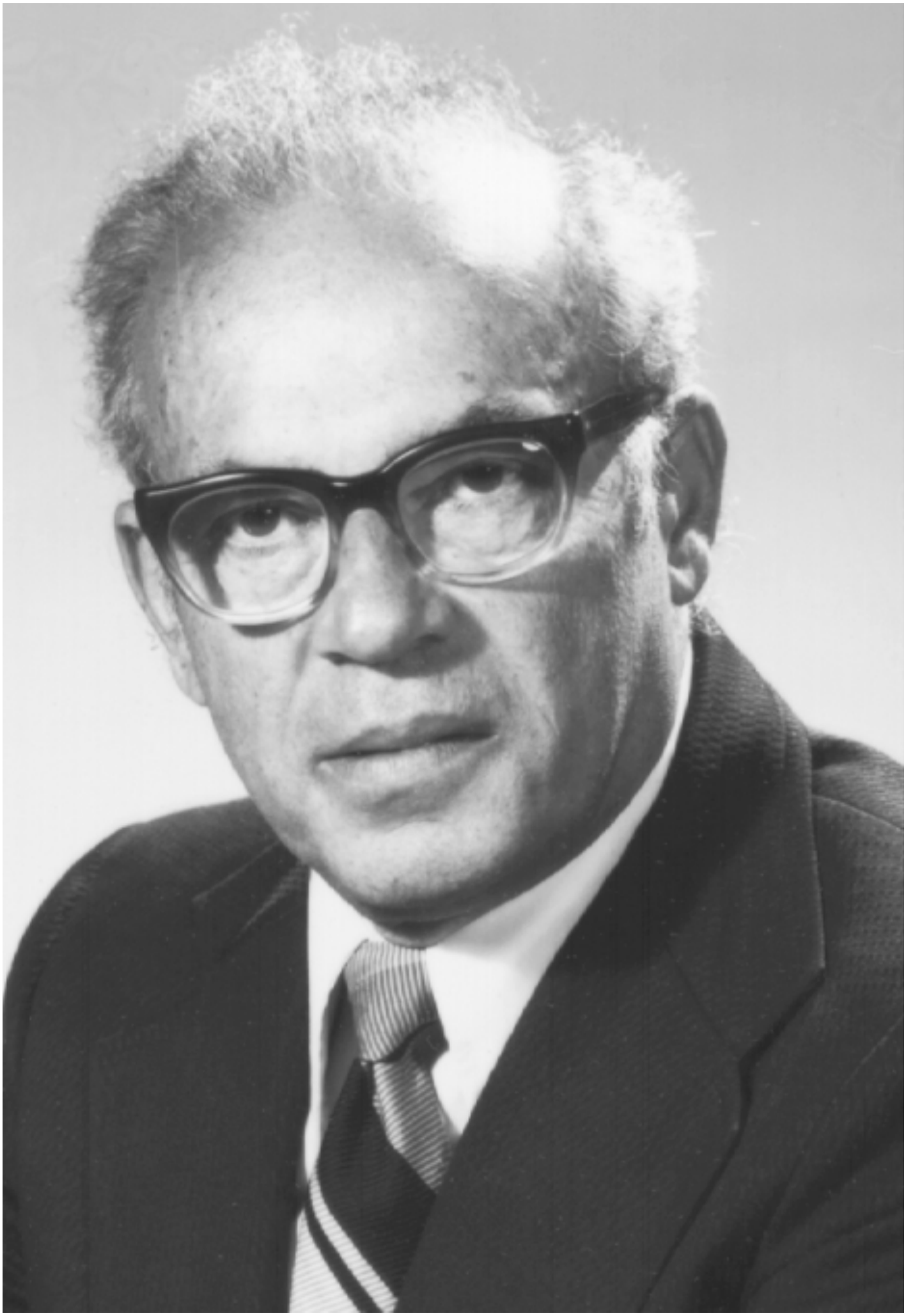

MANUEL STEIN'S FIVE DECADES OF STRUCTURAL MECHANICS CONTRIBUTIONS (1944-1988)

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Abstract

Manuel Stein went to work for NACA (National Advisory Committee for Aeronautics) in 1944 and left in 1988. His research contributions spanned five decades of extremely defining times for the aerospace industry. Problems arising from the analysis and design of efficient thin plate and shell aerospace structures have stimulated research over the past half century. The primary structural technology drivers during Dr. Stein's career included 1940's aluminum aircraft, 1950's jet aircraft, 1960's launch vehicles and advanced spacecraft, 1970's reusable launch vehicles and commercial aircraft, and 1980's composite aircraft. Dr. Stein's research was driven by these areas and he made lasting contributions for each. Dr. Stein's research can be characterized by a judicious mixture of physical insight into the problem, understanding of the basic mechanisms, mathematical modeling of the observed phenomena, and extraordinary analytical and numerical solution methodologies of the resulting mathematical models. This paper summarizes Dr. Stein's life and his contributions to the technical community.

Manual Stein's Life

Dr. Manuel Stein, a Virginia Polytechnic Institute and State University PhD graduate, understood the importance of higher education to an individual's development and maturity, as well as its importance to the prosperity of America. He constantly encouraged his family, friends, students, and colleagues to pursue advanced degrees. His basic philosophy of pursuing excellence at every opportunity not only affected people he interacted with, but also led to many of his own significant scientific achievements. These achievements led to both national and international recognition of Dr. Stein as an expert in the field of structural mechanics.

Dr. Stein also understood the importance and interaction of good citizenship and professional ethics. He always conducted business in a calm and friendly manner, and radiated a feeling of professionalism. He is remembered by his family, friends, and colleagues for his warmth, compassion, humility, friendliness towards others, and especially his sense of humor. Dr. Stein genuinely enjoyed helping people, especially young people. As a result, he mentored many students and co-workers during his nearly fifty-year-long career. A scholarship in his name has been established at Virginia Tech, endowed by his family, friends, and colleagues worldwide which celebrates the exceptional achievements of Dr. Stein and the high ideals he practiced on a daily basis.

Manuel Stein (1921-1991) was born November 27, 1921 in Monaca, Pennsylvania. He was the youngest of four children of Charles and Lena Stein, who had emigrated to the United States from Russia. The family operated Stein's Department Store and the family lived in the rooms above the

store. After attending primary and secondary schools in the area, he enrolled at the University of Pittsburgh. In 1943, he graduated with a Bachelor of Science in Mechanical Engineering.

Manual Stein's Career

After graduating from college in 1943, Dr. Stein moved to Hampton, Virginia to begin employment with the National Advisory Committee for Aeronautics (NACA) at Langley field. The NACA was the predecessor of the well-known National Aeronautics and Space Administration (NASA). The first 17 years of Dr. Stein's career (1944 - 1961) were spent working with and learning from the masters of structural mechanics. These individuals included such names as, Batdorf, Budiansky, Reissner, Seide, Libove, Houbolt, Hedgepeth, Sanders, Mayers, and others. Dr. Stein published 33 highly original technical papers during that time period with these individuals. The last 27 years of his career were spent with Dr. Stein pioneering new research areas, mentoring, and unselfishly transferring his immense knowledge to the next generations of structural mechanists. During this time period Dr. Stein published 38 technical papers, 20 of which were co-authored by next generation researchers. A complete list of his papers is given in the reference list at the end of this paper.

Dr. Stein's work during the early period of his career dealt with mathematical analysis and experimental investigation of the structural behavior of stiffened and unstiffened plates and shells. During this time, he contributed greatly to the development of a nondimensional parameter for characterizing buckling of curved plates and cylindrical shells. Another significant achievement during this period of his career was the formulation of a theory for stress analysis and buckling of sandwich plates and shells. Dr. Stein's theory became the basis for most of the analytical work performed in this area for the next thirty years.

Graduate study was highly encouraged by the management of the NACA. Thus, Dr. Stein completed an MS degree in Aeronautical Engineering from the University of Virginia in 1951. His thesis work dealt with the torsion and transverse bending behavior of cantilevered plates. This work was of great interest to the NACA in that it supported the national effort to develop swept-wing jet aircraft. A couple of years later, Dr. Stein became involved in analyzing low aspect ratio wing structures. He developed a method of analyzing these structures that led to his recognition as a national expert in the field of structural analysis. It was at this time that he met Bernice Malkin. They were married in 1953 and raised four children.

In 1958, President Dwight D. Eisenhower introduced the National Aeronautics and Space Act that created NASA to replace the NACA on a much grander scale. Also in 1958, Dr. Stein received a PhD degree in Applied Mechanics from VPI. His dissertation dealt with the postbuckling behavior of rectangular isotropic plates. This effort and his subsequent work in this area, led to major advancements in the understanding of buckling and postbuckling behavior of plate structures. His publications written on this topic during this period of his career are still both widely referenced today and considered to be benchmark publications by the technical community.

During the next several years, Dr. Stein developed a refined analysis for predicting buckling of pressurized unstiffened circular cylindrical shells loaded in compression. His work in this area supported the development of spacecraft launch vehicles such as the one used to put the first American astronaut, Alan Shepard, into space. His work focused attention on the effects of boundary conditions and prebuckling deformations on the collapse behavior of shell structures. Up until this time, these effects were thought to be unimportant. Dr. Stein's work, originally published in 1962, stimulated a great deal of interest and research in this area for nearly 25 years.

In the early 60's the state-of-the-art for predicting the buckling load and natural frequencies of stiffened cylinders was highly empirical. This commonly led to significant

errors in predicting the buckling load of stiffened cylinders with unprecedented geometry such as was common in the development of new and larger launch vehicles. For example, experimental buckling loads for Saturn class structures were found to be in error by greater than a factor of two from theoretical predictions. Dr. Stein led a group of researchers during that time period in the development of a rational analytical procedure for predicting the buckling of cylinders with eccentric stiffeners. This stiffened shell research coupled with Dr. Stein's research on effects of boundary conditions and prebuckling deformations resulted in highly accurate prediction methods for the analysis and design of high performance stiffened shell structures. These analytical developments helped keep the Nation's Apollo program on schedule and paved the way for modern stiffened shell analysis.

Although Dr. Stein's major contributions were in the field of structural stability of plates and shells, his basic mechanics knowledge resulted in original contributions to the fields of membrane mechanics, vibrations, flutter, and laminate mechanics. For example in the early 60's he and John Hedgepeth developed a theory for partly wrinkled membranes which for the first time permitted wrinkled membranes to be analyzed using traditional approaches. This theory has been subsequently experimentally verified and has been used for the rational analysis and understanding of complex behavior of advanced missions involving membranes over the past thirty years. This work supported the development of paragliders, parasails, ballutes, and other deceleration devices for recovery of orbital payloads. Dr. Stein also made significant contributions to the dynamic analysis of membrane structures. He obtained exact solutions for the arrest of a moving mass by a flat circular membrane, or a membrane strip, attached to the mass. This work contributed greatly to the design and evaluation of structural reinforcements for the radio tracking beacon installations on the Echo II passive communications satellite.

In the latter part of Dr. Stein's career, he analyzed the buckling and postbuckling behavior of laminated composite plates and shells. His work in this area led to the development of nondimensional parameters for characterizing the postbuckling behavior of orthotropic plates. In addition, he formulated a theory for the nonlinear behavior of thick composite plates and shells. Both of these activities continue to support the development of energy efficient commercial transport aircraft that are expected to be operating in the year 2000.

The breadth and depth of Dr. Stein's contributions led to his recognition as an international authority on buckling of plate and shell structures, and to him being awarded the NASA medal for exceptional scientific achievement. Dr. Stein presented numerous talks and published approximately 50 technical papers during his career. He regularly reviewed books and journal articles for organizations including the American Institute of Aeronautics and Astronautics, the American Society of Mechanical Engineers, and the McGraw-Hill Book Company. He also reviewed articles for the International Journal of Solids and Structures and the Journal for Computers and Structures. Dr. Stein was often consulted by researchers at NASA, at other government laboratories, by members of the armed forces, by faculty members, at universities, and by many aerospace companies for advice on the solution of difficult structural mechanics problems.

He was invited to present lectures at universities around the world. His large reservoir of knowledge and experience, together with his talents as an analyst, were very valuable assets which contributed to his own research as well as to the output of others through his consultation and advice. Recent publications from NASA refer to the Donnell-Stein and Batdorf-Stein Equations, acknowledging his impact in these areas.

Dr. Stein was a member of Sigma Xi, Sigma Lambda Tau, and an Associate Fellow of AIAA. He served as a member of the Board of Examiners for doctoral candidates at George Washington University, Virginia

Polytechnic Institute and State University, and the Indian Institute of Technology Kampur. He taught extension classes for George Washington University, Old Dominion University and the University of Virginia at NASA's facilities.

The Dr. Manuel Stein Scholarship established at VPI&SU is awarded annually to an outstanding student pursuing graduate studies in the Department of Engineering Science and Mechanics within the College of Engineering. Recipients of the Scholarship Award shall be selected annually by the Head of the Department upon the recommendation of the Department's Scholarship and Awards Committee. The criteria to be used in the selection of the recipient of the Scholarship Award shall be those so well-reflected in Dr. Stein's own lifetime of service to his profession and commitment to his colleagues and students: the potential for scholarly achievement in teaching and research and a demonstrated dedication to the welfare and well-being of others.

Gifts to the Dr. Manuel Stein Scholarship are placed in an endowed fund with only the annual earnings available for funding scholarship awards; earnings from the Fund qualify for such matching funds as may be provided by the Commonwealth of Virginia under the Virginia Graduate and Undergraduate Tuition Assistance Program.

Gifts to The Dr. Manuel Stein Scholarship should be made payable to the "Virginia Tech Foundation, Inc." and sent to:

The Dr. Manuel Stein Fund
Office of University Development
201 Pack Building
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Summary

Although Dr. Stein made numerous outstanding technical advancements throughout his career, perhaps his most lasting legacy was the unselfish sharing of his immense technical knowledge and insight with numerous researchers at, and associated with the Langley research Center. Dr. Stein's contribution to the aerospace community is poorly measured by publication numbers, but must instead be evaluated by technical quality and significance and by the several generations of structural mechanists that he mentored, consulted with, or otherwise positively influenced. This paper commemorates the historical significance of the five decades of technical and mentoring contributions of Dr. Manuel Stein to the aerospace community. The paper includes a complete bibliography of Dr. Stein's research work for ready reference for future researchers.

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