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**Timoshenko Medal Lecture**

ASME Applied Mechanics Dinner

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It is a tremendous honor to speak at the Applied Mechanics Dinner as this year's Timoshenko medalist. I was one year old when Prof. Stephen Timoshenko delivered the inaugural lecture in this series. I was a teenager when I first heard his name, and used his textbook on elasticity for my undergraduate class.

I have been blessed with the opportunity to work with some of the most talented and creative students, post-docs, visitors and collaborators in my research group. The recognition that I am receiving here is due in large part to their contributions to mechanics, and I accept this honor on their behalf.

I am perhaps unique as a Timoshenko medalist in that, in addition to being an active scientist, I am also the head of a large federal agency. Some colleagues have asked me how I feel being away from academia in Washington. I am reminded of the story associated with Woodrow Wilson, who was president of Princeton University before running for Governor of New Jersey and subsequently for President of the United States. When asked by a reporter why he left his Ivy League school to go into Government, President Wilson is said to have replied, "So I don't have to deal with politics anymore".

The Timoshenko lecture traditionally involves reflecting on one's life journey and career. I honor that tradition tonight as I examine my journey, its twists and turns, and the many serendipitous events that have shaped my perspectives, values, research and career.

I grew up in South India in a lower middle-class family in which education was highly valued — although neither of my parents graduated from university. I was enrolled in first grade at age four, mainly because I was stretching my mother's patience at home. As a result, I was the youngest in my class throughout school and graduated from high school at the age of 15. After a year of pre-university studies in mathematics, physics and chemistry, I was admitted to the Indian Institute of Technology (IIT), Madras. My years at IIT were inspiring and enjoyable with rich course offerings in traditional mechanical engineering.

I set out for the US in August 1977 to pursue graduate studies because it was the expected career path for an IIT graduate at that time. This involved my maiden airplane flight with a half-full suitcase of personal possessions, a one-way air ticket purchased

with a loan, and less than $100 in my wallet. Iowa State University, in addition to being an excellent institution that offered me full scholarship, was an attractive destination for me because they waived my application fee, which I could not afford. By now you have probably figured out how I acquired my "Iowa accent".

Beginning a new life in the US involved many challenges. First, moving from a major city in South India to the quietness of a college town several hundred miles from the nearest metropolis was a difficult adjustment. Second, relocating from the hot and humid climate of Madras to the severe winters of Iowa caused "thermal shock." Third, tasty epicurean options were extremely limited in the food establishments of Iowa in the 1970s for someone who grew up as a vegetarian. Fourth, the cost of a brief telephone call to India was so prohibitively expensive in those pre-internet days that I kept in touch with my family through weekly letters penned in "aerograms". However, all these issues were more than offset by the warmth of the great people of Iowa State. I completed my Master's degree in May 1979 and immediately moved to MIT.

I was fortunate to join the Mechanical Engineering Department at MIT, where key faculty members in the "Materials" group included Ali Argon, Frank McClintock and Rob Ritchie. I became Rob's first doctoral student working on the fatigue behavior of structural materials. His own training at Cambridge University in the academic lineage of Alan Cottrell and John Knott, coupled with his earlier publications with Jim Rice from Brown University and Earl Parker and Victor Zackay at the University of California, Berkeley, positioned him as a rising star in the areas of fracture and fatigue. I had the pleasure of working closely with Rob to establish my doctoral research, as he was establishing his own academic path as a relatively new faculty member.

During the summer of 1980, soon after completing my doctoral qualifying exam at MIT, I had a consulting arrangement at the Lockheed Palo Alto Research Laboratory in the group of Richard Lewis. Dick was a wonderful mentor. He was in charge of a broad portfolio of materials research and took me under his wing. My research blossomed upon my return to MIT in the fall of 1980 and I was able to defend my doctoral thesis in May 1981, less than two years from start to finish. In fact, my doctoral work moved so fast that I had to spend the summer taking additional courses to meet my doctoral credit requirements. Rob Ritchie left MIT to join UC Berkeley in the summer of 1981, and I followed him to Berkeley as his post-doc.

My time at UC Berkeley and the Lawrence Berkeley National Laboratory helped me broaden my knowledge of materials science. In addition to studying mechanisms of fatigue, I initiated new research into the structure–property connections in low-density materials.

After two years at Berkeley, I received an offer to join the Solid Mechanics faculty in the Division of Engineering at Brown University. This was a period of significant advances in mechanics of materials and my ten years on the faculty at Brown were wonderfully

rewarding, thanks to the many talented students, post-docs, and faculty colleagues I worked with. To my pleasant surprise, the process to grant tenure to me was initiated barely a year and a half after my arrival at Brown, owing primarily to the efforts of Bob Asaro.

In 1986, I married Mary Delmar in the Manning Chapel on the Brown campus; members of my research group and all members of the Solid Mechanics and Materials faculty attended our wedding ceremony, and the reception at the Brown Faculty Club. My entire family from India made their first trip together to share the wonderful event with Mary and me. In the next several years, Ben Freund, Alan Needleman, and Rod Clifton, all of whom subsequently became Timoshenko medalists, were wonderful hosts of many dinners at their homes that cultivated my continuing warm feelings for the Brown colleagues and their families. Close research collaborations with Alan Needleman, Fong Shih, and the late Jacques Duffy were particular highlights of my activities in the late 1980s.

I took my first sabbatical in 1990, about a year and a half after the birth of our daughter Nina. This sabbatical, spent at home, provided a unique opportunity to wrap up my book on "Fatigue of Materials", which was published by Cambridge University Press. The anticipated arrival of our second daughter Meera in August 1990 provided a natural deadline for me to complete my book.

What I thought would be a life-long career at Brown University took a different turn in 1993 when Mert Flemings, head of the department of materials science and engineering at MIT, convinced me to return to Cambridge. This new appointment also marked a shift in my research into micro- and nano-mechanics with applications to functional and graded materials and thin films. My activities at MIT also included taking the lead editorship role of the journals Acta Materialia and Scripta Materialia, and helping to establish MIT's first major collaboration with the universities in Singapore. During this time, my co-authorship, with Andreas Mortensen, of several review articles on graded materials culminated in a research monograph that was published by the Institute of Materials.

In January 2000, I became head of the department of materials science and engineering at MIT, a position that taught me a number of valuable lessons in leadership and interacting with people. It also provided many life experiences that took me beyond my comfort zone of teaching and research activities. The job involved fund-raising for the creation of several new laboratories in highly visible parts of MIT and for a major curriculum revision effort in materials science and engineering. The administrative tasks, contrary to my initial fears, did not lead to any reduction in my research activity. When the National Nanotechnology Initiative was launched, I was fortunate to win a grant from the Office of Naval Research to lead a large multi-year effort in nanomaterials. In addition, I was engaged in the writing of a book on thin film materials, in partnership with Ben Freund. It was a great pleasure working with Ben,

and we submitted our book to Cambridge University Press in early 2003. Around this time, I was also fortunate to work closely with Ares Rosakis to develop new technology for stress and reliability assessment of thin films and patterned lines on substrates. These ideas and joint patents led to the creation of a spin-off company in Pasadena that eventually merged with a larger entity. Many visits to Caltech between 1999 and 2005, as the Clark B. Millikan Professor and the Gordon Moore Scholar, gave me an opportunity to benefit from the warm friendship of a number of colleagues, most notably Ares and G. Ravichandran.

The completion of my book on thin films also marked the beginning of a new effort in exploring the connections between human diseases and cell biomechanics. This forced me to learn several new fields including biology, parasitology, and hematology. The risks of venturing into these new fields were high, especially given the simultaneous demands on my time from my leadership roles. But, from the benefit of hindsight, I can say that the intellectual rewards of this expedition into a new research territory have been phenomenal. Interactions with colleagues, most notably Monica Diez Silva, Jay Han, and the late Michael Feld from MIT, C.T. Lim from the National University of Singapore, George Karniadakis from Brown University, and Geneviève Milon from Institut Pasteur in Paris, have contributed to progress in this effort. I owe a special note of gratitude to Ming Dao who has been a key collaborator for more than a decade, and who currently oversees my research group while I am on leave from MIT.

Between 1997 and 2005, I had the opportunity to spend extended sabbaticals with my family at the Royal Institute of Technology in Stockholm, CalTech in Pasadena, Ecole des Mines and Institut Pasteur in Paris, and the Max-Planck Institut for Metallforschung in Stuttgart. Peter Gudmundson, G. Ravichandran, Ares Rosakis, Andre Pineau, Genevieve Milon and Eduard Arzt were wonderful hosts during these visits, and my family and I continue to enjoy their friendship. Each visit helped develop new research collaborations and new scientific perspectives, in new disciplines.

When I decided to step down from my MIT role as department head in January 2006, I planned to return to the quiet life of a full-time researcher. However, that tranquility lasted less than a week. I was invited to serve as the lead faculty investigator in preparing a proposal to the newly created National Research Foundation of Singapore to establish MIT's first research center in Singapore, now known as the Singapore-MIT Alliance for Research and Technology (SMART) Center. The proposal received the approval of the Prime Minister and the Center was launched in early 2007.

In June 2007, I accepted the appointment as the Dean of MIT's School of Engineering, which comprises roughly 40% of MIT's faculty and about half of all MIT students and living alumni. Navigating the School through the Great Recession that was just beginning was a particular challenge. I learned that making counter-intuitive decisions with a long-term perspective can have much more significant pay-offs than relying on conventional wisdom that focuses on the short-term. After careful assessments of several

conservative economic scenarios, I decided to accelerate faculty hiring in the School during the financial crisis — a decision that was unanimously backed by my leadership team of department heads. The result was a successful faculty recruitment process that led to the hiring of nearly 50 new faculty members, including a record number of women faculty members in engineering, in less than three years during the worst economic downturn of our lifetime. My career path at this point had encountered more surprises than an Indiana Jones movie. But Fate intervened once again.

In March 2010, I received an invitation from the White House to serve as the Director of the National Science Foundation (NSF). I was truly humbled by this call for national service from the President of the United States to lead an institution that has had such a wide-ranging impact on science and engineering research and education. After confirmation of my nomination by the US Senate, I took a leave from MIT and started at NSF in October 2010.

NSF is an amazing organization whose reach and impact on the national and international scene are far greater than one could imagine. With an annual budget of $7 billion that supports the diverse scientific explorations of hundreds of thousands of researchers, leading this vast enterprise has been an extremely rewarding endeavor for me. I would like to point out that over the last six decades, NSF has supported over 200 Nobel laureates. The difference between NSF and the Nobel Prize committees is that we recognize the Nobel laureates' potential decades before they become famous — and on average we provide them more compensation. NSF has also brought me unique life experiences that included travels to the highest point in the Arctic Circle and to the geographic South Pole, launching a new research ship, meetings with heads of state, and visiting the President in the Oval Office.

Moving from the past and present to the future, how does one see the evolution of mechanics? In addition to its continuing impact on engineering and physical sciences, I see mechanics at all length scales as playing an increasingly significant role in such ostensibly distant areas as human health, disease diagnostics, and novel therapeutic discoveries. The intersections of engineering, physical sciences, life sciences, medicine and public health represent rich playing grounds in which theoretical, experimental and computational mechanics will continue to have a profound impact. I also believe that the interfacing of engineering, physical sciences and life sciences with the social, behavioral and economic sciences will be essential to address the grand challenges that humanity faces. In sum, mechanics provides a unique platform from which scientific efforts in many interdisciplinary fields can be launched with industrial applications and societal implications that we can only speculate about.

Let me note that receiving recognitions, such as the Timoshenko Medal, imply a certain level of "seniority" in the scientific community about which I do not yet feel fully accustomed to. Nevertheless, in keeping with tradition, let me offer a few suggestions to the younger people in the audience, based on my own experience.

1. Make every effort to focus on deep individual scholarship in whatever research you undertake. At the same time, do not ignore the importance of policy and leadership roles if you would like your work to have greater impact over a broader horizon.

2. Don't be afraid to risk venturing into distant intellectual terrains to question conventional wisdom in remote disciplines. The potential rewards far outweigh any seemingly significant pitfalls.

3. While local political considerations often strongly influence the behavior of scientists, adopt a broader global view of the international scientific community. This will provide you with a balanced and "higher altitude" perspective on the importance and limitations of your own work.

A satisfying professional journey does not result solely from individual effort. Many people play a vital role in shaping its course. I have been blessed with many colleagues whose friendship and generosity have made my journey most enjoyable, challenging and meaningful. I have already cited some key people, but let me acknowledge a few others: Dick Lewis at Lockheed Palo Alto Research Laboratory for all his help in the early part of my career; Joseph and Dotty Gurland at Brown University who made sure that I was well-treated despite being the youngest faculty member; Mert Flemings and Chuck Vest at MIT for their inspiration; Fong Shih for his close friendship over the past thirty years; and Zdenek Bazant of Northwestern University for his many kind interactions.

I am here tonight because of the intelligence, far-sightedness and courage of my late mother who made so many sacrifices to ensure that I had opportunities in life that she was never fortunate enough to encounter. My wife Mary, our daughters Nina and Meera, and my sister Chitra, have given me the inspiration and understanding to strike the delicate balance between a satisfying career and a rich family life. I am most grateful to them for all the joy they have brought to my life.

And in closing, I wish to thank the Timoshenko Medal selection committee, the Applied Mechanics Division and the American Society of Mechanical Engineers for this recognition.