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EMERGING HIGHTECHNOLOGY FIELDS AND THOUGHTS ON RESHAPING THE ENGINEERING CURRICULUM

By

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In the early part of this workshop, I believe Dr. Bergles made a statement indicating that certain schools in America are planning to take the traditional heat transfer and fluid mechanics courses out of their curriculum and that some may have already done so. That statement created some excitement, and I did respond to that in some fashion and make some suggestions. Then Dr. Bergles said "well maybe these matters should be included in a separate discussion period," which is this forum. Because I am working at the Advanced Photon Source at Argonne National Laboratory, I have the opportunity to witness the type of research being done in high technology areas today with the most advanced x-rays, which gives me some sort of advantage for telling you what I see as futufe research directions. Hence, I would like to reflect on all of this along a different avenue, and really my presentation will stress the educational side: essentially engineering education and what our role should be at the universities in teaching the next generation of students coming in and also what our role should be in retraining researchers for the demands of the emerging fields and markets.

Please keep in mind that I did not know before I came to this conference, that I would be speaking on this topic. Therefore, logistically, I am poorly equipped to make a well-documented and neatly prepared presentation.

In the first part, I will cover the issue of the classical heat transfer/fluid mechanics curriculum. It is a fact that heat transfer and fluid mechanics are mature sciences with at least 100 years of history, and so the questions are - what follows next in the curriculum in the universities, what is the role of mechanical engineers in the age of high technology, and what are the indicators to force a change or restructuring? Such directions may be entirely different in Europe, Germany, Russia, etc. In the U.S., there are several indicators for change in these classical fields. First of all, the American Society of Mechanical Engineers,

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the ASME, our professional society, recently included a new section called MEMS - "microelectromechanical systems". This is a strong and very rapidly growing section at ASME. And microscale energy transport is a new session that you now routinely see in the ASME conferences. You may also know that, in the U.S., the future is predicted for governmental funding purposes mostly by the National Academy of Sciences. And National Academy of Sciences has three branches: the National Research Council, the National Academy of Engineering, and the Institute of Medicine. These three entities have boards composed of learned people, and they try to read into the future and then make advisory suggestions to the government. So, looking at the science/education directions from these advisory institutions, one can see where we are headed. And high tech is recommended by all these entities. High tech is only possible if you diminish the length and the time scales. That means length has to become smaller and smaller to really discover and emulate nature, and the time scale has to become shorter and shorter because many events take place in almost non-equilibrium state in micro world and in the high tech fields. So therefore we are heading in the direction of microscaling and then miniaturization of engineering - if you will.

So this is the direction! And so what are the emerging fields? We are more and more looking into solid state devices, materials physics, soft condensed matter, genomics, DNA, biotechnology, biomechanics, microbiology, structural biology, micromachining, microsensors and photonics, and robotics and controls. These are the modern emerging fields. Now in all these, engineers have a significant role to play and, in some, the leading role. Sources for the investigation of the microworld are lasers, x-rays, and x-ray free-electron lasers due to their ultra-short wavelength for fine resolution and also other properties. Optical tools are being used more and more. In fact I compliment Dr. Mayinger for being in the forefront of setting up a very nice optical laboratory at University of Munich to bring modern optical methods into engineering research. These tools are able to dissect dimensions down to the levels that we need for microelectronics, microelectromechanical systems, and microdetectors. Now when you use sources like lasers and x-rays, etc., then there is a material damage issue. These devices put out high heat fluxes either in continuous or pulsed form. Laser and x-ray damage in materials is a current research topic, and there are meetings, like the Denver Damage Symposia, to look into these matters. Who is doing these things today? Largely physicists with only a small number of engineers in all these fields today. This deficiency should be remedied. Engineers can and should handle these emerging fields as a matter of fact. Engineers have, so far, made most of the contributions in the fields of biomechanical devices, robotics, etc.

So that takes me to what Prof. Naim Afgan said earlier - that we should give engineers more physics education to be functional in the emerging fields! We need to know more physics to handle these issues in mechanical engineering curriculum.

What is the connection between engineering education and these new fields and the new investigatory tools? To answer that, let us examine the time-length scale in the physical world. Let's imagine a chart with time scale, t, in the abscissa and then length scale, L, in the ordinate. Now the smallest time scale, "τ_c" is the collision duration of the transport carriers like the electrons, photons and phonons. The order of magnitude here is about a femtosecond or so. The next time scale is "τ" which most of you know as the mean free time between collision. And then "τ_r" is the equilibration time after tens of collisions. And then beyond this, "τ_d" is the diffusion time of classical transport theory that we all are intimately familiar with and about which we got the most formal learning. In the length scale, the smallest spatial element is λ_c, the wave length of energy carriers, typically on the order of Angstrom. The next scaling length is the mean free path, l. And then "l_r" is the equilibration length scale for usually several times the mean free path. Now, if we draw a grid with these time/lengh scales, we get different regions where different physical phenomena are in effect. Only beyond the equilibration length, l_r, and beyond the equilibration time, τ_r, do the classic fluid mechanics and heat transfer hold. This is the region of classic transport theory and macroscale engineering and sciences. Now the region defined by τ_c and λ_c, is where wave phenomenon and Maxwell's equations prevail depending on the energy carriers you are dealing with. Here we are talking about optical phenomena, diffraction, tunneling and interference, etc. This is truly the physicists domain - both theoretical and experimental. In between this region and the macroscale engineering domain as defined above, there is a vast region bounded by these respective scales requiring different theories and formulations. In this vast domain we learn only a little about the molecular dynamics (statistical theory) in a narrow region around τ and l. Then there are regions where physical processes can be temporally averaged but not spatially or spatially averaged but not temporally. About such non-equilibrium states, we normally are taught nothing.

Under the extremely intense flux of lasers and x-rays, there are material interactions where material is unable to relax. It is totally a non-equilibrium thermodynamics. Hence the Fourier heat equation is no longer valid. Definitions of classic thermo-physical properties vanish. The heat equation goes into a wave equation (heat waves). These areas are not covered in today's engineering curriculum. The regions sketchily covered above are contiguous starting from Maxwell equations. What we need to do is to teach transport processes and physics, which necessitates a fundamental understanding of the wave quantum nature of transport and the carriers as electrons, photons, and phonons. From Maxwell equations, we can drive the Boltzman transport equation. Under certain conditions, the Boltzman transport equation reduces to what is called the Cattaneo equation, which is the wave form of the transport equation. The Catteneo equation, under certain conditions and, fortuitously, for most macroworld processes and engineering cases, reduces into classical Fourier equation. From this global perspective, one can see that with the Fourier diffusion equation we are at the very bottom of learning of transport phenomena in our current curriculum. So, therefore I am suggesting to you that, in order to train engineers who can be functional in the emerging hightech world, the engineering curriculum has to include a very good basis on microscale energy transport and microelectromechanical systems (MEMs). Now who is doing this today? In the U.S., such curriculum adjustment is already being made at certain leading universities, such as California and Stanford and MIT to name a few. Those are schools that I know of, and I am sure there are more. And in fact, these people have already put out a textbook that I would like to show to you, *Microscale Energy Transport*; it is an edited book and covers all these subjects I mentioned to you. This is a book that engineers should probably learn as a minimum. This just came out last year. There is journal called *Microscale Thermophysical Engineering* also published by Taylor and Francis. Then, there is a serialized Japan-USA workshop on molecular and microscale energy transport. The ASME conference MEMS proceedings are available for the past few years. In the *International Journal of Heat and Mass Transfer* I am seeing increased paper submissions on micro-energy transport.

In summary, I believe that we have to make a transition in our engineering curriculum to train students who can function in the emerging high-tech related research and engineering fields. We have to teach more physics. And, in this extemporaneously prepared commentary, I simply expanded on one field, which is the generalized transport theory that this workshop is exclusively involved with. My colleagues from academia in the audience may have other views and suggestions on other disciplines.

Thank you.