Mechanical Engineering: Future Forward

by Erik K. Antonsson

Mechanical engineering is the branch of engineering that is generally concerned with understanding forces and motion and their application to solving problems of interest to society. The field traditionally includes aspects of thermodynamics, fluid and solid mechanics, mechanisms, materials, and energy conversion and transfer, and involves the application of physics, mathematics, chemistry and, increasingly, biology and computer science. Importantly, the field also emphasizes the process of formulation, design, optimization, manufacture, and control of new systems and devices.

For most of the 20th century, mechanical engineering meant fluid and solid mechanics, thermodynamics and design. However, technical developments in the last decade have established the importance of interdisciplinary engineering and science, presaging the emergence of new technical disciplines within mechanical engineering. These new areas build on an understanding of the fundamental behavior of physical systems; moreover, the focus of this work is at the interface between traditional disciplines. Examples of the new disciplines include several overlapping mechanical engineering areas: micro/nano electro-mechanical systems (MEMS/NEMS); simulation and synthesis; integrated complex, distributed systems; and biological engineering. These new disciplines represent the crucial directions for Mechanical Engineering (ME) at Caltech.

Micro/nano systems have enormous promise to introduce sensing, actuation, controls, and computation into a wide range of situations. Everything from control of flow and combustion in gas turbines, local climate control in buildings, to advanced surveillance systems is being contemplated.

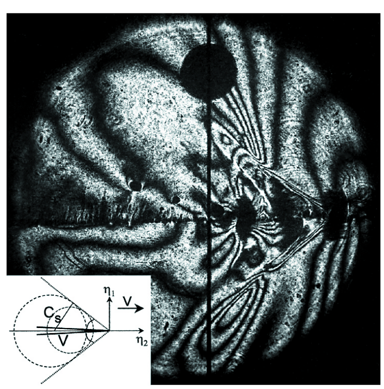
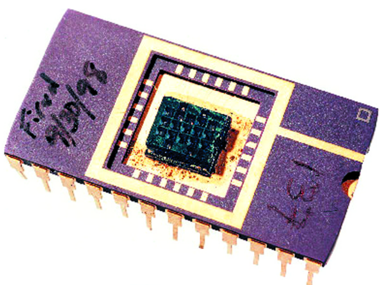


Image of an intersonic shear crack moving at a speed higher than the speed of shear waves and creating a shear sonic boom. From the research of Ares J. Rosakis, Professor of Aeronautics and Mechanical Engineering.

The road to realization of this promise will be long and challenging and requires the application of all of the traditional mechanical engineering disciplines to this new field. Many research efforts are underway at Caltech, from developing novel micro-thrusters and sensors for micro-spacecraft, developing novel active materials for micro-actuators, to constructing advanced modeling methodologies that bridge the length-scales from atomistic to continuum.

Simulation and synthesis of novel engineering designs is an exciting area of research at Caltech. In the early 1960s, engineering design methodology underwent a renaissance. Methods began to be developed to guide engineers through a process to produce high-quality designs. In the mid-1980s, these methods began to evolve from their informal (guide-



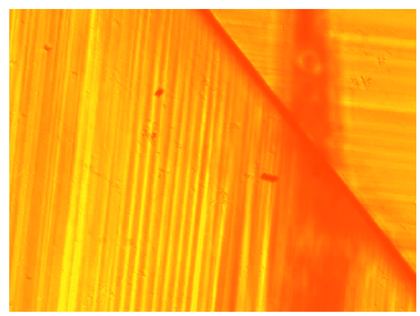
The digital propulsion "rocket chip" was developed at Caltech in collaboration with TRW and the Aerospace Corporation as enabling technology for micro-spacecraft. The micro-thruster array consists of a three-layer sandwich of silicon and glass, and is shown here mounted in a standard 24-pin ceramic dual-inline electronics package. This prototype contains 15 individual thrusters in the central 3 by 5 array. The visible bond wires are connected to resistors in each thruster that initiate combustion of the lead styphnate fuel. Each thruster cell produces 0.1 milli-newton-seconds of impulse, and about 100 watts of mechanical power. A successful suborbital test flight of these MEMS devices has been conducted.

line-like) origins to more formal, i.e., computable, methods. Recently, the foundations of methods to automatically synthesize new designs have begun to be developed. Synthesis is a difficult task; the creation of new designs is often thought of as a fundamentally human act. Emerging research has demonstrated that aspects of synthesis can be formalized and the foundations now exist to actively pursue highly automated synthesis techniques.

Integrated, complex distributed systems are all around us. Almost no engineered devices exist and operate in isolation. Automobiles and aircraft are part of a larger transportation system; manufacturing equipment is part of a larger production system; medical sensors are part of a larger health-care system. The modeling, simulation, and design of engineered devices must be done in the context of the increasingly highly interconnected distributed systems of which they are a part.

The recent explosion in the field of biology makes clear the urgent need for the development of the discipline of biological engineering to leverage the scientific advances for the benefit of society. Accordingly, Caltech's Bioengineering Option has strong participation from Mechanical Engin-eering. Our view is that just as chemical engineering has built on the scientific advances in chemistry to develop useful products and systems, bioengineering will build on the advances in molecular and neural biology. These new directions will take us far into the future—and the ME faculty are poised to help lead the way. A full strategic plan is available on the ME website.

In recognition of increasing student interest, the faculty has instituted an *undergraduate option* in Mechanical Engineering to begin in the 2002/03 academic year. The aim is to prepare students for research and professional practice in this era of rapidly advancing interdisciplinary technology. The program builds on the core curriculum to combine individual depth of experience and competence in a particu-



Microscopic patterns of the ferroelectric material barium titanate. This photograph was taken by Eric Burcsu, a Caltech graduate student jointly supervised by K. Bhattacharya, Professor of Applied Mechanics and Mechanical Engineering, and G. Ravichandran, Professor of Aeronautics and Mechanical Engineering. This material and related ferroelectric materials have an interesting property known as electrostriction: they change shape when an electric voltage is applied to them. Therefore, they are used as actuators that drive various micro-devices. Bhattacharya and colleagues predicted and demonstrated a new mode of electrostriction based on manipulating these patterns; the resulting electrostriction is at least 10 times larger that what was previously known.

History of the ME Option at Caltech

Mechanical Engineering has a long history at Caltech, and indeed the origins of the Option predate the formation of Caltech itself. The May, 1907 Throop Polytechnic Institute *Bulletin* indicated that "Although courses in Mechanical, Civil and Mining Engineering are not outlined below, considerable work is given in these branches of engineering and their collateral subjects. It is also the purpose of the Institute to extend the work along these lines as demand for it arises."

Apparently there was vigorous demand. Only a month later, in the June, 1907 *Bulletin*, a four-year program of subjects required for graduation in mechanical engineering "looking toward the degree of B.S." were published. These courses included Chemistry, Physics, and Calculus, as well as Shop Work, Machine Details, Prime Movers, Surveying, and Commercial Law.

A year later, in the May, 1908 *Bulletin*, it was noted that a Mechanical Laboratory had been established, and was "equipped with apparatus for the investigation of the strength of materials, to which will be added immediately, the apparatus needed to fully equip in other lines of mechanical experimentation."

The importance of engineering to the developing Throop Polytechnic Institute was made clear in the April, 1910 *Bulletin*: "The Institute confines its degrees to Electrical, Mechanical, and Civil Engineering." By January, 1917, Chemical Engineering, Chemistry, Engineering, and Economics, and General Courses had been added to the list of Bachelor of Science degrees offered by the Institute. The December, 1928 *Annual Catalog* of the (now) California Institute of Technology included a page showing the numbers of students in each area. Seventy-nine seniors were listed in Engineering (21 of whom were in Mechanical Engineering), out of a total Senior Class of 110 students. These numbers grew steadily to slightly over 40 seniors in ME until World War II. At the end of the war, the pent up demand for Mechanical Engineering was evident, with nearly 70 seniors, and 91 juniors in the program. A graduate program was added in 1933.

The Mechanical Engineering program continued through the 1959–1960 academic year, along the way adding a fifth year to the undergraduate program for students interested in a more specialized education. In 1960, however, the Institute chose to consolidate its undergraduate engineering offerings into a single program. The September, 1960 *Catalog* indicates "The California Institute of Technology has adopted a single engineering curriculum strong in the sciences and humanities with great flexibility of choice among the engineering sciences." Thus began the E&AS undergraduate program that currently graduates nearly 100 students each year.

In 1997, in recognition of student and faculty interest in a program more focused on Mechanical Engineering, a "Concentration" in Mechanical Engineering was introduced. The *Catalog* listed a set of required courses for students interested in ME. Students satisfying those requirements would earn an E&AS degree from Caltech, but with a notation on their official transcript, that they had "Concentrated in Mechanical Engineering." The number of students choosing to concentrate in ME has steadily grown, reflecting a continuing strong interest in the discipline.

With the reintroduction of the undergraduate Option in 2002/03, the Mechanical Engineering program at Caltech has come full circle.

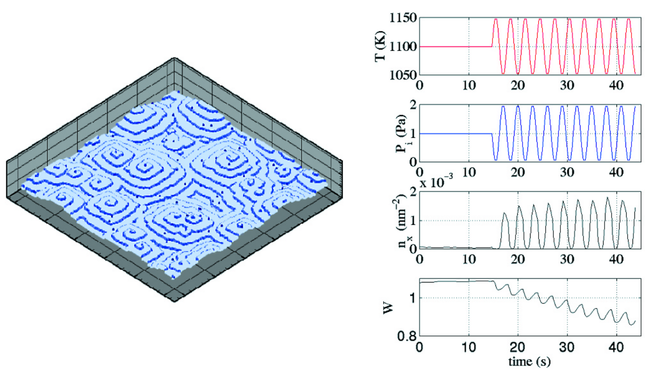
lar chosen mechanical engineering specialty, with a strong background in the basic and engineering sciences. It maintains a balance between lectures, laboratory, and design experience, and will emphasize the problem-formulation and solving skills that are essential to any engineering discipline. The program will also strive to develop in students self-reliance, creativity, leadership, professional ethics, and the capacity for continuing professional and intellectual growth.

Mechanical engineers are found in a wide range of application areas including automotive, aerospace, materials processing and development; power production, consumer products, robotics and automation; semiconductor processing; and instrumentation. Mechanical Engineering can be the starting point for careers in bioengineering, environmental engineering, finance, and business management.

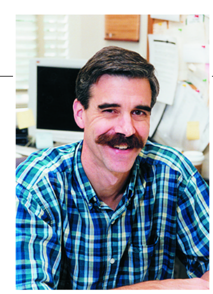
ME CENTENNIAL

The year 2002 marks the 95th anniversary of the establishment of Mechanical Engineering at Caltech and 2007 will mark the Centennial of the Mechanical Engineering program at Caltech. We are now initiating plans for this important event. Historical vignettes, photographs, and publications will be enthusiastically welcomed to help illuminate the distinguished history and contributions of the program. ENG

To learn more about the ME Option and the anniversary celebrations visit
http://www.me.caltech.edu



A dynamic thin-film deposition. Use of time-varying process conditions may enable deposition of films with novel properties or lead to lower-cost processes. From research on engineering microstructural complexity in ferroelectric devices by David G. Goodwin, Professor of Mechanical Engineering and Applied Physics.



Erik K. Antonsson, Professor of Mechanical Engineering, is the Executive Officer of the ME Option. His research interests include formal methods for engineering design, formal design synthesis, representing and manipulating imprecision in preliminary engineering design, rapid assessment of early designs (RAED), structured design synthesis of micro-electro-mechanical systems (MEMS), and digital micropropulsion microthrusters. His research work is supported by the NSF, DARPA, and industry. He has published over 100 scholarly papers in the engineering design research literature and holds four U.S. Patents. He is a Fellow of the American Association of Mechanical Engineers (ASME), a co-winner of the 2001 TRW Distinguished Patent Award, the recipient of the 1995 Feynman Prize and a 1986 NSF Presidential Young Investigator Award. He served as an editor for the ASME Journal of Mechanical Design *and is currently on the editorial board of two international journals:* Fuzzy Sets and Systems *and* Research in Engineering Design.