BERT FUNG

An Interview Conducted by

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IEEE History Center

December 12, 2000

Interview #408

For the

IEEE History Center
The Institute of Electrical and Electronics Engineering, Inc.

And

Rutgers, The State University of New Jersey

It is recommended that this oral history be cited as follows:

Bert Fung, Electrical Engineer, an oral history conducted in 2000 by Frederik Nebeker, IEEE History Center, Rutgers University, New Brunswick, NJ, USA.

Interview: Bert Fung
Interviewer: Frederik Nebeker
Date: 12 December 2000
Place: La Jolla, California

Nebeker: Could we start by you telling us where and when you were born and a little about your family?

Fung: I was born in China in the town called Changzhou. It is in Kiangsu Province, about midway between Shanghai and Nanjing. Shanghai is the largest commercial city in China and Nanjing was China's capital until 1949.

Nebeker: What year were you born?

Fung: I was born in 1919. My family was an educator's family. My father was born in a period of transition between old China and new China. He didn't have Western education, but he was a promoter of Western education in our town. He worked in the Office of Education at the time.

Nebeker: For the Chinese government?

Fung: For the city. He was a registrar of a University in Beijing when I was in junior high school. My mother was a housewife. My father was a scholar of Chinese classics, a talented musician, and artist, and a poet.

Nebeker: Did you have brothers and sisters?

Fung: I have six brothers and sisters. One brother, five sisters. I was born in a period in which Japan and China were involved in military conflicts. When I entered junior middle school I was twelve years old. On September 18th, 1931, Japan invaded Manchuria. All students were ordered to have military training. I remember we had to get up in the middle of the night to run even when it was raining.

Nebeker: That was ’31?

Fung: Yes. Then Japan invaded Shanghai, that was close to my home.

Nebeker: Was that ’37?

Fung: January ’32 and also July ‘37.

Nebeker: Also in ’32 they invaded?

Fung: In January ’32 Japan invaded Shanghai. My family fled to Beijing. The Japanese didn’t stay long in Shanghai. But by the end of the year, Japan invaded a city in inner Mongolia not far from Beijing, and we fled back to Changzhou. War was really a shadow over my life when I grew up.

Nebeker: There was also something of a civil war within the Communists and before and after World War II.

Fung: Chinese civil strife existed ever since the Republic of China was established by Sun Yat Sen, who was a political leader unable to rule the country by law. Local military leaders were uncontrolled. We called them warlords. The warlords fought each other. I remember we had to flee nearly every Christmas time. The warlords fought each other and the people were caught in between. We tried to get out of the way by hiding away somewhere.

Nebeker: Were the living conditions difficult, having enough to eat?

Fung: Hiding is always difficult, particularly for a young kid. The warlord thing existed before the Japanese invasion in ’31. There was a period when foreign countries tried to divide China.

Nebeker: For trading rights?

Fung: Not only trading rights. They were in fact formally thinking about dividing it up politically into their satellites. The U.S. was against the cutting up of China and China survived. People suffer. That is why I have always thought that a unified country is better than a divided one. In Chinese history there were cycles of unity and division. History has shown that without exception, the divided periods were periods of great calamity for the people.

Nebeker: You experienced a period yourself growing up of this division and warlords.

Fung: Yes.

Nebeker: Were you living in Changzhou when the war with Japan started in ’37?

Fung: 1937 was the year I graduated from Suzhou Senior Middle School. When I went to register for the college entrance exams in Shanghai, Japanese planes were circling over Shanghai. On the wall of the registration place I saw a notice saying that the Central University was adding a new Department of Aeronautics. I signed up under the feeling that I’ve got to fight back.

Nebeker: That’s like the technology of the future aeronautics.

Fung: That’s how I got into aeronautics.

Nebeker: This is in Shanghai? What University?

Fung: The National Central University was located in Nanjin, 250 miles northwest of Shanghai. It gave entrance examinations in Shanghai and Nanjin. I didn’t finish the exam. Halfway through we were told, “The railroad was closed and there’s no rail transportation now. You better go home.” The Japanese were attacking the main station. I went home. Later I learned that I was lucky enough to have been accepted into the University.

However, when I got the acceptance letter, the Central University had already moved inland to Chongqing. Chongqing is about 1400 miles from my hometown along the Yangtse River. By the time I got there it was already October.

Nebeker: You mean to say it took a couple months to travel that distance?

Fung: There was no continuous transportation. I caught boat rides whenever I could. In my memory, that trip was certainly out of the ordinary. It took me to a strange province where I studied and worked for eight years.

Then there was another lucky incident in my life. In 1944 there was a team of ten or twelve American professors visiting China. They had a dinner with the Minister of Education. One of the professors asked the Minister, “We used to have Chinese graduate students, but we haven’t seen any recently. Why is that?” The Minister said, “China is at war and the economical situation will not permit the government to support any graduate students to go abroad.” So the professor said, “If we get some scholarships, will you let the students go?” The answer was yes.

The next year, this group was able to secure 40 scholarships to China from different schools. The Chinese Minister of Education set up a nationwide exam to select the candidates. There were many applicants because it had been five years without sending anybody out. I was lucky enough to be chosen as Caltech’s candidate. That’s how I got to Caltech.

Nebeker: I’d like to hear about your college years. In late ’37 you finally started in Chongqing. It was the Nanjing University relocated?

Fung: Yes. The National Central University in Nanjing relocated to Chongqing.

Nebeker: How did those years go? I mean, were there hardships or disruptions because of the war?

Fung: We had a very difficult physical situation, but we had a very good faculty. When we got to Chongqing we rented space from Chongqing University. We built buildings that were mud huts with thatched straw roofs. Classes were carried on. Students did not mind. For example, there was no running water, so we had to go down to the river to take baths. But we did not mind.

But in the later years, the Japanese bombed Chongqing. Chongqing was a foggy city. Every morning by 10 am the fog lifted a little, the Japanese bombers would be coming in. We took classes at the crack of dawn, till about 9:30 or so, then we went to the dugouts. The University was on the banks of a big river, the Jialing River. The rocky banks were our natural dugouts. That's where we spent most of our daytime.

Nebeker: How long did that period of Japanese bombing last?

Fung: About four years.

Nebeker: Four years of that.

Fung: Yes. Gradually, we adapted to the condition. Small laboratories were built in the dugouts. There was a lack of electric power, so we worked with kerosene or vegetable oil lamps. We kept good spirit and it didn't harm us too much.

I came to the United States and arrived at Caltech in January 1946. I reported my arrival to Dr. Sechler. He sat back and laughed: "The scholarship was offered two years ago. The money was long spent. There's no need for you to register for classes because all Caltech courses were started in September and ran continuously for a whole year. You don't need to waste your tuition money." But he was awfully kind. He took me in as a lab aide.

Nebeker: What was his field? Was it aeronautics?

Fung: Yes. Dr. Sechler was Professor of Aeronautics with specialization in aircraft structures. He gave me the best opportunity in the world. He said: "You may audit any classes. And if you feel confident enough you may take exams. If you pass, we keep the record." With that kind of offer I was able to get many preliminary requirements for Ph.D. passed.

Nebeker: How was your English at that time? Were you able to understand lectures and to take tests and so on?

Fung: Not much worse than I am now, I suppose.

Nebeker: You had learned a lot of English in China.

Fung: In China, some teachers use English for lecturing. Chinese education was okay. Equipment was poor, but mathematics was okay. I got to Caltech in 1946 and I got my Ph.D. in 1948. It shows that my poor English didn't hinder me too much.

Nebeker: The degree you received in China, was that a Bachelor's in Engineering?

Fung: Bachelor's of Aeronautical Engineering first. I stayed two more years to get my Master's degree in Aeronautics.

Nebeker: How was that new situation? You were living in Pasadena. Did that appeal to you?

Fung: Caltech was wonderful. I was taken in and I felt very much at home. At Caltech a foreign student was accepted and mixed with American students very well.

Nebeker: Tell me about your thesis work.

Fung: My thesis was in a new area called aeroelasticity, the mathematical theory of aeroelasticity. It deals with the dynamics of airplanes in storms and gusts. Every airplane has a natural upper limit of velocity. If it flies above that the wings would flap like a bird. My thesis determines the critical flight velocities of aeroelastic instabilities.

Nebeker: Was this a recognized phenomenon?

Fung: In the beginning aeroelastic instabilities were studied as theoretical curiosity. By the time I got my degree in ’48 it was recognized as a central problem for high performance aircraft.

Nebeker: I know that speeds were getting faster with the jet airplane.

Fung: Yes.

Nebeker: Did you take that up because you believed this would be very important in aeronautics?

Fung: No. I did not know its importance to aircraft industry until I became a consultant to aircraft companies years later. But I knew it was a broad new field requiring basic research. I learned about the field soon after I got my MS degree from the Central University in China. I went to work for the Bureau of Aeronautical Research in Chengdu. I was assigned to drafting the first year, and to write a section of a handbook for the design of airplane tail the second year. Tail design was essentially a dynamics problem. The concept of tail control reversal and flutter fascinated me.

Nebeker: Was there at that time enough theoretical understanding that the design could be based on mathematics?

Fung: Yes. There existed a U.S., U.K., and German literature. When I got to Caltech I spent the first nine months auditing courses and taking exams. When school started in the fall I was ready to begin my thesis research.

Dr. Sechler, my mentor, asked, "What would you like to work on?" "Well," I said, "I would like to work on aeroelasticity." "Ah," he said, "Just right. In 1942 the Tacoma Bridge on Puget Sound in Washington State was blown down by wind. Von Kármán said that the oscillation was caused by vortex shedding from induced aerodynamic forces. The State of Washington Public Works sponsored a research project here. When von Kármán retired that job was given to Dr. Louis Dunn. When Dr. Dunn became the director of the Jet Propulsion Laboratory a few months later, he handed the job to Maurice Biot. Biot soon left. They left a filing cabinet here which you may take a look."

Now, this was tremendous news to me. Von Kármán and Biot were my heroes. I truly loved their book on Applied Mathematics.

Nebeker: Did these papers go back to von Kármán or were they Biot's?

Fung: The filing cabinet was a disappointment. It contained letters from the Washington State Public Works telling Caltech to stop working on this project because its scope had become too broad. It contained no scientific papers or writings of von Kármán and Biot.

I inherited a wind tunnel designed particularly for this project. I used it to study the bridge. I found bridge aerodynamics very difficult – very awkward. Airfoils are simpler and cleaner. So I began working on aeroelasticity of the wings. I formulated the general aeroelastic problem and then designed ways to systematically study it step by step.

Nebeker: So, you were interested in a more general theory of aeroelasticity rather than how a particular structure responds?

Fung: Yes. I wrote one of the first books on aeroelasticity. MIT was Caltech's competitor. MIT was bigger than Caltech by a factor of five. Bisplinghoff and Ashley at MIT published a book on aeroelasticity one year ahead of me, and another book on the same subject one year after me. It made me happy that in the second book they changed their scheme to mine.

Nebeker: Was that theory about aeroelasticity important in aircraft design?

Fung: I think so. In late 1940's it became a very important part. Aeronautics in American Universities at that time consisted of two parts: one was aerodynamics, the other was structures. Aerodynamics people talked about steady flow, they rarely worked on oscillatory wing and dynamic problems. Structures people worked on the safety of structures against steady state aerodynamic loading. Aeroelasticity combined these two parts. In the interdisciplinary area, aerodynamic loading came from structural deformation and vice versa. Aeroelasticity wasn't very important until high-speed aircraft came about. Then it became a very ticklish thing. The main reason why industry really worried about this is something like this. When a plane is designed, the structures are tested all along. The performance, the aerodynamics are tested all along. By the time a plane is made, they know very well how it will perform and how fast it can fly with the engine. But they do not know the upper limit of the permissible speed. You can dive too fast until the plane shakes to pieces by aeroelasticity. But aeroelasticity is something which you cannot test all along. You can test a number of very basic things, but you cannot test the whole airplane until it is made. The time you do the testing is when the prototype is built. At that time, if some problem happens, the production line stops, and that is fantastically expensive. At the time of first flight test, the whole plant is waiting for the testing report, to learn whether you get to the design speed without problem or not.

Nebeker: That means that this theory was very, very important.

Fung: An aircraft company of course wants to be able to predict as accurately as possible. I learned about its importance when I served as a consultant to various companies.

Nebeker: How about the computational side of this? Was it very difficult to carry out computations in those days?

Fung: Computational side for aircraft flying at incompressible flow speed was fairly well in hand at that time. Analysis of purely supersonic flow is not very difficult. What's difficult is the transonic flow.

Nebeker: That's the transition?

Fung: Yes, between high subsonic and supersonic flow. When you have high subsonic flight, the flow at some locality may be supersonic already. That's called transonic because somewhere there is supersonic flow whereas the rest of the flow field is subsonic. Transonic flow problems are most difficult.

Nebeker: And that's where the airplanes could shake to pieces?

Fung: Aeroelastic problem may occur at any speed range. But in the 1940's the hardest problem in aeronautics is the transonic flow.

Nebeker: Did you have numerical techniques or analogue devices to help you?

Fung: Numerical approach is preferred. In advanced aerodynamics and elasticity most problems do not have closed form solutions. Aerodynamics and elasticity computations can be very elaborate. Some questions of convergence and uniqueness of the solution still remain. For nonlinear problems you may obtain a solution, but whether that solution is unique or really happens in nature or not needs a separate proof.

Nebeker: I asked about the computational side because I know in a number of instances computing devices were developed specifically for aircraft design. In Germany in World War II it was in aircraft design that certain problems arose that led to Konrad Zuse's design of a computer.

Fung: Computing was the life of aeronautics. The finite element method was initiated by people in Boeing Aircraft Co. and the University of Washington in Seattle. Aeronautics people have always concentrated on computation. Today's airplanes are designed by computing.

Nebeker: Did aeroelasticity find early applications in bridge design or anyplace else outside of the aircraft design area?

Fung: Bridge designers learned to avoid aeroelastic problems. For example, the new Tacoma Bridge is Washington is larger and heavier. The designers felt that the mistake of the original design was an underestimation of the traffic and the decision to build a lightweight bridge. It was the lightweight that created aeroelastic problems. So the second one was much heavier and the bridge bed has holes to change its aerodynamic characteristics. Designers of new bridges taking advantage of new materials of high strength and light weight have to study the aeroelastic issues very carefully.

Nebeker: The aerodynamics becomes more important with the lighter structures. What happened on completion of your Ph.D.?

Fung: I became a faculty member working on aeroelasticity and structural dynamics of aircraft and missiles.

Nebeker: For particular missile projects or more generally?

Fung: Generally on basic principles.

Nebeker: But a person at a University might pursue more general research.

Fung: For a person in a University who served as a consultant to industry occasionally, I contributed what I knew and helped with what I could. But in later years my interest shifted to biology and physiology, so I left that field. I left Caltech and went to UCSD mainly because I wanted to work on new biomedical problems one hundred percent of my time.

Nebeker: Can you tell me how you first became interested in biomedical problems?

Fung: I became interested in biomedical problems for a personal reason. In 1957 I took a sabbatical leave with a Guggenheim Fellowship and went to Germany. My mother had acute glaucoma, a very painful disease, and I could do nothing for her. In frustration, I read American literature on glaucoma and sent her a weekly translation or summary. I told her, “If you cannot use it, give it to your surgeon.”

Many years later, in 1973, I finally went back to China. My mother's operation was a success. Her surgeon thanked me.

In Germany, right across the street from the Aerodynamics Research Institute was the Physiology Institute of the University.

Nebeker: This is in Göttingen?

Fung: Göttingen. It was the Göttingen Physiology Institute. I enjoyed their library and their facilities. That's the beginning of my interest in that field. Gradually one thing became quite clear to me: the biologists do not think about what we engineers always think about – namely, the force, motion, and transport phenomena. Furthermore, biology is full of interesting nonlinear problems. The field seems to ignore the kind of things which you can do. I found the field very attractive.

After returning to Caltech I began to work on physiology. A few years later my feeling was that I wanted to work on it full-time; I didn't want to dilute it with other work. That's how I ended up at UCSD.

Nebeker: Was this largely a matter of your reading about physiology?

Fung: When I got back at Caltech I began experimental studies.

Nebeker: I mean, rather than a particular person that you got to know in physiology.

Fung: I began with my reading and thinking about it. But pretty soon I made new friends.

Nebeker: So, you just felt that the kind of analysis that you'd been doing with aircraft or with other structures might be applied to it.

Fung: I found interesting things in physiology that have nothing to do with aircraft or flutter. The perspective was entirely new. But one has a background that one cannot shake off even when we think new thoughts.

Nebeker: Right. The kind of mathematical analysis you used earlier could be used for physiological studies.

Fung: Precisely. But I think that the most important thing is the attitude – the way of looking at things. An engineer has an engineer's way. After many years in the field, I really think that an interdisciplinary area is not just the one area plus another. It's the new product in-between, which is neither of the mother fields. The interesting part is the new in-between part.

Nebeker: I'm very interested in this central issue of biomedical engineering – what the engineer brings to physiology, let's say. One obvious thing is a quantitative approach, but I think there's more than that. Biophysics has a somewhat longer history and physicists of course were very mathematical and quantitative. Don't you think there's something more that an engineering background can contribute?

Fung: I think bioengineers should be biophysicists. The bioengineers differ from biophysicists by being closer to medicine, man and larger or smaller animals. It's that closeness which makes us think of engineering. If you ask me, "How much mechanics do you do daily in life in this new field?" I would imagine no more than one or two percent. 99% of my time is spent on biology. But the one percent using my old tools is important and enjoyable. Bioengineering focuses on engineering invention and design, not limited to the understanding of the physics of life.

Nebeker: I've also heard it argued that the engineers, in contrast to the physicists, brought this kind of systems analysis view – you know, taking the large view of things and how everything fits together. They brought simulation techniques and later computer modeling techniques that were not so developed in physics itself, where the emphasis might be on the mathematical theory.

Fung: True. Of course, the system's point of view is the engineer's forte.

Nebeker: I think maybe in contrast to the physicists who came to biology and who might focus on a particular physical situation, the engineer is more likely to take the overall view.

Fung: Yes. Although the viewpoint and the objectives differ, I think engineers should learn from biophysicists. And physicists probably should learn something from bioengineers too. There are things for all of us to work on.

Nebeker: When I have looked at, say, physiology research reported a hundred years ago, there might be some very elaborate diagrams, very careful drawings, and so on, but you see almost no quantitative data at all.

Fung: The quantitative approach is the engineer's contribution. Biologists often make a hypothesis, do an experiment, and draw a conclusion. The distance between the hypothesis and the conclusion is so short that the experiment must answer the whole question directly.

Now, engineers know that most questions cannot be answered that way. You need to lay out a plan and fill in each step in a quantitative manner. Then you put them together and draw conclusions very carefully, with limitations pointed out. In other words, my feeling is that the distance between a hypothesis and the conclusion is quite long. It can be very long and can even be impossible. The middle steps are where we put our effort in.

The most difficult part for engineers to learn biology is the breadth of the biological knowledge. Most biologists can integrate it in their head. Some people are fantastically intuitive and can put things together and understand the whole story. They don't feel the need to use the analytic tools like the engineers. The engineers solve the problem part by part, every part quantitatively.

Nebeker: For this glaucoma issue that you became interested in, did that lead to you doing any research yourself?

Fung: I didn't make any contribution there.

Nebeker: What were the first problems in biology?

Fung: Blood circulation.

Nebeker: What specifically?

Fung: Blood vessels, blood vessel elasticity, and elasticity of the blood cells.

Nebeker: Creating mathematical models of blood vessels and blood cells?

Fung: Creating models in order to be able to recognize important parameters and measure them.

Nebeker: I imagine that is not a simple thing to get measurements on.

Fung: We know that classical mechanics is based on some very simple hypotheses, simple axioms, such as the conservation of momentum, energy, and mass. The next thing you need to know is the mechanical property of everything you're talking about. With the mechanical property of water you have hydrodynamics. With the mechanical property of biological entities you have biomechanics.

Now, the mechanical properties of biological tissues were virtually unknown in the 1940's. The question was how to describe the mechanical properties and what to measure. Today you would consider successively the hierarchies of organelles, cells, interstitial materials, tissues, organs, and the individual. Historically, the study was done in downward order of hierarchies.

Every step is difficult. For example, it was very difficult to quantify the mechanical property of tissues, but without that you cannot begin. With testing, theorizing, and hypothesizing, you hope that you'll eventually understand the materials that you are dealing with.

Nebeker: What instruments were you using in the early years to get data on these blood vessels and blood cells and so on?

Fung: Most instruments we use were designed by ourselves.

Nebeker: What types of measurements were you taking? Pressures, strain, gauges, what sorts of things?

Fung: Pressure transducers and strain gauges we bought. Anatomy, histology, dimensions, measured. Stress has to be computed. There is no stress gauge. You can measure displacements to determine strain.

Why do you talk about stress while no gauge exists? It is because strain is related to stress, and the boundary conditions of many problems are specified in terms of stress. The differential equations are expressed in terms of stress and strain and the material properties. To compute the stress and strain we must know the mechanical properties of the materials. Hence the measurement of the mechanical properties of living cells and tissues are important.

Nebeker: So, studying the blood vessel wall – is that the sort of thing you measure?

Fung: Yes. Let me tell you a story. One of the strange mechanical properties known in the early 1960's was studied by physiologists, particularly my colleague Dr. Benjamin Zweifach, a famous microcirculation physiologist. His years of work led to the conclusion that the strongest, hardest blood vessel is the smallest blood vessel.

Nebeker: The capillaries?

Fung: Yes. Capillaries have a diameter of about ten microns (about one-third the thickness of our hair) and a wall thickness of one or two microns. Dr. Zweifach and his associates could not detect the change of the capillary diameter when the blood pressure was changed by as much as a hundred millimeters of mercury. Since they used an optical microscope for the measurement, this means that the change of diameter is much less than one wavelength of light, or 0.5 micrometer.

Nebeker: Isn't it surprising, because such a thin structure should respond to that change in pressure.

Fung: Yes. Very surprising if we think of the capillaries as small cylindrical tubes. Collagen or steel tubes can do it, but not a single layer of endothelial cells with a thickness of 1 to 2 microns.

Where did this rigidity come from? I looked at the problem and my suggestion was that the rigidity came from the surrounding media. In other words, the capillary blood vessels we have are not a tube, but a tunnel lining.

Nebeker: There's a tunnel lined with these epithelial cells? Is that's what they're called.

Fung: To verify that the rigidity comes from the tunnel material outside, I measured the material properties of the stuff outside the capillary, then computed the expected deformation of the capillary. I found agreement. That kind of thing makes engineering thinking suddenly relevant.

Nebeker: I certainly see the value of that for understanding circulation in general. Did it have any immediate application in pathology?

Fung: The immediate application was to reassess the mass transport in our body. But I thought it was more urgent to find a counterexample in our body. It was easy to think of one, and that is the lung, because a lung is a structure whose whole purpose is exchanging oxygen between the blood and air. Walls of pulmonary capillaries are very thin, about 2 microns. There is no other tissue outside, only gas. Hence, the next thing I wanted was to determine the elasticity of the capillaries of the lung. Then to fully understand the counterexample, and work out the implications of the new understanding on the physiology, pathology, diseases, and injury of the lung. In this endeavor, I was fortunate to have the collaboration of a famous physiologist, Dr. Sidney Sobin, and my former student and colleague, Michael Yen, and many graduate students of ours.

This was where the payoff from an engineering point of view of physiology came in. If you look at the lung, you see that it is an organ of capillaries. These capillaries, however, are not single long tubes; they are organized into two-dimensional sheets. The geometry is unique. We had to measure the dispensability of the sheet, analyze the flow, and understand the physiology.

Nebeker: I imagine the material properties of these lung capillaries weren't known.

Fung: Everything was new.

Nebeker: So you have to make all of these measurements.

Fung: From geometry, anatomy, histology, mechanical properties, to physiology and pathology.

Nebeker: Even the microanatomy wasn't fully known at that time?

Fung: The Sobin-Fung sheet-flow model of pulmonary capillary was novel. It changed the language of pulmonary microanatomy. It showed that the classical Poiseuille formula of blood flow dos not apply to the lung. It showed that it is simpler to think of a continuous sheet with a pattern of obstructions.

Nebeker: Just obstructions in a flow?

Fung: Yes, with a hexagonal pattern. I worked out the details of blood flow in these sheets. The result is called the sheet flow theory.

Dr. Sobin and I applied the engineering analysis to the anatomy of the spatial distribution of arterioles and venules in the lung. Arterioles are the smallest arteries supplying blood to the capillaries. Venules are the smallest veins draining blood from the capillaries. We made plane sections of the lung and photographed the anatomical section. We marked every arteriole with a white dot and every venule with a blue dot. We looked at the dots and found they divide the whole section into territories of arterioles and venules. The interesting thing about these territories is that they form a two-colored map. A two-colored map can represent only islands in an ocean. Therefore, the anatomical question is simply which is the ocean? We found a simple answer that the arterioles are islands and the venules are ocean. This immediately tells you how the blood flows in pulmonary microcirculation.

With this type of study, Drs Sobin, Yen, my graduate students and I proceeded from anatomy, histology, to larger vessels, airways, their mechanical properties, blood and gas flow, physiology, pathology, impact injury, tissue remodeling, tissue substitute, and other problems.

Nebeker: Were you working with a physiologist? Was it Zweifach?

Fung: I worked with a famous physiologist, Dr. Sidney Sobin in pulmonary research.

Nebeker: Where were we? In the mid- to late-'50s you were in aeronautics at Caltech. Were you tenured at that point?

Fung: Yes.

Nebeker: Of course you're in the aeronautical engineering department and you're starting to get interested in this.

Fung: Caltech has no departments. We attach names to laboratories. I was a Professor of Aeronautics. Caltech is a wonderful place to work. I left it only because I wanted to work on bioengineering one hundred percent of my time.

Nebeker: What year was that, roughly?

Fung: 1966. Caltech was saying you may work on whatever you want. Caltech's tradition is that you can change your field and you can change your title if you want to. All you need to do is to tell the Institute. However, Caltech is small. Caltech refused to grow like most other places. The rate of faculty growth was very slow. At that time I had a fair number of graduate students working with me on Ph.D.s.

Nebeker: These were all in aeronautics?

Fung: Aeronautics. Now, I can change myself. I cannot change my students. I cannot say I don’t want to teach those courses anymore. I cannot say I don’t want to supervise the students anymore. Fred Lindvall, the Director of Applied Sciences at Caltech at that time, told me that if you want a bioengineering laboratory, one of the Board of Trustees is willing to fund one. In other words, changing was no problem. But my feeling was that I cannot have my one hundred percent in a new area.

Nebeker: How did your attention go to UC San Diego?

Fung: We were very lucky. We started from ground zero.

Nebeker: Who besides you?

Fung: The Caltech group, Marcos Intaglietta, Benjamin Zweifach, and I.

It was an interesting story. At that time UCSD had a Dean of the School of Medicine. The School of Medicine had not broken ground yet, but it had an unusual plan designed by a biologist, Dr. Bonner. It was to emphasize basic science, including physics, mathematics, and engineering. One day in June 1965, Zweifach, Intaglietta and I came to La Jolla to visit a good friend, Per Scholander. On our way home we dropped in the office of an ex-Caltech professor, Dr. Penner, who was the Chairman of Engineering in UCSD. Dr. Penner asked, “What are you people doing?” We told him we were working on bioengineering. “Oh,” he said. “One minute. Let me call the Dean of the Medical School, Dr. Stokes.” He called Stokes and said, “Here are three friends from Caltech working on bioengineering.” Dr. Stokes said, “Stop them! Ask them to give a seminar tomorrow morning.” That was how it all began.

Nebeker: Had they been looking for bioengineers of some sorts?

Fung: Apparently so.

Nebeker: Somehow there was this conception that there should be engineers interested in medical problems.

Fung: Yes. The whole design was that the medical school’s chemists should be hired in the Chemistry Department of the general campus, physicists in the Physics Department, mathematicians in the Mathematics Department, bioengineers in the Engineering Department.

The three of us became one of the first groups of employees in the medical school. This was a tremendous advantage to us because when they recruited professors of medicine and surgery, we were the ones to interview them. That broke down the professional barrier. By the time they came on campus, we were friends. In fact, we had tremendous relationships with the surgeons.

Nebeker: More so than other doctors?

Fung: I think so. Surgeons really see immediately that engineering is what they need. We had very good collaborations with the surgeons. The barrier was broken down almost without effort. I think we were extremely lucky on that.

Nebeker: How quickly were positions established and how quickly did you and the others move down here?

Fung: Drs Zweifach, Intaglietta and I came in 1966. We lured Drs Arnost Fronek and Kitty Fronek to join us in 1967.

Nebeker: That was very fast from your visit to your moving here.

Fung: Yes, very fast. Fast because UCSD was a new campus. We started with a full program, with BS, MS and Ph.D. programs beginning in 1966.

Nebeker: Was this called Bioengineering?

Fung: It was called Engineering Science with specialization in Bioengineering. UCSD had a very unusual structure at that time. We had a large department called AMES, Applied Mechanics and Engineering Science. It included Aeronautics, Chemical Engineering, Bioengineering, Civil Engineering, Mechanical Engineering, and Applied Mechanics. The AMES department has a counterpart called APIS, Applied Physics and Information Science.

Nebeker: You must have had a name for the bioengineering.

Fung: We were called the Bioengineering Division in the Department of AMES.

Nebeker: Bioengineering was the name that you chose?

Fung: Yes.

Nebeker: Was it mainly what you thought of as biomechanics?

Fung: At the beginning we centered on biomechanics and physiology. But we collaborated with many surgeons, and in our mind our objective was broader, and we felt that bioengineering was a better word.

Nebeker: How did your research go from that time onward? Were you continuing to work with microcirculation, these problems you’ve mentioned already?

Fung: After microcirculation, I worked on the whole lung, the heart, the ureter, the muscle, and more recently concentrated on the blood vessel’s tissue remodeling under stress. Physiology is funny. It’s such a big field, but real experimental observations are done on very few things.

Nebeker: Where the anatomy lends itself to study?

Fung: Where it can be seen. Microcirculation is a big field, but really the organs they study are not many: the mesentery, the cheek pouch, the skin flap, and a few others. Everybody is interested in muscle, but there aren’t many muscles tested. First the frog, which was very early.

Nebeker: It goes way back.

Fung: It’s no joke. When A.V. Hill worked on muscle mechanics he used British frogs and got poor results. One day he visited Italy. He got the Italian frog, then it worked.

Nebeker: So that was the advantage Galvani had.

Fung: There are really not many models that people make observations on.

Nebeker: And moving into other types of engineering? I mean chemical and maybe electrical.

Fung: Almost all of our new faculty recruits are chemical engineers.

Nebeker: Did you get any electrical bioengineers?

Fung: This campus was weak in that area. There are many electric engineers to be consulted, willing to do some work, but not many willing to say this is “the” job. We are trying to solve this problem. We have the new Bioengineering Building under construction, and the new Bioinformatics Group organized. Many electric engineers expressed interest. We are recruiting. I am very interested. I think we are breaking new ground.

Nebeker: Did your work on the lung microcirculation have application to diseased conditions of the lungs?

Fung: Our work has direct applications to the understanding and treatment of pulmonary edema, pulmonary hypertension, high-altitude disease, respiratory distress syndrome, impact injury to the lung, lung surgery, and lung tissue remodeling under stress.

Nebeker: In your own work were you continuing to work with Dr. Zweifach and other physiologists? Who were the people you were most often collaborating with in your own research?

Fung: Dr. Zweifach passed away in 1998. Dr. Sobin is still full of ideas. My former students and colleagues Yen, Liu, Huang, Yin, Matsuzaki, collaborate with me. And I keep close collaboration with my colleagues Drs Shu Chien, Geert Schmid-Schönbein, and others.

Nebeker: Everybody in the bioengineering group?

Fung: I have more contact with older colleagues than new ones. On my new work on gene expression I collaborate with Dr. Konen Peck in Academia Sinica in Taipei.

Nebeker: What publications are you proudest of? I know of your mechanics book.

Fung: It’s difficult to answer. I do not want to be immodest! I continue to publish.

Nebeker: I don’t mean that this is a new story, but which of the ones that are out there already?

Fung: I collected the papers I am happy with in two volumes entitled *Selected Papers on Biomechanics and Aeroelasticity, Parts A & B*, 1985 pages, by Y.C. Fung, published by World Scientific Publishing Co., Singapore and New Jersey, 1997.

Nebeker: Have you retired from the teaching side?

Fung: I have retired from regular teaching. Then I volunteered to introduce a freshman course "Introduction to Bioengineering." Let me explain: UCSD bioengineering is getting fantastic, excellent students. How fantastic? In California, if you get A's in every course the GPA is 4.0. But high school kids' GPA can be greater than 4.0 if college level courses were taken. In recent years, every year we got more than a hundred "super freshmen," as we call them, with better than 4.0 GPA. That's too many for our Department. We want about half that number.

Nebeker: So you have an average GPA of more than 4.0 for the entering people?

Fung: Entering class. Now, that's a burden to us. But once the University took them in we don't pay attention to them. The students take physics, mathematics, chemistry, humanities. They were not told what bioengineering *is*. I want to do something for them. So, I volunteered to offer a course called BE-1, Introduction to Bioengineering, to the freshman. The purpose is very simple. First, I want them to know what their professors are working on. Secondly, I want them to know each other. Thirdly, I want to instill a spirit of invention and design in them. I feel that the spirit of engineering can be taught.

I offered the course as an elective not required for graduation. People sign up voluntarily and get one unit of credit. I invited every faculty member to give a talk so the freshmen will know every faculty member's face.

Nebeker: And they also learn about some different areas of bioengineering that way.

Fung: After the first lecture I wanted them to tell me an invention they would be proud of. Then I organized the like-minded people into groups. The first time I offered it

I had thirty students, mostly graduates. The second year there was about eighty. The third year I had a hundred and fifty students.

Now the course is taken over by a colleague.

Nebeker: It sounds like a very good contribution to the program.

Fung: The notes of this course will be published in a book to come out in 2001.

Nebeker: What about your professional affiliations? What professional societies have been most important to you?

Fung: ASME, the International Society of Biorheology, Microcirculatory Society, AIMBE, BMES, ASB, the World Council for Biomechanics. We organized the World Congress of Biomechanics.

Nebeker: When was that?

Fung: We hosted it in 1990. Since then it has been held once every four years.

Years ago, IEEE ran ACEMB, which became Alliance of Societies, and AMB. For many years I went to those meetings and had good and close contact with electric engineers. For good and bad we finally got biomechanics by ourselves. It lost contact with electric engineers. That’s the bad part of it. I don’t go to those meetings regularly now.

Nebeker: Well, there’s always that tension between keeping different specialties together and then the greater focus when you have a more specialized society.

Fung: That’s right.

Nebeker: What about your connection with Taiwan? Did you ever live in Taiwan?

Fung: The longest period I was there was three months. I know many people there. I’m a member of Academia Sinica since 1966.

Nebeker: I was very impressed learning from Dr. Chien these close ties between people of Chinese background and what's going on in Taiwan today. I think that's very remarkable.

Fung: My connection with the Mainland is also quite close. The U.S. and China broke the ice by Nixon in 1971. In '72 I led a group of West Coast professors to visit China. In 1979 one group of Chinese bioengineers came to UCSD and stayed for three months. Then we had visiting scholars from Taiwan and Mainland.

In 1983, the U.S., China and Japan held a very good conference on biomechanics in China. This conference became peripatetic afterwards.

Nebeker: Cultivating the broken ground.

Fung: I think China and Japan have much to offer. Besides their unique contributions such as acupuncture and herbal drugs, there is the matter of style that is interesting. Let me name an example. The heart assist device, using balloon inflating, was invented in the late '60s in this country. It was studied a while and then dropped. One day while visiting China, I found a group that had carried on this research for 20 years. They used them on many patients and got very good results. I have wondered why here we just dropped it.

Nebeker: So there was an advantage in the way research was funded there, that if a professor wanted to continue in a certain area he could continue this.

Fung: In the U.S., trends of research change with NIH funding. In China, people stick to a successful lead much longer, and efforts to bring research to clinic are more persistent there than in the U.S.

Nebeker: I find it very interesting when there are these national differences that different areas get developed better in different countries. That must be gratifying for you with a Chinese background to see that that work is being done. Is it more in Japan than in China or in both areas that blood rheology is being done?

Fung: Blood rheology is popular in Japan. In China it is used widely in clinics. Different countries do have different attitudes.

Nebeker: How is it now from an international standpoint? I would imagine the work in Taiwan and Japan certainly is at the highest level. Is that also true of what's going on in Mainland China in the areas you know?

Fung: Mainland China is attacking biomechanics vigorously. But the funding level is too low. They need a system like our NIH, with annual funding pegged as a fixed percentage of GDP.

Nebeker: How did things go for your own family, your parents and brothers and sisters?

Fung: They survived the Cultural Revolution and are making good progress.

Nebeker: Is there anything I haven't asked about that you'd like to comment on?

Fung: I would like to add a word about humanity. Bioengineering has a tremendous future. Now is a pivotal time for progress. The twenty-first century is a century for biology. But the field is too important to be left to biologists, engineers, and physicians. Since bioengineering aims at human happiness and societal well-being, humanity is involved. Future bioengineering must include humanity.

Nebeker: Is ASME the usual profession affiliation of the people working in biomechanics?

Fung: Besides ASME, I would add the American Society of Physiology, the Biomedical Engineering Society, and various international societies.

Nebeker: And the field is growing.

Fung: Yes. The real payoff is coming.

Nebeker: You mean payoff in medical terms?

Fung: In medial, societal, intellectual, and humanistic terms.

Nebeker: But there have been some fantastic real successes in physiology, I mean in the understanding side, but you'd still like to see more of the medical.

Fung: Of course we want to understand man and the biological universe. Bioengineering should contribute to a better understanding. And contribute to health through engineering, inventing, designing, and making useful things.

Nebeker: But do you think that's a good thing for the field of biomechanics? One might argue that research gets distorted because there's money for certain problems that may not be the best one to be investigated with the tools that are at hand.

Fung: I think biomechanics will be there always. No understanding can be reached if force and motion are ignored. I don't ever think that application can be minimized. Applications always have surprises of some real good important discovery.

Nebeker: From the purely scientific viewpoint.

Fung: Even from the scientific point of view. Biomechanics is the middle name between structure and function.

Nebeker: A final question that occurs to me is from my outsider point of view; looking over the last fifty year, it seems like biomedical engineering kind of grows like this. There are very many fruitful channels that have gotten deeper and deeper. As you said, you used to go to the annual meeting that included many types of biomedical engineering. Does this mean that you get less communication?

Fung: I think so. I think specialization implies isolation in a certain sense, but what everybody should do is to avoid that consciously.

Nebeker: Keep in touch with different types of resources.

Fung: Right. Renew oneself. Use all resources to renew oneself. This applies to any individual and to any field of science, engineering, biology, and humanity. Maintain the strengths and let it go ahead. Don’t let it dry out and disappear.