Preface

0.1 INTRODUCTION

Solid mechanics is a fundamental discipline which, in current research, addresses as yet poorly understood phenomena in the mechanical response and failure of materials and structures. Research in solid mechanics is essential not only for basic understanding of mechanical phenomena, but also to advance engineering methodology in a host of areas throughout mechanical and structural technology. Advances in the subject are central to assuring safety, reliability, and economy in design of devices, machines, structures, and complete systems, and hence to the continued development of power generation technologies such as fusion, nuclear and gas turbine power, aerospace and surface transportation vehicles, earthquake resistant design, offshore structures, orthopedic devices, and materials processing and manufacturing technologies.

For example, the generation of nuclear power is now greatly restricted because of a variety of safety issues lying squarely in the domain of solid mechanics. Fusion power of the future is not expected to be possible without development of principles of solid mechanics applicable to extreme conditions of neutron bombardment and operation of structures in strong magnetic fields. The exploitation of high-temperature ceramics for efficient fossil-fuel power requires advances in understanding mechanics principles for design with brittle materials. Advances to assure performance and economy of operation in the aerospace industry depend critically on understanding the mechanics of fashioning and joining of lightweight composite materials. The reliability of modern electronic devices is dependent on understanding the mechanics of interfacial cracking and fatigue under thermal cycling in their processing and operation.

Advanced solid mechanics research directed to the microscale of materials is an essential component of modern materials science work on relating nonelastic deformation, cavitation and fracture properties of materials, whether metals, ceramics, polymers, composites, or artificially structured devices, to their microstructure. These studies have great potential for the design of new engineering materials with properties tailored for applications and for guiding the macroscopic analysis of deformation and fracture.

In bioengineering, the solid mechanics of tissue, muscle and bone is critical to advances in a host of areas including crash survival, rehabilitation, artificial implants, and fundamental understanding of such topics as organ operation and the growth and repair of living systems. In geotechnology and geophysics, solid mechanics is a central discipline for hydrocarbon resource extraction by drilling, hydraulic cracking and reservoir stimulation, for mining, tunneling and underground waste storage, for understanding the large scale flows of the Earth's mantle and crust which shape its surface, and for earthquake forecasting and prediction of strong ground motion in earthquake rupture propagation.

Some of the fundamental science issues confronted in modern solid mechanics research include the following: Micro and macro-mechanics of cracking and dynamics of fracture propagation in all classes of materials; non-linear and possibly chaotic dynamics of mechanical systems and structures, including those coupled to fast moving fluids and to intense electromagnetic fields; response of materials to extreme conditions of temperature, chemical environment, irradiation and deformation rate; exploitation of modern techniques, especially laser-facilitated optical methods, for new measurements of rapid mechanical phenomena in traditionally inaccessible situations; prediction of macroscopic mechanical response properties, both linear and nonlinear, for heterogeneous aggregates, whether in the form of artificially structured composites or conventional engineering materials whose microstructural complexity is considered; constitutive description of large non-elastic deformations of solids and basic mechanics developments for bifurcation and loss of stability in the form of phase transformations or shear localization, including techniques for mechanics analysis in the post-localization regime; stress-coupled processes of diffusive transport and chemical reaction in porous materials; inverse formulations for inference of buried defects or other material inhomogeneities from interactions with ultrasonic wave fields; stress-induced morphological development in living biological systems.

In all areas of solid mechanics research, whether related to advanced engineering methodology or fundamental phenomena, the impact of modern computational mechanics has been enormous. Continued advance of that area requires basic research on devising new algorithms, attuned to aspects such as parallel processing in advanced computing systems, for the vast range of complex and non-linear mechanical response that is not yet routinely analyzable. Nearly all the fundamental and applied research areas mentioned will profit from continued adoption of computational techniques and widespread availability of advanced computing systems to solid mechanics researchers.

0.2 THIS REPORT

In fall 1983 the Applied Mechanics Division of ASME established a committee on Solid Mechanics Research Directions. The committee consists of M. M. Carroll (co-chair), R. M. Christensen, R. J. Clifton, D. S. Griffin, F. A. Leckie, F. C. Moon, and J. R. Rice (co-chair). It was charged with identifying and, to the extent possible, fostering promising future research directions in solid mechanics. Recognizing the somewhat fragmented nature of the field and its lack of strong visibility in many funding agencies, it seemed appropriate for the committee to assemble a report which surveyed the entire field, identified the important trends in modern solid mechanics research, and pointed to outstanding research opportunities for the future.

This report is the result and, as the following subsection will reveal, it has involved the active participation of many members of the solid mechanics research community. The report is divided into 15 chapters. Chapters 1 to 5 examine research in the mechanics of specific classes of materials or material systems, whether biological, geological, or technological (metals, polymers, composites). Chapters 6 to 9 address cross-cutting phenomena (fracture, waves and dynamic response) and methodology (experimental, computational) valid for all classes of materials and structures. Chapters 10 to 13 focus on modern structural mechanics research and some specific application areas in mechanical and electronic technology. Chapter 14 addresses mechanics research needs for modern processing and manufacturing technology. Finally, chapter 15 examines solid mechanics research overall, draws together recurring themes in the earlier chapters, and points to new and promising approaches on the foundations of solid mechanics. *Each chapter closes with a summary of research needs in its area.*

We have not directly addressed in this report issues related to the suitability of funding for solid mechanics research and needs such as those for modernization of experimental facilities and provision of better access to advanced computers. Those are, however, issues of grave and continuing concern to our committee and, certainly, to the community at large, and will be addressed in other contexts. It will perhaps suffice to note that the unity, vitality, and promise that we show here for modern solid mechanics is not well mirrored in the structure and support priorities of many funding agencies. Much of active solid mechanics progress is at the interface with other fields of science (materials, biomedical, geological) or engineering technology. While this is healthy, it means too often that support for basic solid mechanics is accorded low priority in research funding programs whose priorities tend to begin with the centers of gravity of neighboring fields. The direct support for basic solid mechanics within the Engineering Directorate at NSF in recent years has been relatively static, strongly eroded by inflation, and generally unresponsive to the exciting developments in the field; at the time of writing, a substantial drop in this NSF support has been projected for the coming year. Also, while DoD agencies have provided substantial support, civilian agencies such as DoE and NASA, whose missions have been and will continue to be strongly impacted by advances in basic solid mechanics, have been badly underrepresented in provision of core support for the field.

0.3 THE PROCESS

We wanted wide involvement of the solid mechanics research community in our study. This was achieved in the following ways. We began in spring 1984 by asking each ASME/AMD Technical Committee involving solid mechanics to prepare an oral presentation on research trends and opportunities in its area. These presentations were delivered at a panel session, organized and chaired by M. M. Carroll, at a June 1984 ASME meeting in San Antonio. Topics and speakers were as follows: biomechanics, Y. C. Fung; composite materials, R. A. Schapery; fracture, C. F. Shih; geomechanics, S. Nemat-Nasser; computing in applied mechanics, S. Atluri, R. H. Gallagher, R. Barsoum, T. Cruse and L. Davison; elasticity, L. Wheeler; experimental mechanics, M. Fourney; shock and vibration, A. Leissa; wave propagation, S. Datta.

Following those presentations our committee met, decided to divide the study into chapter headings which approximate those that follow here, and assigned responsibility for preparing preliminary written drafts to different committee members. Those preliminary drafts which were completed by November 1984 were distributed to other committee members for comment before the next occasion for a major meeting with the solid mechanics research community.

That occasion was the late November 1984 NSF Solid Mechanics Grantees meeting organized at Menlo Park by G. R. Abrahamson and F. A. Leckie, then advisors to the NSF Engineering Directorate. Our committee was invited to participate, had access to documents submitted beforehand by other meeting participants giving their views on research opportunities in solid mechanics, and took part in the discussions of the meeting on solid mechanics research needs for industry and advanced technology.

The committee met immediately afterwards, on 1 December 1984, to critique the preliminary drafts of our chapters and advise on the approximate scope of the next "semi-final" drafts in light of discussions at the NSF Solid Mechanics Grantees meeting. At that time the present set of chapter headings was adopted and the decision was made to recruit additional help from F. P. Chiang, E. H. Dowell, Y. C. Fung, R. M. McMeeking, and A. Needleman for some of the chapters. The committee also drew-up lists of "readers" for each chapter, i.e., recognized experts in research on the topic of that chapter who were to receive and be asked to comment on the semi-final drafts. The lead authors for each chapter were given the option of enlarging the list of readers, and the intention was to use the readers' comments as a basis for preparation of the final versions which appear here.

The semi-final drafts of the chapters were completed at various times between December 1984 and March 1985 and the final versions, published here, between April and July 1985. We have acknowledged those readers who commented, and others who made direct contributions, just after listing the lead author for each chapter. However, we wish also to acknowledge here the very significant contributions to our study made by members of the ASME/AMD Technical Committees and participants in the NSF Solid Mechanics Grantees meeting. The committee also received helpful advice from D. C. Drucker and from representatives of mechanics funding agencies, C. J. Astill, A. Kushner, and M. J. Salkind.

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Report Editor, July 1985