Chapter 4
The American Society of Mechanical Engineers Spirit

Abstract Of great importance is the innovative and enduring influence that a well-organized professional society may have on the development of a science. This is the case of mechanical engineering with the American Society of Mechanical Engineers. As documented in this chapter, this society provided a specific forum to its members at a spot-on time. It brought a spirit that permeated many American works in continuum mechanics. This may be described as: good modelling (without too much abstraction and unnecessary formalism), good applied mathematics providing real applicable solutions with numbers and curves, and a specific interest in the relationship of these solutions with experimental facts. The prominent figure obviously is the founder of the Applied Mechanics Division of the ASME, Stephen P. Timoshenko. For easiness in presentation, a few most influential centres are highlighted in this chapter. These are Stanford (with Timoshenko himself), the M.I.T (with Eric Reissner), Brown (with William Prager) and Columbia (with Raymond Mindlin). Each of these is most representative of identified avenues of research: advanced strength of materials, mathematics applied to problems of engineering, tremendous and contagious developments in the theory of plasticity, and accurate dynamical theory of structural elements (e.g., plates and shells) and coupled fields (electroelasticity). This was to swarm all over the USA and then the whole world community of mechanics.

4.1 Introduction

One way to find out to which science group a scientist thinks he belongs is to ask him his own answer to that question (that is the most honest way). Another way is to find out in what scientific journals this person publishes most often since he is expecting this place to be the most suitable forum for his work and in turn to receive the best feedback possible. Accordingly, a professor who officially belongs to a department of engineering but publishes essentially in journals with the

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"applied mathematics" label may be called an "applied mathematician". The person herself should agree with that since there is no visible insult in this categorization. In this chapter we focus on a rather large group of contributors to continuum mechanics who are affiliated with the *American Society of Mechanical Engineers* (for short, the A.S.M.E) and who published essentially in the journals of this society, principally, the *Journal of Applied Mechanics* (Transactions of the A.S.M.E). We think this to be justified by the fact that both society and journals carry with them a specific spirit that can be delineated thus: good modelling (without too much abstraction and unnecessary formalism), good applied mathematics providing real applicable solutions with numbers and curves, and a specific interest in the relationship of these solutions with experimental facts. This departs very much from the other view that will be exposed in the next chapter.

Because of the clear-cut US professional context this concerns mostly American *mechanical engineers* or foreign scientists who made a career in the USA. Of course we are above all concerned by the *Applied Mechanics Division* (A.M.D) of the ASME. This division is involved in the fundamental and applied field of mechanics, including solids, fluids and systems. According to the Society's definition,

> it strives to foster the intelligent use of mechanics by engineers and to develop this science to serve the needs of the engineering community. Areas of activity cover all aspects of mechanics, irrespective of approach, including theoretical, experimental, and computational methodology. The field of mechanics, which is the study of how media responds to external stimuli, includes fundamental analytical and experimental studies in: Biomechanics, Composite materials, Computing methods, Dynamics, Elasticity, Experimental Methods, Fluid dynamics, Fracture, Geomechanics, Hydrodynamics, Lubrication, Mechanical properties of materials, Micromechanics, Plasticity and failure, Plates and shells, Wave propagation, other related fields.

Many of these sub-fields fall in the large subject matter of this book.

The possibilities of publishing papers originally fitting the ASME journals were much enlarged in the 1960s with the creation by Pergamon Press (Oxford, UK) of a series of international journals dealing with subjects of engineering sciences, but often at a more formal level (e.g. the *International Journal of Engineering Science*, the *International Journal of Solids and Structures*, the *International Journal of Non-linear Mechanics*, etc.). The *Journal of Elasticity*, founded in 1971 by Marvin Stippes (1922–1979), was also a good forum for the same papers, but in times it turned more to the style that we shall examine in Chap. 5. Also, many American mechanical engineers of British origin continued to publish in British journal of applied mathematics and mechanics. A short history of the AMD-ASME was given by Naghdi (1979).

4.2 The Stanford Connection and Timoshenko

The *ASME* was founded in 1880 explicitly "to provide a setting for engineers to discuss the concerns brought by the rise of industrialization and mechanization". Its *Applied Mechanics Division* is one of the oldest and largest divisions of the

ASME. This division was founded by Timoshenko and others, Timoshenko acting as its first chairman. The relevance of this division to our subject matter is made crystal-clear when we scan the list of recipients of the three famous medals bestowed by this division, the Timoshenko, Drucker and Koiter medals. Here we find, among others, the names of Goodier, Biot, Mindlin, Prager, Koiter, Lee, Eshelby, Ericksen, Naghdi, Argyris, Drucker, Irwin, Rivlin, Budiansky, Fung, Rice, Willis, Tvergaard, Maier, etc. between the years 1957 and 2000. All theses names appear in due place in the present book.

The prominent figure obviously is **Timoshenko** (1878–1972) of Ukrainian origin. Educated as a Railway engineer in St Petersburg, Timoshenko had a rather erratic career in the Russian Empire and Zagreb in Croatia before he moved to the USA in 1922 at the age of 44. At this time he had already contributed to several areas of engineering mechanics: complex structures, computation of eigen frequencies, simple approximate methods, stability of frames, etc. This was already an all round activity in the field. It is in Kiev in the years 1907–1911 that he developed an interest in studies of buckling and that he wrote the first version of his famous textbook on the *Strength of materials* (Timoshenko 1930). On his move to the USA he first worked for the Westinghouse Electric Corporation (1923–1927). He joined the University of Michigan in 1927 and transferred to Stanford in 1936 to stay there until he took a well deserved retirement in Germany in 1960 where his daughter was living. He published books on all aspects of engineering mechanics; these books were translated in more than thirty languages, a record achievement in the field. Among his many books (Timoshenko 1930, 1948, 1951, 1953, 1959, 1961) we like to single out his unique and well documented *History of the strength of materials* (1953). He may be considered the father of modern engineering mechanics in the USA. The Institute of Mechanics of the Ukrainian Academy of Sciences in Kiev is named after him.

Timoshenko was also a tremendous lecturer and supervisor of students' doctoral works (about 40 in the USA). Among those he mentored, we note in Michigan: Donnell (1930), Goodier (1931), Horger (1935), Hetényi (1936), and in Stanford: Lee (1940), Hoff (1942), and Popov (1946). His own most famous contributions are to the beam theory, the deflection of membranes, the bending of plates with Ritz method, and buckling in general. But the variety of his interests is also reflected in the title of the many books he wrote and the domains to which his doctoral students contributed, e.g. Hetényi (beams on elastic foundations, photo-elasticity, general elasticity problems), Donnell (bending of beams, bucking of shells, thick plates, the Donnell-Vlasov equation), Goodier (thin-walled structures), Horger (fatigue, photo-elasticity), Hoff (aeronautical structures), Popov (strength of materials). Remarkably enough, four of Timoshenko's students (Goodier, Donnell, Hoff, Hetényi) became chairmen of the AMD of the ASME.

Herrmann (1921–2007), after stays at Columbia and Northwestern University, joined Stanford in 1970 to remain there until his retirement. He perpetuated the ASME spirit although he also created a new journal, the "International Journal of Solids and Structures". A Swiss/American polyglot born in Russia, he was for a long time editor of the English translation of the top Russian journal of mechanics and applied mathematics Prikladnaya Mekhanika i Matematika (P.M.M.). He worked in many fields including shell theory, stability of structures, vibrations of elastic bodies, wave propagation, fracture, and the theory of material forces (configurational mechanics). He was instrumental in bringing to Stanford Juan Simo (1952–1994), a foremost authority on computational mechanics in finite strains, and Alicia Golebiewska (1941–1983), a noted specialist of the theory of defects and configurational mechanics, both unfortunately for a rather short time.

4.3 The M.I.T Connection and Reissner

The MIT in Cambridge, Mass., with its announced banner, is most often seen as *the* temple of technology, what meant mechanical, civil, electrical and chemical engineering in the first half of the 20th century. In time, this has evolved by including new sectors of engineering as they were born, electronics, nuclear engineering, computer sciences, and then embracing all scientific fields to the highest degree. But in the period of interest here—say, when the writer was admitted to, but did not join, the MIT graduate school—"classical" engineering still was an obvious lighthouse. An excellent recruit for the MIT faculty in 1937 was Eric Reissner (1913–1996) who had previously been educated at the Technical University of Berlin. Rather typical of MIT policy, Reissner obtained a professorship in mathematics that he held from 1939 to 1969. This was the vision of mathematics at MIT at the time, by which should be understood "mathematics applied to problems of engineering". The mathematical dexterity and rigour of Reissner perfectly suited this definition. Reissner more than fulfilled the expectations of the faculty board by becoming one of the most productive, successful and internationally recognized engineer-scientist in the field of structural analysis with applications to both civil and aeronautical engineering. In particular, Reissner improved on solutions by Timoshenko in the elastic theory of beams, thin-walled structures, plates and shells. This is illustrated by his theory of shear deformation in plate theory. His works are marked by the exploitation of variational principles (e.g. the celebrated Hellinger–Reissner variational principle that accounts simultaneously for both displacement and stress conditions); cf. Reissner (1953) and an obvious easiness in dealing with complex analytic problems.

Personal touch: During a lecture by the writer in Blacksburg, Virginia, Prof. Reissner intervened publicly to tell that, even with special efforts on his part, he could not understand why the name of Hellinger was associated with his own name for the so-called two-field variational principle. This tells something on the personality of Eric Reissner with whom the author should have worked, had he joined the MIT for graduate studies.

The best known doctoral student of Reissner at MIT may have been James K. Knowles (1931–2009) who is the author of many seminal works in elasticity and phase-transition problems. This he achieved in close collaboration with Eli Sternberg (1917–1988) and younger colleagues, e.g. Horgan and Abeyaratne.

He was a professor at Caltech from 1965 until retirement. Knowles and Abeyaratne are the authors of a remarkable monograph on phase-transitions fronts (2006), a domain to which they contributed with energy and ingenuity in the period 1990–2000 with works on shape-memory alloys, the dynamics of propagating phase boundaries, and the kinetics of austenite–martensite phase transformations. Rohan Abeyaratne (PhD Caltech 1979) joined MIT in the late 1980s and became head of its Department of Mechanical engineering (2001–2008).

4.4 The Brown Connection and Prager

The disproportionately important contribution of Brown University to engineering and continuum mechanics is somewhat of a mystery. This rather small but old university resides in Providence, Rhode Island, in the smallest state of the USA with only about one million of inhabitants. It was founded in 1764, belongs to the Ivy League—along with Harvard, Yale, Princeton—and has the oldest undergraduate program in engineering in this class of colleges. A single division of engineering gathering small departments was created in 1926. Still the engineering faculty remains relatively small with—at the time of writing—about forty full-time members and a body of about one hundred and fifty graduate students. It is complemented by an active division of applied mathematics. But Brown succeeded to be almost the centre of the World for studies on elasticity and plasticity starting in the 1940–1960s. The following list of professors and PhD students at some time at Brown speaks for itself, looking like a real "dream team": Prager, Drucker, Rivlin, Symonds, Sternberg, Kestin, Rice, Weiner, Freund, Clifton, Needleman, Budiansky (PhD 1950), and in applied mathematics dealing with problems of continuum mechanics Gurtin (PhD 1962) and Dafermos.

Prager was the driving force behind all developments in plasticity theory at Brown. He is most well known for his proposal (1949) of the format of plasticity with kinematic hardening (plasticity surface moving with the evolving state of plastic strains; Prager (1955, 1961), his introduction of the notion of locking materials (i.e. materials exhibiting a saturation in strain; Prager (1957)) and his deeply thought books in the field of plasticity and general continuum mechanics (). Drucker (1951) gave his name to the *Drucker inequality* (non negative product of stress rate and plastic strain rate), i.e.

$$\dot{\sigma}_{ji}\dot{\varepsilon}^{p}_{ij} \geq 0, \tag{4.1}$$

and Drucker's stability postulate in the self explanatory form

$$W = \int_0^t \left(\sigma_{ji} - \sigma^0_{ji}\right)\dot{\varepsilon}^{p}_{ij}dt \geq 0, \tag{4.2}$$

where σ^0 is the original state of stresses and $[0,\ t]$ is a closed time-cycle of loading and unloading. Greenberg (1949), also at Brown, was one of those who proposed in 1949 a variational formulation of plasticity (minimum principle exploiting a convexity argument). This was improved by Budiansky and Pearson (1956/1957). Symonds (1951) introduced the ingenious notion of plastic hinges that allows one to treat the collapse of truss structures, and set forth the elements of shake down (or limit) analysis (Drucker et al. 1952). The seminal works of Rivlin were examined in Chap. 3. Gurtin and Sternberg (1962) worked in the linear theory of visco-elasticity (also Sternberg, 1964). Rice (1968) produced his famous works on path-independent integrals and the thermodynamics of plasticity, while Kestin became the most acute observer and critic of the thermo-mechanics of continua (see his celebrated treatise on thermodynamics 1966). Weiner expanded the statistical theory of elasticity (see his wonderful book of 1983). Freund produced his theoretical works on dynamic fracture, while Clifton performed landmark experiments in the same. Constantine Dafermos, a former PhD student of Ericksen, is an applied mathematician specialist of the dynamics of continua and hyperbolic systems. The world reputation—especially Prager's—of the Brown school, a true "Mecca" of plasticity, reached such a level that many foreign visitors came to Brown to get acquainted with the then most recent developments in plasticity (among them, Paul Germain from France in 1952–1953; See Chap. 7); also Hans Ziegler from Switzerland. Those formed in Brown then spread over the USA to continue the successful expansion of the Brown spirit.

4.5 The Columbia Connection and Mindlin

To be able to fully understand the University of Columbia in New York City, it might be requested be a born New-Yorker. Indeed so many people seem to have been born in New York, made their basic high-school training, college and university studies in the same city, and finally ended teaching also there. I even know some of these people who never travelled farther than New Jersey, spending in their youth some week-ends and later on some holidays in Atlantic City (otherwise famous for its Mafia connection and Frank Sinatra). One such character seems to have been Raymond D. Mindlin (1908–1978), although I met him abroad occasionally (CISME Lectures in Udine in 1970). Born in New York, Mindlin obtained all his university degrees (BA, BS, CE, and PhD) at Columbia where he taught from 1936 to 1975, with a few visits in Michigan to attend summer lectures from Timoshenko in the summers of 1933–1935, and a War scientific service at the Applied Physics Laboratory in Maryland in the period 1942–1945.

Mindlin's PhD work published in 1936 was already a masterpiece. He solved in it what is now called the "Mindlin problem": determine (analytically) the stresses in an elastic half-space subjected to a sub-surface point load. This is a generalization of results obtained by Kelvin and Boussinesq in the 19th centuries. It receives applications in geotechnical engineering. The roster of mechanical subjects treated, modelled and/or solved by Mindlin is extremely rich including such different items as: photoelasticity, classical elasticity problems, generalized elastic continua (strain-gradient theory, media with deforming microstructure and couple stresses—see Chap. 13), frictional contact and granular materials, waves and vibrations in isotropic and anisotropic plates (in the so-called Mindlin's theory of plates), wave propagation in rods and cylinders (cf. the Love-Mindlin lateral inertia), electro-elasticity and piezoelectric crystal resonators, crystal lattice theories. His work in vibrations of plates set forth standards in the theory of real and imaginary multiple coupled branches of dispersion. In the 1950s, he wrote on the subject a monograph for the US Army Signal Corps, which monograph stands out as a classic in the field (published in book form and edited recently by J. Yang 2007; Mindlin 2007). His theory of electro-elasticity with polarization gradients (1968–1972; cf. Chap. 12) opened up new horizons in the description of electromechanical couplings in materials that do not allow for the existence of standard linear piezoelectricity (for which no centre of symmetry is allowed). Mindlin has been a chairman of the *AMD* of the ASME. He collected many honours, among them a Presidential Medal of Merit (1946) for his scientific contribution to the War effort during WWII and the National Medal of Science in 1979 in recognition of his all round contributions to American engineering and applied physics. Collected works of Mindlin are given in Mindlin (1989).

One of Mindlin's doctoral students, Tiersten (1930–2006), seems to have inherited some traits of his mentor. Also born in New York, Tiersten also obtained all his degrees (BS, MS, and PhD) at Columbia. But he spent six years at Bell Telephone Laboratories (in nearby New Jersey), before joining the Rensselaer Polytechnic Institute in Troy (still in New York State) in 1967. But the writer succeeded to bring him to Paris for an international conference in 1983. He also had a continued and fruitful co-operation with the US Army Laboratory in Fort Monmouth in New Jersey, with Arthur Balluto, another New Yorker with mobility limited to New York City and the coast of New Jersey. Tiersten contributed to the elaboration of continuum theories exhibiting the role of a microstructure. His most powerful contributions, however, are in the field of piezoelectric couplings (cf. Tiersten 1969), vibrations, and the nonlinear theories of magnetized deformable bodies and electro-elasticity including thermal effects and the case of semi-conductors.

Raymond Parnes (born 1933, PhD 1962 with Mindlin), another New Yorker, who remained in New York and Columbia before moving to Israel became a noted specialist of problems in elasticity. Yih-Hsing Pao (born 1930, PhD with Mindlin in 1989) became in Cornell a well known specialist of physical acoustics and wave propagation in solids, with some excursion in electro-magneto-mechanical interactions. Lee carried the flame of piezo-electricity in the Department of Civil Engineering at Princeton with his PhD students Xanthippi Markenscoff and Jiashi Yang, themselves now professors of mechanics in California and Nebraska, respectively. George Herrmann spent some of his first years in North America in Columbia with Mindlin; he considered himself a disciple of both Prager (who advised him on his doctoral work in Zürich) and Mindlin, in the honour of whom he edited in 1974 a complimentary volume that provides a detailed technical description of Mindlin's scientific contributions by his main co-workers (Herrmann 1974).

Another colleague of Mindlin at Columbia was Boley (born 1924). Although born in Trieste (Italy), Boley may also be considered a New Yorker. Indeed, he obtained all his diplomas in New York City (College of the City of New York, Brooklyn Polytechnic—where Hoff was teaching) and left New York only for a short experience in industry, a short stay at Cornell (1968–1972), and a longer stay at Northwestern (1972–1986) where he served as Dean of Engineering. But he joined Columbia in 1952 until 1968 and back in 1986 until retirement, and then with emeritus status. A good friend but not a co-worker of Mindlin, he is most well known for his contribution to the theory of thermo-elasticity for which he wrote a classic in the field (1960) together with Columbia's colleague Weiner. He founded the journal titled "Mechanics Research Communications" of which the aim remains the rapid publication of short contributions (somewhat in the spirit of "letters").

4.6 Concluding Remarks

Here above we have selected a few places which, in our opinion, are representative of a style of some scientific/engineering developments in the 1940–1960s as they smell good the ASME spirit. This is not to say that these are the only such places. We cannot ignore other institutions where some luminaries contributed to definite advances in the same spirit. To the risk of missing some important places (but this is only due to our ignorance), such places are: Harvard (with Budiansky and Rice), Cornell (with Pao and Moon), Yale (with Onat), Purdue and Princeton (with Eringen), the University of Pennsylvania (with Hashin and others), Lehigh University (with Rivlin, Erdogan and others), the University of Michigan, the University of Chicago and Northwestern University in Evanston (with Achenbach and Bazant, and more recently Belytschko), the Illinois Institute of Technology, the University of Minnesota (with Ericksen), the University of Illinois at Urbana-Champaign, the University of Houston, the Texas A&M University, and, obviously, the University of California at Berkeley (with Naghdi), and Caltech. On perusing the short biographies of mechanicians given in the Appendix the reader should be able to form some good idea of the contribution of these institutions, taking however, account of the great mobility of many researchers (save for the above mentioned New Yorkers). It is the opinion of the present writer that some names already cited in this chapter (e.g. Gurtin) have also contributed to another "spirit", that of the axiomatization line launched in the 1940–1950s by Truesdell. This is examined in the next chapter.

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