Guest Editorial

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2018 Timoshenko Medal Acceptance Lecture: Academic Family

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Dedicated to my immediate academic family, my wonderful graduate students and postdocs and Stefan Timoshenko's academic great, great, great, great, great, great grandchildren.

Dear friends,

I was brought up in Greece to believe in the power of families. As a result families are very important to me and so are all of you, whom I consider to be my extended academic family. This is exactly the reason for which I feel so excited and honored to receive the Timoshenko Medal in front of you tonight since I truly consider all of you, working in the general area of mechanics at all length and time scales, as my cherished academic brothers and sisters, parents and grandparents.

So please allow me to make "Academic Family" my theme for tonight, because I truly feel that in addition to inspiration and creativity, *collegiality and mentoring* are the two most important corner stones of our profession.

Speaking of families, receiving a medal that bears the name of Stefan Prokopovych Timoshenko is very special since Timoshenko is actually my academic, great, great, great, great, great-grandfather (five academic generations back). He was also an academic immigrant, just like myself, who came to the U.S. in 1922 in search of intellectual opportunity to be found within America's wonderful and truly international research universities which had already at his time captivated the imagination of students and aspiring academics all around the world.

But my excitement about this great honor does not stop here. It is also truly remarkable to be reminded of the names of so many of my idols and mentors who have received this special award through the years:

Theodore Von Kármán, whose chair I hold at Caltech, G. I. Taylor, John Eshelby, Eli Sternberg, George Irwin, Jan Achenbach, Jim Rice, Rod Clifton, John Hutchinson, Ben Freund, Zdenek Bazant, Tom Hughes, Sia Nemat-Nasser, Alan Needleman, Bob McMeeking, have all been my scientific idols and many of them my mentors, advisors, teachers, and inspirations. While Subra Suresh and Michael Ortiz have both been my close collaborators and life-long friends.

The first Timoshenko Lecture that I ever heard was in 1985 when Eli Sternberg, the late Caltech professor and Continuum Mechanician par excellence, received this award. I recall that Eli gave a brilliantly humorous, yet caustic, lecture that influenced and inspired me throughout my career. I was then a young faculty member at Caltech and I thought that I would never, ever, be able to fill such shoes even if I was ever lucky enough to get the medal.

I come from a highly educated Greek family, with a father who was obsessed by academia and admired professors. So from the beginning of my memories there was no doubt in my mind, that I should be pursuing a Ph.D. and I would eventually become a professor, of "something." I recall saying this since I was at least 10 yr old, way before I realized what that "something" will be. This was the predetermined fate for both me and later of my brother, Phoebus, who, as many of you know is also a Professor of Mechanics, albeit, lamentably, theoretical mechanics.

The defining moment in actually choosing a field, choosing that something, was the day in the fall of 1973 when I attended a lecture given by Professor Pericles Theocharis, who was then the Rector of the National Technical University of Athens. Professor Theocharis gave a visually impressive, yet entirely incomprehensible lecture, at least to me, on applying optics and elasticity theory to the study of all sorts of crazy fracture problems. I vividly remember the interferometric images, the colorful fringes patterns, the shadow spots and bright caustics, the psychedelic crack tip lobes, and the elegant long mathematical equations that were apparently in "perfect agreement" with the experiments. That was it for me!! I was immediately sold by the artistic glamor and the mathematical elegance of our field. I also wanted to be the great magician he was. Since then, I have met many magicians in solid mechanics and I will tell you how their elegance and wonderful scientific magic has influenced my career to this date.

As a student in Greece I attended "Athens College," a very rigorous Greek-American high school, created in the 1920s. Such schools, were established all around the Mediterranean and were part of the grand master plan of the U.S. to spread American cultural values around the world, to eventually attract the best minds to their emerging universities and to make the U.S. academic environment a truly international experience. By fostering an international environment in higher education, the U.S. engaged in one of the first experiments in "cultural diplomacy," "global cultural diversity," and "academic globalization" that helped to solidify the world-wide pre-eminence of American higher education in all fields, including our own. Unfortunately, as you well know, these days the idea of globalization, academic or not, is increasingly under fire and, if this new tendency is not resisted, it will inevitably lead to other parts of the world taking the lead in all fields of knowledge including pure science, technology, technology transfer, and eventually entrepreneurship and innovation. Be that as it may, "Athens College" was pivotal to my development because it taught me how to think, how to debate, and instilled in me the value of clarity of thought and the importance of rigor in science.

I first landed at Oxford University in 1975 to study Engineering Science. My parents were not very keen for me moving to the

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U.S. since, as they put it, at least in England, they could even drive themselves there to get me out of trouble. The U.S. had to wait for another three years for the family to get ready.

University College Oxford was a fascinating cultural and academic experience, but was also a cultural shock of sorts. Back in the seventies it offered a unique mixture of British pageantry and ancient tradition, mixed in with a very vibrant and high-powered international body of faculty and students, mostly from the colonies, that gave me my first glimpse of how a world university feels and operates. It was there, that over a "glass of sherry in his rooms at the College" I first met Denis Campbell, my senior tutor who, unknown to me at the time, was one of the co-inventors (with Jacque Duffy of Brown University) of the "Torsional Kolsky Bar," otherwise, falsely, known as the torsional split-Hopkinson bar. My fate was sealed once again, Brown University solid Mechanics was my inescapable future destination, whether I realized it or not. Indeed, a few months before graduating, and as I was convalescing from a severe cold in my rooms at the college, there was a knock at my door and a very nice gentleman, Professor Jacque Duffy from Brown walked in to tell me about graduate work opportunities at Brown and about a new and exciting ONR project on the dynamic fracture of structural steels that he, Rod Clifton, and Ben Freund had just started at Brown. He walked out of my rooms with my cold and I walked out of the UK with an offer to do graduate work in the U.S. Unknown to me at that time was the fact that I was about to enter the Mecca of Solid mechanics and that I was to remain in the U.S. for the entirety of my career. This contract was sealed when I received a very kind offer letter on behalf of the department from Professor Alan Needleman whom I immediately imagined as a venerable old professor with a white beard. You can imagine how surprised I was when I first met Alan, a few months later when I arrived at his office at Brown and I saw a young man with a smiling face wearing an informal shirt and blue jeans with his feet resting on his desk treating me as an equal and ready to help and discuss anything. I had arrived in America and all the formality of British academia had just evaporated.

At Brown, I worked with two of the best advisors possible;

Ben Freund is a superbly clear thinker who is responsible for formulating numerous elegant theories addressing key problems and revolutionizing many important areas in our field. The amazing thing though about him is that his results always looked simple and intuitive, thus encouraging the design of fundamental mechanics experiments.

My second advisor, Jacque Duffy was an inspired experimentalist. I really appreciated that he gave me enormous freedom to try crazy things in the lab like designing and building from scratch a totally cost in-effective, Cranz–Shardin, high-speed camera with the great Experimentalist Harry Kolsky. What a great teaching experience that was!

While at Brown I was extremely lucky to take courses from and interact with many other legendary figures in Mechanics and in related areas, including Rod Clifton, Jim Rice, Fong Shih, the late Bertram Broberg, Xanthippi Markenscoff, Nick Triantafyllidis, and Oxford Seismologist Shamita Das. All of them were superb researchers and teachers and became close friends and coworkers later in life.

Brown never followed the fashion of the day. It emphasized fundamentals of science and engineering and cutting edge research in interdisciplinary Solid Mechanics as well as teaching and mentorship. They admitted people with very diverse backgrounds like myself and my life-long friend, colleague, and collaborator G. Ravichandran, and expected us to grow in their very interdisciplinary environment obsessed by the basics of mechanics.

For the past 36 years I have tried to emulate Brown's academic school of thought at Caltech both as a faculty member and as an administrator.

I landed in Pasadena in September of 1982 and have stayed at Caltech as a faculty and later as an administrator. Caltech is the ultimate academic paradise and what makes it so is its obsession with academic quality coupled with its insistence of remaining extremely small. As a matter of fact, being small also makes Caltech naturally interdisciplinary, by necessity, since faculty never have enough similarly trained colleagues around them to keep them happily isolated within their own discipline. So they have to reach out whether they like it or not. This characteristic has indeed influenced me throughout my career.

As an assistant professor at Caltech I was lucky to be mentored by a series of superb Mechanicians including two great theoreticians Eli Sternberg and Jim Knowles and two highly imaginative experimentalists, Wolfgang Knauss and Chuck Babcock.

Knowles and Sternberg were also phenomenal teachers—the best I have seen. They made teaching look effortless—they would talk about the most complicated subject and still made you feel like you understand everything, whether you did or not.

My research at the time evolved around elastic plastic and dynamic fracture mechanics and I even ventured into numerics and theory as I was building up my own high-speed photography and dynamic fracture lab initially based on Wolfgang Knauss's wonderful facilities.

It was at that time that I worked with K. Ravi-Chandar from UT Austin and Francisco Benitez (U of Seville) on three-dimensional crack problems. I also started collaborating with my close friend Ravi and my brother Phoebus studying the physics of the conversion of plastic work into heat in rate sensitive metals and exploring the phenomenon of temperature softening and adiabatic localization. Our work in developing full-field, high-speed infrared diagnostics led to the first direct measurements of transient temperature fields at crack tips and dynamically growing shear bands and it was the beginning of collaborations that have lasted a life time.

My group at that time was also developing new optical techniques to be used in the study of fracture and localization in *opaque solids*, but it was the development of the Coherent Gradient Sensor method, CGS, that was the game changer in our research. Not only could we suddenly measure surface displacement gradient fields at crack tips and adiabatic shear bands growing in opaque structural solids, such as metals, ceramics or composites, but we could also measure stress-induced slopes and curvatures on large 300 mm, micro-electronic wafers and flat panel displays and in theory, we could even connect those to their processing histories.

As luck had it, this was the time during which Subra Suresh happened to be at Caltech as the Clarke Millikan visiting Professor and was also working on the analysis of thin film and patterned line stresses in wafers. One bright California morning we met over coffee at the Red Door Cafe on campus and jotted down on a napkin the basic idea combining CGS and his analysis thus creating new technology for stress and reliability assessment of thin-films and patterned structures on substrates. We then walked to the Technology Transfer Office and at the enthusiastic encouragement of Rich Wolf, the then Director of Caltech's new Tech Transfer office, filed a provisional patent, which eventually formed the basis of a spin-off company in Pasadena and later in Silicon Valley that eventually merged with a larger entity. This line of work continued for many years and involved many other colleagues from Caltech, MIT, and Northwestern, most notably, Yonggang Huang from Northwestern. More important than the science, the patents and the company, this work led to a warm and lasting friendship between Subra, Yonggang, and myself.

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Indeed, my close friendships with peers from all fields, such as G. Ravichandran, Subra Suresh, Yonggang Huang, Huajian Gao, Fong Shih, Horacio Espinoza, Toshio Nakamura, Nick Triantafyllidis, Nadia Lapusta, Jose Andrade, Costas Synolakis, Andy Douglass, Emmanuel Gdoutos, Paco Benitez, Dave Barnett, and with Caltech colleagues such as GALCIT director Mory Gharib, former Provost Ed Stolper and former JPL Director Charles Elachi, amongst others, has made life in academia very pleasant and infinitely rewarding.

Back in the late eighties and nineties, we witnessed the large-scale introduction of composites materials in everyday practice and with this the need of fracture mechanics in the presence of complex interfaces at all length and time scales. Inspired by the pioneering work of Hutchinson, Evans and Suo, and encouraged by the imaginative and enthusiastic program manager Yapa Rajapakse of ONR, whose program funded my work for over 25 years, my group in collaboration with Yonggang Huang, Alan Needleman, and Arun Shukla, devoted much of its time to the study of all sorts of dynamic fracture problems involving bimaterial interfaces and carbon fiber composites.

Dynamic crack growth in bimaterials and multiphase composites was full of surprises for us. These interfacial cracks seemed to violate all conventional wisdom from classical theories and were very independently minded. They preferred to grow at surprisingly high speeds exceeding the characteristic speeds of the surrounding solids, becoming inter-sonic, shear dominated and often featuring large-scale contact in their back faces. I clearly remember the day that my postdoc came to my office to report outrageously high speeds in a polymer/aluminum interface. My initial response was to send him back to repeat the measurement, because it seemed to violate the theory. Then, I stopped myself and decided that we should really do some serious thinking regarding the underlying limitations of the theoretical models.

Everything was unusual about these cracks. Most surprising yet was the observation that interfaces separating even identical solids, when subjected to asymmetric impact, were able to host shear cracks which easily exceeded the shear wave speed forming shear shock waves and thus becoming *Super-shear*. This was a phenomenon that was theorized as possible by Freund in the seventies but had never before been seen in experiments. With unidirectional, carbon fiber, composites the crack tip speeds reached a phenomenal 7.5 km/s, which is surely the fastest, cracks tip speeds to have ever been observed in nature.

My group spent many years looking at this fascinating spectrum of experiments and worked with many colleagues, including Huajian Gao, Yonggang Huang, and Alan Needleman to analyze and rationalize the new phenomena which were found to be persistent in all length scales of interest to practical engineering all the way down to atomistic interfacial mechanics. In these days, I also wondered whether faults, earth's long natural interfaces, could also host such ruptures but I didn't know the answer.

Until one day in 1998 as I was having coffee with a wonderful scientist, the then Caltech Seismo-Lab director Hiroo Kanamori, I asked him whether there have been any inferences of Supershear earthquake rupture speeds from seismological field data. He said that although a few people in the seventies have reported some suspicious seismogram recordings from the 1979 Imperial Valley Earthquake in CA and attributed them to Super-shear rupture bursts, the community has never bought this explanation. Instead, seismologists at that time, routinely restricted rupture speeds to be sub-Rayleigh in their kinematic inversions. His own feeling was that this was an unlikely scenario for spontaneously generated frictional ruptures on faults but was still very interested to investigate. This conversation led to a scientific bet whose purpose was to prove (or disprove) that spontaneous, earthquake type, frictional ruptures can indeed be born or transition to super-shear and to investigate its possible implications to seismic hazard. It also led to the creation of the Caltech "Laboratory Earthquake Facility."

I, who bet on the side of Super-shear also being important in Earth and planetary dimensions won the bet. Most importantly, however, is that this bet was instrumental in fermenting a wonderful interdisciplinary collaboration between my group in Mechanics and many colleagues from the Earthquake Physics community. Indeed, in the last 18 years, and inspired by many collaborators starting with Jim Rice (Harvard) and Hiroo Kanamori (Caltech) and then later with Charlie Sammis and Yehuda Ben-Zion (USC), Raul Madariaga and Harsha Bhat (ENS Paris), David Oglesby (UCR), David Pollard (Stanford), Shamita Das (Oxford), Michel Bouchon (Grenoble), and Nadia Lapusta (Caltech), I became almost entirely emerged in the beauty of the interdisciplinary interface which I like to call "seismo-mechanics" but which is most commonly known as "Earthquake Source Physics." Together with my collaborators we have searched the world for super-shear earthquake rupture events and believe me, these days we are finding a lot more every single year, including the most recent, Sept. 28, 2018, Magnitude 7.5, strike slip earthquake near Palu Indonesia. Perhaps such events, having been seen in the lab, have now become more easily recognizable in the field, or perhaps, mechanics, in its infinite wisdom, has finally given its permission for them to happen.

I now spend a lot of my time preaching Mechanics in the geophysics community and, doing so, constantly reminds me of the great power that our trade has in shaping other disciplines and in solving problems of lasting societal impact.

Mechanics in my mind is a *great and an elegant enabler of other scientific disciplines,* but it should neither loose its distinct identity and rigor nor remain static itself. It needs to continuously evolve and enrich itself by developing new ideas, in the form of multiphysics theoretical models and computational methodologies and also in the form of imaginative experiments by embracing new technologies and advanced diagnostics at all length and time scales. Evolving and incorporating new knowledge in to our discipline is crucial since it is the only way to keep it intellectually vibrant and practically successful. It is however also very important for our community not to lose its own identity and culture of accuracy and rigor and to achieve this we need to keep our wonderful Mechanics family, cohesive and collegial while always welcoming to all those coming from other disciplines, who are eager to join us. Indeed, Mechanics should remain the main attractor for members of other disciplines who care to embrace its philosophy and rigor, rather than the other way around.

I have spoken about my academic family. However, what has given me the luxury of devoting myself to teaching and research has been the stability, support, and infinite love that my own family has provided me for over 30 years. My wife Ioanna, our three children, Angele, Phillip, and Alexandros, as well as my brother Phoebus, have always been my strength. Their humor, patience, and never-ending love have given me the luxury of having a fulfilling career. They also taught me how to *slow down and smell the flowers* as I learned the hard lesson of how to balance my priorities in life.

Finally, speaking once again of family, I have intentionally avoided mentioning any of the names of all of my, 48, wonderful Ph.D. students and postdocs who have been at my side for the past 36 years.

Some of you are here tonight and I would like to acknowledge your presence by asking you to stand up and be recognized. Ladies and gentlemen, please give them a warm round of applause.

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All of you have helped me shape my scientific future and have kept me inspired and excited for the last 36 years. You are my academic children and I am very proud of all of you and love you all. It is for these reasons that I want to dedicate this award and this lecture to you all.

Thank you.

Ares J. Rosakis
2018 Timoshenko Medal Recipient
Theodore von Karman Professor of Aerospace and
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Graduate Students: *(In order of Graduation year)*

1986	R. Narasimhan	2001	L. R. Xu
1987	A. T. Zehnder	2001	K. Haberman
1989	S. Krishnaswamy	2001	O. Samudrala
1990	X. Deng	2001	B. Chow
1991	L. Lu	2002	D. Anderson
1993	J. Mason	2005	K. Xia
1994	J. Lambros	2006	G. Lykotrafitis
1994	C. Liu	2007	M. Brown
1995	H.A. Bruck	2009	X. Lu
1996	K. Fey	2010	L. Lamberson
1997	J. Hodowany	2014	M. Mello
1998	D. Conner	2014	J. Mihaly
2001	P. Guduru	2015	V. Gabuchian
2001	D. Coker	2018	M. Gori

28 Graduate Students

Postdoctoral Scholars: *(Alphabetical order)*

D. Anderson	M. Mello
F. Benitez	D. Owen
H. Bhat	T.-S. Park
V. Chalivendra	S. Roshankhah
V. Eliasson	C. Rousseau
X. Feng	V. Rubino
M. Gori	O. Samudrala
S. Hong	R. Singh
H. Lee	H. Tippur
Y. J. Lee	M. Zhou
	J. Zhu

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