2015 TIMOSHENKO LECTURE — MICHAEL ORTIZ

Howdy! I am your after-dinner entertainment!

I am also this year's Timoshenko Medal recipient, a staggering honor that I'm still trying to wrap my mind around and come to grips with. The recognition of one's peers is the sweetest thing of all in our line of business, and it is one of the main things that keep us going in our careers. To say that I am deeply moved and honored by this award is an understatement, I am actually tickled pink. My deepest gratitude goes to all those who took the time to nominate me and the superb fiction writers who wrote the letters of support. I would also like to thank the Timoshenko Medal Committee for seeing fit to honor me with this award. Foremost in my mind, at this time, are all my teachers, mentors, students, colleagues and collaborators over the years that made this award possible. Last but not least, I am grateful to my family and friends, above all to my parents, brother and sister, my late wife of 33 years, Minerva, and my sons Daniel and Pablo, for their life-sustaining love and support.

I actually have a personal, if twice-removed, connection with Stepan Prokopovych (Stephen) Timoshenko in that I am one of his academic grandsons, being the Ph.D. student of Egor P. Popov at UC Berkeley who was himself a Ph.D. student of Timoshenko at Stanford University. Let us take a moment to remember Stephen P. Timoshenko, eminent structural engineer, teacher and mentor, author of seminal works in the areas of engineering mechanics, elasticity and strength of materials, many of which are still widely used today. On a more personal note, I would like to recognize Timoshenko's works, *grato animo*, for impressing upon me, early on, the beauty of engineering, mechanics and mathematics.

Having attained a certain seniority and having been recognized as Timoshenko medalist, I am expected to reflect sagely on my life and times for your general edification. I will try to make this as painless as possible… I hope you find my remarks almost interesting…

As my accent inevitably betrays, I am a native of Spain, where I completed my schooling and my undergraduate education, the latter in *la Escuela de Caminos, Canales y Puertos*, literally the 'School of Roads, Canals and Harbors', the quaint traditional name of the School of Civil Engineering of the Polytechnic University of Madrid, founded in 1802 by the brilliant engineer Agustin de Betancourt y Molina under King Carlos IV. The school was modeled after the French system and, specifically, after *L'École Nationale des Ponts et Chaussées*, the 'National School of Bridges and Roads' in Paris, which Betancourt had visited in 1784.

Given these origins, I find it interesting to contrast this Continental European conception of undergraduate engineering education with our own undergraduate system here in the US. Our system was shaped by powerful technological, societal, corporate, national defense and federal funding pressures. Early on, the model of educating an 'engineering labor force' for industry took precedence over the Continental European notion of an 'elite engineering corps' that I was educated under. Our system of undergraduate engineering education here in the US has traditionally served the engineering profession well. However, it is not clear that the system is in keeping with the times anymore, especially as regards the ability of our engineering graduates to deal with increasingly complex technological challenges. Buoyed by these and similar concerns, the notion of requiring a master's degree for professional engineers has been hotly debated for many years. Recently, the debate has been gaining again a higher profile, exemplified by the 'Raise the Bar' initiative of the American Society of Civil Engineers (ASCE). Also, in its 2005 report entitled "Educating the Engineer of 2020", the National Academy of Engineering came out in favor of a master's degree as a requirement for licensing in engineering, as have numerous other leaders of academia and industry. Certainly, the adoption of that standard would bring engineering licensing closer to that of other distinguished professions, including law and medicine. On the other side of the debate, the idea has also drawn entrenched opposition from professional societies and industry.

It is not for me, here, to take sides in this debate or to pretend to have the answer, I really don't. I'm only reminded of one of the many pearls of wisdom that Ben Freund lavished upon me, free of charge, during my formative years at Brown University, when he said: "Michael, the reputation of an individual or institution is its greatest asset: It is as good as money in the bank". How very true! Regardless of our views on the matter, I think that we can all agree that it is incumbent upon us, meaning academia, professional societies, national academies, licensing boards, accreditation boards and industry, to work together to preserve and augment the prestige and standing of the engineering profession in the US! As Ben Freund taught me, it is our greatest asset!

The end of my own college studies coincided with the 70's worldwide economic crisis, which in Spain was never-ending. That meant few good jobs to be had and, given the bleak situation, it occurred to me that it might be fun spending one year abroad pursuing a master's degree. I applied to the Fulbright Foundation in Madrid and I was lucky enough to get a one-year scholarship to study abroad in the US. The Foundation applied on my behalf to universities in the US broadly. I was admitted to four of them: UC Berkeley and three lesser universities, which will remain nameless. At that time I did not know Berkeley from a hole in the ground. The Fulbright Foundation advisor in Madrid told me: 'Go to Berkeley, young man'. So, I went to Berkeley. For that, I will be eternally grateful to the Foundation.

In this connection, I would like to refer to another exceptional aspect of our academic system that, I believe, is well-worth preserving. When I arrived in Berkeley in 1977, I was the typical foreign student struggling with my English and learning the ropes of a new academic system. As it turns out, I was in very good company indeed! A 2013 report of the National Foundation for American Policy, which analyzes National Science Foundation enrollment data from 2010 by field and institution, provides some amazing figures: foreign students made up the majority of enrollments in US graduate programs in science, technology, engineering and mathematics, or (STEM) programs, ranging from 70.3% of all full-time graduate students in electrical engineering to 40.3% in Chemistry.

Our system of graduate studies has traditionally been open to—and welcoming of—international students. In fact, our ability to attract top talent world-wide to our graduate programs is the envy of the world. However, there are no grounds for complacency. The US visa options for graduating

Ph.D. students remain arcane and onerous. The list of sensitive countries whose students are subject to special restrictions remains long. Export control regulations keep expanding and increasingly restrict participation of foreign students. Most troubling of all, some federal funding agencies are now placing restrictions on foreign-student participation. These concerns were lucidly articulated in a 2004 report of the Council on Governmental Relations (COGR) and the American Association of Universities (AAU), to the White House Office of Science and Technology Policy (OSTP), entitled "Restrictions on Research Awards: Troublesome Clauses." These are troubling trends indeed, in my opinion. I submit to you that it behooves the academic community to be vigilant and work together to ensure that US universities remain true to their universal calling and mission and remain open to all worthy students, regardless of origin!

Going back to my own lifeline, Berkeley for me was an extreme formative experience. I fell immediately enamored with the intellectual ferment, the scholarly research that took place there, the can-do attitude, the feeling of being part of a cutting-edge avant-garde. Egor Popov was the perfect advisor. His humanity, his high standards of scholarship and his stature as a practicing engineer were greatly inspirational to me. I was fortunate to learn continuum mechanics from Karl Pister, continuum thermodynamics from Jacob Lubliner, computational mechanics from Bob Taylor, all part of the now mythical Structural Engineering and Structural Mechanics division. I was also given free rein to take courses in other departments, which I did with abandon, including courses in mechanical engineering, electrical engineering, physics and mathematics. Popov generously gave me free rein to work with other faculty members and graduate students, which I also did with relish. I was fortunate to work with Jacob Lubliner on materials with memory and with Karl Pister and Bob Taylor on computational mechanics. I also had the opportunity to interact with brilliant graduate students such as Peter Pinsky and the late Juan Carlos Simó. I look back to those times with great nostalgia and fondness…

My graduate studies at Berkeley came to a very reluctant end in 1982. The one down side of Fulbright Scholarships is that they require the recipients to go back to their countries of origin for a period of two years. So, I dutifully lined up post-docs back in Spain working in government labs. By my own reckoning, I spent back in Spain two years and three days. That gives you an idea of how I feel about forcing our graduate students to return to their countries of origin against their wills…

In the second year as a post-doc in Madrid, I managed to line up three faculty job interviews back in the US during the Christmas break of 1983. One of them was at Brown, where my good friend from Berkeley, Peter Pinsky, had just vacated a position in solid mechanics by moving to Stanford, something for which I will remain eternally grateful to Peter. Three months later, in March of 1984, I received a phone call from Rod Clifton while I was hard at work at the Ministry of Public Works in Madrid. He said that the search committee at Brown had decided to make me an offer. I immediately answered: "I accept!". That must have been the shortest faculty job negotiation in history! There was really nothing to negotiate. I knew that that was my big break. That same June, I was in Providence with my wife Minerva. My startup package amounted to a grand total of $5,000. It was plenty.

In fact, I believe that startup packages for junior faculty are somewhat overrated and overblown these days. In my opinion, what is really important for young faculty starting out is good colleagues, good students and good shared facilities. Brown provided those in spades. For me Brown was like a second and a third Ph.D.'s. I really received a tremendous education from my colleagues. The micromechanics revolution was in full swing at that time, which meant that there was plenty of interesting problems to work on. My senior colleagues, Jerry Weiner, Ben Freund, Rod Clifton, Alan Needleman and Bob Asaro, took me under their wing and introduced me to the mechanics community, the funding agencies, included me in group proposals such as MRLs and URIs. I could not have hoped for better mentoring. My junior colleagues at the time included Rick James and Subra Suresh. Talk about a star lineup! Three years after I arrived in Brown, Alan Needleman came to my office and announced: "It is time for you to get tenure". I said: "OK". Three months later, Alan Needleman came back to my office and said: "You have tenure". And I said: "OK". And that was that. Those were simpler times indeed…

These reminiscences bring me to another pet subject that I enjoy musing about, given the opportunity: Our tenure-track system for junior faculty and our system of tenure. Tenure is the cornerstone of our academic freedom, an essential requirement for creativity and innovation. The institution of academic tenure was put in place in the US as early as the late 19th century, and was significantly reinforced after the Second World War, to assure that faculty could not be fired for their views. Indeed, we are in the business of generating new ideas that, sometimes, challenge entrenched and established interests or conceptions. These challenges would not be possible without the academic freedom that comes with tenure.

Regrettably, tenure and, by extension, academic freedom, has been increasingly under siege in the US in recent years, especially at public universities. The recent cases of Wayne State University in Detroit, Michigan, the University of Wisconsin, and others, come immediately to mind in that regard. Fortunately, top universities understand that, without tenure, they would not be able to attract top talent to the faculty, which itself is a requirement for being able to secure highly-competitive federal funding, a major part of the operating budget of most universities. This bodes well for the future. However, here again there are no grounds for complacency. Already, only one in four university instructors nationwide are tenured or tenure-track. Tenure review procedures, junior-faculty tracking committees, and other similar bureaucratic-minded procedures that undermine tenure and the independence of junior faculty are becoming increasingly common. Here again, I believe that we need to work together as a community to safeguard academic freedom and the tenure and tenure-track institutions on which it is founded!

Going back to my own lifeline, in 1994 I went on sabbatical to Caltech as a Fairchild scholar. My late wife, Minerva, was part of an extended family of eight brothers and sisters, countless cousins, nieces and nephews, all of whom lived in California. Our two sons, Daniel and Pablo, were eight and four at the time, and we thought that growing up as part of an extended family would be greatly to our sons' benefit. So, in 1995 I officially joined Caltech, where I have now enjoyed over twenty glorious and blissful years with wonderful colleagues and students. Nevertheless, the move from Brown was bittersweet and Minerva, the boys and I have always kept the fondest memories of our time back in Rhode Island.

Fast-forward to 2015. How has applied mechanics changed since I was a graduate student back at Berkeley? Well, the evolution of the field, that I have had the good fortune of witnessing and being part of, has been truly momentous in a number of ways, including veritable revolutions in experimental science, computational science and applied mathematics. This ferment of innovation, adaptability and renewal, which continues unabated at present, attests to the vitality of applied mechanics and bodes well for the future of the field.

The advances in experimental science over the past three decades have been phenomenal, including digital imaging, microscopy, diffraction methods, sensing and others. These advances have provided impetus for the development of new theories of material behavior and new computational paradigms, such as multiscale modeling and simulation. They also have changed radically the nature of applied mechanics from a data-starved field to an increasingly data-rich field, which opens the way for the application of emerging paradigms such as Data Science.

The growth of computational mechanics has been equally astounding. Several stubborn challenges have kept the field going strong to this day. One of those challenges is material modeling and, by extension, multiscale modeling and simulation, the going material modeling paradigm of choice at present. From the early days, discerning computational mechanicians understood that the fidelity of our material models is one of the main bottlenecks that limit the predictiveness of our codes. Indeed, the results of our simulations are only as good as the material models we use, never better. Other bottlenecks, such as resolution and clock time, could be addressed through advances in raw computing power and the use of brute force. By contrast, the search for better material theories and models has been a truly intellectual endeavor. It naturally led to the consideration of the physics underlying material behavior at increasingly smaller length and time scales. This is what we now call 'multiscale analysis', a trend that effectively continued the micromechanics revolution of earlier days.

At some point in this quest, solid mechanicians finally descended to the atomic and quantum shires and, there, they came face to face with an interesting and quaint folk: applied physicists and physical chemists. For me, this handshake had two particular names: Rob Phillips and Emily Carter. I will be forever indebted to them for all that they taught me and for the unrelenting intellectual stimulation that they provided.

The growth of scientific computing over the past three decades has been remarkable indeed. However, here I would like to take a somewhat contrary view: In my opinion, scientific computing has become so prevalent and dominant that we may rightly begin to wonder whether it is having a stifling effect on science altogether. To paraphrase an old tobacco ad: "Are we computing more and more, but enjoying it less and less?" The fundamental problem is that computers have great trouble dealing with complexity, or "NP-complete' problems, as they are sometimes referred to. Give a computer an NP-complete problem to analyze and it dies, regardless of computational power. By contrast, the human brain has evolved an extraordinary capacity for abstraction, for dealing with complexity and to generate true conceptual knowledge. The pressing philosophical question is: "Does scientific computing generate true knowledge or just the appearance of knowledge?" This and similar deep questions are being increasingly raised and debated in connection with the emerging field of Data Science. In a review article on the subject, Katarina

Avramides, of the University College of London, cautions us: “Technology makes it easier to generate information that does not constitute knowledge but is perceived as such.” She goes on to add: “Recipients of this information lack understanding of knowledge validation.” In my opinion, the problem arises when scientific computing becomes the ‘be all and end all’ of science, at the expense of theory and experiment. The act of sitting down at the keyboard to code should be the last step of a long thought process, not the first step. At best, we should regard scientific computing as an interim tool to be used, for lack of anything better, while we generate true scientific knowledge, either experimentally or by force of reason.

In this latter this regard, I would like to mention, in closing, another breathtaking revolution that has quietly taken place over the last three decades in the field of mathematics and that impinges directly and powerfully on theoretical mechanics: the development of the ‘modern calculus of variations’. This endeavor was pioneered by Charles B. Morrey, Jr., at UC Berkeley and Ennio de Giorgi, at the University of Pisa, two of the greatest mathematicians of the 20^{th} century. It was developed further by the remarkable generation of mathematicians that followed, including the likes of Luigi Ambrosio, John M. Ball, Robert V. Kohn, and Gianni dal Maso, among others, and later by their students. The modern calculus of variations is an intellectual tour de force that does generate true knowledge by force of reason. The notions of weak convergence that pervade the field are every bit as fundamental as statistical mechanics or continuum thermodynamics. They provide just the ‘hammer’ that is needed for dealing effectively with complexity in physical systems, precisely the type of complexity that computers have great trouble with. I believe that developments in mathematics and theoretical mechanics will have a strong role to play in the future as a complement and counterweight to scientific computing. For me, personally, the opportunity to work with mathematicians of the caliber of Stefan Mueller, Alexander Mielke, Andrea Braides, Adriana Garroni and Sergio Conti has been one of the most rewarding, enlightening, but also humbling, experiences of my career.

But, to paraphrase Jane Austen, I believe that ‘I have delighted you long enough’. I will, therefore, hastily take my leave expressing my firm believe that the state of applied mechanics is strong, its future is bright, and thanking you kindly for your patience and indulgence. Thank you very much!