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Yuan-Cheng Fung : A Scientific Giant and a Kind Man

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It was a stroke of good luck that I met Prof. Y. C. Fung. One day in the spring of 1962, I was waiting in the corridor connecting the Guggenheim and Firestone Buildings at the California Institute of Technology (CALTECH) to see Professor Ernest Sechler, the executive officer of the Aeronautics and Astronautics Department. I heard a loud laugh. Shortly afterward I saw a tall (by Chinese standards) man, with a broad forehead and Mona Lisa style smile, walking toward me. As he passed me, he turned and asked, "Can I help you?" With my broken English, which was a foreign language to me at that time as I was a new student who just got there from Taiwan, I said that I had been admitted to CALTECH and was waiting to see Prof. Sechler for financial support. He said, "Why don't you drop by my office after seeing Sechler?" I did. The man was Prof. Yuan-Cheng Fung. I started to work for him the next day and became his student when the fall semester began. For the next 40 and more years, I have worked for and with him. It is indeed my great fortune to have a scientific giant and a kind man as my teacher, and my mentor.

1 A Scientific Giant

Prof. Fung has reached the pinnacle of achievements in science and engineering. He is known as the father of modern biomechanics. His accomplishments are best described by a Tang Dynasty poem:

"....On the tallest peak in the mountains, all hills around look small...."

Prof. Fung was born in China in 1919. He studied airplane design in college, with the goal of helping China fight for its survival. After the war, he entered CALTECH in 1946 and received his Ph. D. in aeronautics and mathematics in 1948. He stayed on as a faculty member at CALTECH until 1966 and then moved to the University of California at San Diego (UCSD).

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Prof. Fung published his first book on soaring and gliding in clouds in 1944, when he was only 25. At the age of 36, he was already a well known and accomplished scholar. He published his seminal book, *An Introduction to the Theory of Aeroelasticity,* in 1955. It deals with the phenomenon of flutter, a dynamic instability of airplanes, spacecraft, and birds when their flight-speed exceeds certain critical value. This book became a bible for aeronautical students and engineers, who were concerned with how to safely design high speed flying-craft. In years that followed, he had solved many problems dealing with structures, vibrations, elastic waves, stochastic processes and protection of structures against nuclear bombs. In 1966, he published *Foundations of Solid Mechanics*, which lays out a spectrum of concepts of solid mechanics with great insight, clarity and authority. This book helps the readers understand the unifying concepts of continuum mechanics. It became the basic educational source for many students and engineers, since.

The work Prof. Fung did prior to 1965 would have been enough to constitute a career for anyone. But he did not stop. In 1965, he turned his scientific interests towards the aspects of physiology. His interest in this field actually began in 1957, when his mother was diagnosed with glaucoma. In order to help his mother, he translated medical articles on glaucoma into Chinese, and sent them to his mother and her surgeon. From this began a burning urge to figure out how the human body works. As Dr. Fung has said:

"...force, motion, flow, stress, strength, and remodeling – pervade the living world, ... I resolved to dedicate myself to the development of biomechanics."

In 1966, Prof. Fung moved from CALTECH to UCSD to concentrate his research on biomechanics. He brought a new perspective to the field, because of his thorough understanding of the laws of physics, and mastery of applied mathematics. He applied the principles of mechanics to solve many important and difficult problems in

biomechanics, spanning from basic constitutive relations to applications to microcirculation, heart, lung, tissue and blood vessels, and their mechanics, growth, healing and remodeling. He started many new areas in biomechanics, and coined the term 'tissue engineering'.

Since then, he has written several books on biomechanics: *A First Course in Continuum Mechanics* (1969, 1976, 1993), *Biomechanics*: *Mechanical Properties of Living Tissues* (1981, 1993), *Biomechanics*: *Circulation* (1984, 1996), *Biomechanics: Motion, Flow, Stress and Growth* (1990). He authored more than 300 journal publications. A collection of his papers was published as *Selceted Works* (*of Fung*) *on Aeroelaticity and Biomechancs*, in 1996. I have the high honor of coauthoring his 2001 book *Classical and Computational Solid Mechanics*, which revised his seminal work, *Foundations of Solid Mechanics,* with an expanded discussion on the theories of plasticity, large elastic deformation with finite strain and computational mechanics.

In the past half century, Prof. Fung has consistently inspired us and conveyed new knowledge. His precise writing teaches in a very approachable manner, – like the man himself. As Savio Woo, a colleague, said: "And we learned! ...."

To the twentieth and twenty-first centuries biomechanics, Prof. Fung has given clear and forward looking advice. In 1968, he wrote:

"...To a modern worker, it appears that much of the work has to begin from the very beginning. To an analytical mechanist, the most serious frustration lies in the dearth of information about the material properties, i.e., the stress-strain history laws of living tissue. Without the constitutive law, no analysis can be done. On the other hand, without the solution of boundary value problems, the constitutive laws cannot be determined. Thus, we are in a situation in which serious analyses (usually quite difficult because of non-linearity) have to be done for hypothetical materials in the hope that experiments will yield the desired agreement. If no agreement is obtained, new analyses based on a different starting point would be necessary."

In addition to his research, Prof. Fung has provided leadership in many other ways. This includes founding or cofounding the US National Communities on Biomechanics, the World Congress of Biomechanics, the American Institute for Medical and Biological Engineering, the Journal of Biomechanical Engineering and the World Council for Biomechanics. They are now the major organizations or journals leading and promoting research and development in the field. Prof. Fung, Dr. B. W. Zweifach and Dr. M. Intaglietta cofounded the Bioengineering Department at UCSD, now among the nation's top departments. Through Prof. Fung's work and leadership, biomechanics has been transformed from a relatively unknown discipline in the early sixties to a major field of endeavor today.

Due to his many pioneering contributions to aerospace sciences and bioengineering, Prof. Fung was elected to be a member of Academic Sinica (the China Academy, 1965), a member of the US National Academy of Engineering (1979), a member of the US Institute of Medicine of NAS (1991), a member of the US National Academy of Science (1993), and a foreign member of the Chinese Academy of Science (1994). He has received numerous prestigious awards and medals, which include the Founders Award of the National Academy of Engineering, the von Karman Medal from ASCE, the Timoshenko Medal and the Lissner Award for Bioengineering from ASME, the Poiseulle Medal from ISB, the Borelli Medal from ASB, the Landis Award from Microcirculation Society, the Alza Award from BMES and many others. He is Honorary Professor of 15 universities in China and received a *Doctor of Engineering Science Degree Honoris Causa* from the Hong Kong University of Science and Technology in 1994, from the Drexel University in Philadelphia in 2001, from the National Central University in Taichong in 2002, from Sichuan University in Chengdu in 2002 and from the Cheng Kung University in Tainan in 2003. He is scheduled to receive the same from the Northwestern University in Evanston in June 2004. Especially in year 2000, he received the highest scientific honor given by the United States - the President's National Medal of Science. Honors fall upon Prof. Fung like rain in spring (as said by Chia-Shun Yih, Prof. Fung's best friend since childhood).

No single individual has done more to shape the modern development of biomechanics than Dr. Fung. People say scientists stand on the shoulders of giants. In this case, he IS the giant!

Prof. Fung sees significance from the obvious and the not-so-obvious. His extraordinarily high intelligence and training in both the fields of mechanics and biomechan-

ics allow him to question what was taken for granted by others.

For example, everybody understands that arteries are elastic and veins are collapsible. Baez (1960) has shown that the smallest blood vessel of the peripheral circulation, the capillaries, are so rigid that no measurable change of diameter can be seen when the blood pressure in these vessels were changed from 0 to 100 mmHg. So it was accepted that capillaries are rigid. Prof. Fung saw the capillaries as tunnels imbedded in connective tissue gel. He explained the apparent rigidity of capillaries by the tunnel concept, and revolutionized the mass transport analysis of the blood circulation.

Mammalian red blood cells are biconcave disks, which can swell into spheres in hypotonic solutions. The diameters of the red blood cells are about the same as those of the capillaries. These red cells deform severely in capillaries, affecting the interaction with the endothelial cells and the mass transport across the vessel boundaries into the tissues. Determining red cell geometry was difficult in the 1960's. Even harder was the analysis of the large deformation. Based on the principles of mechanics, Prof. Fung concluded that the red cell interior is a liquid. This conclusion implies a low pressure difference between the interior and the exterior of a red cell in the state of static equilibrium, permitting a sharp trailing edge for a deformed cell in flow and allowing cell sphering without any complex anisotropy in the properties of the cell.

Before 1966, capillary blood vessels in the lung were idealized by Weibel (1963) as circular cylindrical tubes arranged in hexagonal pattern. Prof. Fung and Dr. S. Sobin realistically described the pulmonary capillary blood vessels as a network of alveolar walls. They called the networks *capillary sheets*. The sheet model shows that blood vessels remain smooth as the blood pressure increases and allows the direct derivation of a theoretical relationship between the sheet thickness, transmural pressure, and tissue stress. Prof. Fung, his students and colleagues went on to identify how the capillary networks are supplied and drained with blood and determine the hemodynamics of the lung. Better understanding of the hemodynamics in the lung has led to improved treatment of edema and lung injuries.

Prof. Fung and Dr. S. Q. Liu induced pulmonary hypertension in rats by hypoxia. They observed tissue remodeling of the intima, media and adventitia layers of the vessel wall. Prof. Fung and Dr. W. Huang further identified the genes in the cells of the vessel wall that express under hypertension. As gene expression controls protein production in cells, the correlation with mechanical stresses points the way to study the mechanics of cells and tissues.

If a baby does not cry at birth, the doctor spanks the baby, thus making the baby to do so. Is that cruel? No, Prof. Fung explains, because the crying helps the baby open its lungs, and make the baby take its first and subsequent breathes to live.

Prof. Fung has extraordinary memory. He has written many books and papers with large number of equations and references. Once I asked him how he managed to assure the consistency of all cross references of the equations and references, when he made changes during writing. He said that he remembered where every quotation of equation or reference was.

Beyond being a scientist, Prof. Fung possesses many other talents including calligraphy, painting, and carving. He also has a green thumb. He is indeed a complete man.

2 A Kind and Happy Man

Prof. Fung is kind and gentle. He always helps people, including strangers, as he did with me so many years ago. He is generous with his knowledge as well as his time. His caring and support have enriched the lives and launched the careers of many – his graduate students, his post-doctoral collaborators, his colleagues, and people around him. Despite his great achievements, he is humble. He lives with harmony.

His character was best described by Robert Nerem, a colleague:

"Bert (Prof. Fung's English first name) also epitomizes the concept of being 'a gentleman and a scholar' for he surely is a gentle man. It is this gentleness which underlies his greatness. He taught us that research is a collegial activity, not a competition, but an endeavor in which by working together, by sharing ideas, by making constructive suggestion to others, and by graciously receiving such input from others, we all benefit and entire field moves forward."

A person who is so brilliant and kind and gentle is a rare combination. That's what Professor Fung is.

Prof. Fung loves to discover. He is always fascinated

with matters of nature. Chia-Shun Yih said that Prof. Fung seems to sing while working. Quoting a beautiful poem by Wang Si-Cheng of Ching Dynasty, Yih described Prof. Fung's mood at work:

"The winds of May have blown so much green into the willows, that the swallows cannot refrain from coming home."

Prof. Fung also describes his joy in work:

"....Waves of excitement went through me. Again and again I see beautiful vistas of the future...."

Prof. Fung loves Wang Kuo-Wei's quotation of three stanzas from three famous Chinese poems (translated by Donald Hall and Chia-shun Yih) to describe the moods of the stages of any significant accomplishment - the vision of the prospects, the hard work and frustration, and the joy of sudden and unexpected success:

I (Yen Shu, 991-1055)

"Last night the west wind ringing,
stripped leaves from the green tree.
I climbed alone to the top floor
of my house, and looked up the road
as far as the horizon."

II (Lie Yung, 990-1050)

"For love of her, I grew pale;
I turned thin and haggard.
For love of her, the belt
hung loose on my robe.
... Yet I regretted nothing."

III (Hsin Chi-his, 1140-1207)

"I look for her in the crowd
a hundred, a thousand times.
Then suddenly, as I turned
my head, I glimpsed her
in the dim light, in half darkness."

Laughing loudly and happily is Prof. Fung's trademark. He appreciates people and things. Mrs. Fung described him at his 70^{th} birthday:

"He laughs frequently and heartily. He loves deeply. He loves his family. He loves his friends. He lives simply. He does not demand anything. He does not compete with anyone, and never tries to keep up with the Jones."

Prof. Fung has benefited from his partnership with, and the love of, Mrs. Fung. She is as much a member of the biomechanics community as he is. Thus, Prof. Fung's work is not only testimony to his scholarship and his influence on the field, it is also a testimony to his relationship with Mrs. Fung.

I have had the privilege and great fortune of being a student of, and mentored by, Prof. Fung, and being bestowed the friendship by him and Mrs. Fung. They have profoundly influenced and enriched both Jean's (my wife) life and my life. We thank them for what they have done and continue to do for us. It is a high honor to write about this perfect teacher. Despite my best effort and intentions, I cannot adequately portray Prof. Fung's greatness and his extraordinary career and achievements. To all readers, I urge you to peruse his work and find the treasure for yourselves.