, the results of which can provide increased confidence and perhaps point the way to further improvements or refinements in these methods.

Matrix methods using high-speed computers have already demonstrated great utility in the design of aircraft structures. Papers presented during this conference will highlight the great progress you have made in the past three years. You educators also have a responsibility to continue refining, organizing, and adding discipline to this technology to encourage its wider use. I hope the succeeding years will bring an even greater growth in solid achievements in this important area.

A conference banquet was held at the Wright-Patterson Officers' Club on the evening of 15 October 1968. The Honorable Alexander H. Flax, Assistant Secretary of the Air Force (Research and Development), was guest speaker for the occasion. His long association with, and his outstanding contributions in structural mechanics, particularly in aeroelasticity, qualified him as the most appropriate speaker. He was introduced by Colonel Marshall E. Sanders, Deputy Commandant of the Air Force Institute of Technology.

BANQUET ADDRESS

The Honorable A. H. Flax*
Assistant Secretary of the Air Force
(Research and Development)

It is a great pleasure to have been invited here to this Second Air Force Conference on Matrix Methods in Structural Mechanics. The convocation of a conference such as this one dealing with a highly-specialized technique which, in spite of that, is broadly applicable to a wide range of scientific and technical problems is characteristic of the current state of science and technology. The need for information networks to make possible the flow of technical knowledge among people concerned with the specialized techniques in different fields of application has been increasingly apparent. The Air Force and the other military services, as major users of much of modern science and technology, are always pleased to encourage and participate in the exchange of such basic information. I would like to take this opportunity to discuss the growing role of the specialist in engineering, and the impact of this development on the engineering profession and its responsibilities.

In ancient times, the Egyptians, Greeks, and Romans built major engineering works of great splendor and magnificence, but there is little evidence that scientific principles or analytical methods had anything to do with the process. In 1742, when Pope Benedict XIV asked three leading mathematicians of the day to analyze the causes of cracks and other damage that had become apparent in the dome of St. Peters, originally designed by Michelangelo, there ensued a great furor over the validity of this attempt at rational structural analysis. One of the more practically minded critics said, with some justice, "Mathematics is a most respectable science, but in this case it has been abused." In 1822, Thomas Tredgold, a leading British civil engineer and a leader in the efforts to advance the application of scientific methods and research to engineering, was still constrained to say, "The stability of a building is inversely proportional to the science of the builder." And the instance of a vast chasm between

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*Now, President of the Institute for Defense Analyses, Arlington, Virginia scientific principles and engineering practice was not limited to structures; in the midnineteenth century, Prof. E. J. Henderson of Harvard, a physiologist and student of science in the large, asserted that science owed more to the steam engine that the steam engine owed to science.

The need for application of ever more advanced analytical and experimental techniques in modern engineering arises from the present high rate of scientific and technical advancement and the rapidity with which new science is being applied to industrial processes and products. This situation demands of engineers a scientific knowledge of hitherto undreamed of breadth. Even in the engineering of old products, new and varied scientific background information is often now required. For example, solid state electronics is being introduced into such varied products as television sets, automotive ignition systems and automatic controlled machine tools. On the production line, electrical discharge cutting electron beam welding, chemical milling, and ultrasonic inspection techniques have gained wide acceptance. In addition, entirely new products such as atomic reactors, gas turbines, electronic computers, plastics, synthetic fibers, rocket motors, and vehicles for reentry from space are now being manufactured. None of these technologies and products existed 30 years ago, and many had not even been thought of at that time.

In the past when the rate-of-change of concepts, materials, and design practices was relatively slow, engineers relied heavily on judgment, experience, and common sense to compensate for their conscious and unconscious oversights in rational design and analysis. Experience, intuitive judgment, and common sense are all really different aspects of the same thing -- history. As William James has so aptly pointed out, common sense is the tribal memory of discoveries made by remote ancestors. With the rapid changes in products, processes, and materials that have become commonplace today, there is sometimes little history that bears on many of the engineering problems faced today.

I am sure you are all familiar with many cases in which a new material was adopted because it gave substantial advances in one of its physical properties, only to introduce, in turn, other problems not previously critical, because of deficiencies in other physical properties or in the structural arrangements that result from application of the new material. This is, of course, not new. The first steel truss bridges were far more susceptible to lateral buckling of the chord members than their wooden predecessors because the higher allowable strength of steel led to a reduction in the dimensions of chord members. It took some time before this was realized and corrected; although it may appear that this must have been back in antiquity, it was in fact only 120 years ago. In more recent times you are probably familiar with the effects of the introduction of certain of the higher strength aluminum alloys into airframe design with disastrous results, because of the critical fatigue situation that was thereby introduced and not recognized in the then current practices of structural analysis and test.

Many of our current engineering enterprises involve complex and expensive systems. Not only are prototypes for engineering or service test very expensive, but they take a long time to design and build, a long time to test, and a long time to change for retest. Thus, we have been forced to rely to an increasing degree on more rational and reliable methods of analysis and design to assure the highest possible degree of success before the first prototype is tested. Clearly, there is economic justification for a great deal of concentration on analytical methods by the engineering profession.

The matrix method of structural analysis is one of the important techniques that has evolved in response to the current need for improved analytical methods in engineering.

Although much of the underlying theory existed much earlier, the widespread practical application of matrices to structural mechanics during the past 20 to 30 years represents a remarkable step in the evolution of engineering toward rational methods of design. To some extent, this evolution was synergistic with the emergence of computers that could adequately and rapidly perform operations on high-order matrices. There is no doubt that the progress that has been made in aeronautical and space technology since World War II would have been impossible without the availability of modern computers mustered in support of such specialized techniques of engineering analysis as matrix methods in structural mechanics.

Yet, all great scientific and technical advances may be either beneficial or detrimental to man, depending on the way they are applied. This is as true of computers and matrix methods as it is of fire, nuclear energy, the automobile, and television. The users of large, very capable digital computers have, at times and with some justice, been accused of using the computer as a substitute for thought. There is at least one instance, of which I am personally aware, when several volumes of computer calculations were used to derive what could be learned from a relatively simple mathematical analysis on one page.

However, such abuses do not in any way detract from the fact that the computer is an essential tool of modern technology and that there are many things we now take for granted in engineering that could not reasonably be undertaken at all without the modern computer.

Matrix methods too may be either used or abused. Granted that the development of mathematical techniques and the means for applying them to structures may be considered a worthwhile end, it is incumbent on the structural analyst and designer to be sure that he does use matrix analysis to enhance his understanding of the structure he is designing or analyzing and not as a substitute for such understanding. And from an even more mundane standpoint, he must be sure that he does not set up methods of computer analysis that result in a cost of $10,000 for a job that can be done for $1,000. Technique-oriented specialists are sometimes prone to do this.

J. Willard Gibbs, the great American physicist, when he has devised what he considered to be an improved method of determining planetary orbits through the application of vector analysis, was not at all sure that astronomers, set in their ways, would take advantage of his new method. The astronomer, Asaph Hall, of the Naval Observatory wrote to Gibbs.

"You need have no fear, I think, that astronomers will not adopt any real new improvements in their method of computing. In fact, it is curious to see how a set of computers will find out the easiest way to do a piece of work. The way is not always the shortest, but it is the one requiring the smallest amount of physical and mental labor. The computer is a real mercenary and does not care for the reputation of anybody. He is like a stream finding its way down a mountainside. A good illustration of the principle of least action." This was perhaps easier to believe when the computations were done by hand and by one or a few people. Now, the work is sent to the computer department and all the complication and expense that may be involved are lost sight of. Only neat and copious results return to the analyst. It is not so obvious that any optimization principle is operating.

The practitioners of the matrix art in structural analysis have recently been accused of devising analysis methods with crass disregard for the cost of computer operation. It was pointed out that, in effect, the most widely used methods for certain types of analysis go about solving the problem of multiplying a sum of figures by another number by multiplying each number in the sum separately and then adding the products. This procedure obviously increases the number of computer operations manyfold in comparison with the most economical method. This is easy to do in applied mathematics. An earlier example is the occasional instance when engineers, impressed by the sheer mathematical elegance of Cramer's Rule for the solution of simultaneous linear algebraic equations in determinant form, actually went about solving a set of equations of high order by this method, thereby enormously increasing the number of arithmetic operations required in comparison with the more elementary and more primitive elimination method of Gauss. Without attempting to pass judgment on the merits of current practices, I would like to suggest that in matrix analysis of structures, and in other specialized techniques of engineering, there is need for a calculus of economy to be applied in parallel with the theory of error propagation.

The need for this arises from the fact that, with the more complex systems, structures, devices, and machines that engineering is creating today, research and development costs are taking an ever-increasing fraction of our economic and human resources. The cost of engineering and technical assistance in manhours alone on some Department of Defense programs is of the order of hundreds of millions of dollars. Conservation of economic resources is one of the important and traditional responsibilities of the engineer, and it must be applied to all significant costs of the program for which he is responsible.

The complexity of many weapon systems is such that the combined efforts of many specialists are required to produce a satisfactory end product. The growth of science and technology has made it difficult, if not impossible, for an engineer to have both the depth and the breadth of knowledge that is required for the total job; yet, paradoxically, the satisfactory functioning of these weapon systems depends upon a carefully calculated interaction of complex components, structures, materials, and machines, with close attention to all the ways in which the many fields of engineering operations may lead to either desirable or undesirable interactions. In order to cope with these problems, the modern engineering of an aerospace vehicle depends on dozens of functional specialists in each area of technology and in addition on yet other specialists who are interested in the operation and interaction of the system as a whole. We have had to identify, define, and subdivide the function of an engineer into ever more narrow compartments. For example, take reliability and value engineering. These have come to be highly specialized arts. And yet they embody considerations that can hardly be separated from the essentials of engineering design. We are led then to ask who, among all these specialists, is really responsible for the development of an end product, satisfactory in all ways for its intended use.

Let me quote from the writings of Robert Lewis Stevenson, who from observations of his grandfather, who was an engineer, remarked, "What the engineer most properly deals with is that which can be measured, weighed, and numbered. . .these are the certainties of the engineer; so far as he finds a solid footing and clear views. . .but the province of formulas and constants is restricted. . .The rains, the winds and the waves, the complexity and the fitfullness of nature are always before him. He has to deal with the unpredictable, with those forces that are subject to no calculation; and he must still predict, still calculate them, at his peril. His work is not yet in being, and he must foresee its influence: how it shall deflect the tide, exaggerate the waves, dam back the rainwater, or attract the thunderbolt. . . . .he must not only consider that which is, but that which may be.''

Since the time of Stevenson's grandfather, we have come a long way in supplying scientific experimental and analytical methods to the solutions of our problems, but there is still no substitute for the assumption of total responsibility by the engineer.

If, as Stevenson has said, it is impossible for the engineer to see, know, and calculate everything, it is equally impossible for the Air Force to include every aspect of modern engineering design, sound analysis, good fabrication, good processing, and good quality control in detailed specifications or contract clauses. Even in an age of great specialization, it is clear that success in designing and developing modern weapon systems that rely on complex interactions of many intricate subsystems cannot be attained without considerable attention to the qualities of the engineers about which Stevenson spoke, particularly the statement that ''he must not only consider that which is, but that which may be.'' This is the attitude of acceptance, of total responsibility which characterizes the true professional. In the field of structures, for example, it is not enough to accept someone's statement of the loads or the environment as a statement of the problem to be pursued thereafter in academic isolation. When some component is under review, it is necessary to be suspicious, to think of environmental conditions that are not the ones someone else regards as most critical. It is necessary to inquire as to the location of the nearest corrosive fluid tank or valve and to ask what steps in the handling, cleaning, machining, heat treating, or assembling might affect properties of the material -- its structure, its surface condition, and its dimensions -- or what might introduce residual stresses, low-cycle fatigue, or other ailments that will afflict the component later in its service lift.

Too few engineers go out to the shop or test laboratory to see that things are really being done as they were conceived at the time the part or the test was being designed.

Often an examination of the parts that passed the test is as important as the analysis of those that failed. Sometimes it is apparent to the trained and experienced eye that failure was incipient and would have occurred with a slight change in test conditions -- remember that even the most rationally qualified test is, to a considerable degree, arbitrary.

I hope you will not think that I have just been laboring the obvious. I should explain that every comment and suggestion made relates to an action not taken on a specific Air Force weapon system with the result that considerable additional cost was incurred, and in some cases, operational systems were inoperative for a period of time. The potential exists for even greater difficulties in the future as we deal with more advanced systems and more severe environmental conditions associated with higher performance equipment. The Air Force or any other service or government agency cannot solve all these problems simply by writing specifications; they must rely on a high degree of cooperation from industry and on both the professional knowledge and professional attitude of engineers.