125 Years of Mechanical Engineering

at

The University of Michigan

Department of Mechanical Engineering and Applied Mechanics

ANNUAL REPORT 1992-93

Mechanical Engineering Faculty, 1868-1993—Joseph Akerman•Rayhaneh Akhavan•John Allen•Wyeth Allen•Herbert Alvord•Henry Anderson•Vedat Arpaci•Ellen Arruda•Eugene Ash•Anthony Atkins•Arvind Atreya•James Barber•Myron Begemen•Kurt Binder•Jay Bolt•Claus Borgnakke•O. W. Boston•Frederick Boutwell•Thomas Boyle•Giles Brereton•James Brown•Joseph Bursley•Robert Caddell•James Cairns•Floyd Calhoon•Harry Campbell•Robert Carson•Steven Ceccio•Milton Chace•Michael Chen•John Clark•Samuel Clark•Howard Colby•David Cole•Lester Colwell•Maria Comninou•Gerald Conger•Mortimer Cooley•James Daily•Joseph Datsko•J.B. Davis•Walter Debler•Charles Denison•Warren DeVries•Donald Douglas•David Dowling•Debasish Dutta•Glenn Edmonson•John Emswiler•Arnet Epple•Rune Evaldson•Lary Evans•John Faig•Shaya Fainman•Spilios Fassois•David Felbeck•Charles Fessenden•Robert Fijan•Francis Fisher•Walter Fishleigh•William Flaherty•Richard Flinn•Richard Folsom•Julian Frederick•Victor Gauthier•William Gilbert•Steven Goldstein•Charles Good•Charles Gordy•William Graebel•William Graves•Mark Greg•Anton Greiner•John Grennan•George Grimes•Mehrdad Haghi•Keith Hall•Frederick Hammitt•Arthur Hansen•Ransom Hawley•William Hazelton•Naeim Henein•Alexander Henkin•Robert Heppinstall•Robert Hess•Dean Hobart•Robert Hoisington•Oliver Hollis•Harold Holmes•John Holmes•Stanley Jacobs•Clarence Jagodzinski•Gordon Jensen•Glen Johnson•Carroll Jones•Robert Juvinall•Elijah Kannatey-Asibu, Jr.•Bruce Karnopp•Massoud Kaviany•Hugh Keeler•Robert Keller•Clarence Kessler•Noboru Kikuchi•Henry Kohler•Yoram Koren•Sridhar Kota•Ralph Kraft, Jr.•Edward Lady•Jonathan Laitone•F.X. Lake•Poul Larsen•Walter Lay•Charles Lipson•Robert Little•Harold Lloyd•Donald Long•Roger Low•Kenneth Ludema•Axel Marin•Joseph Mazur•James McElhaney•Robert McKee•John Melvin•Herman Merte, Jr.•Frank Mickle•William Miggett•Henry Miller•William Mirsky•Karl Moltrecht•George Morley•James Moyer•Clair Myron•Jun Ni•De Owen Nichols•John Nickelsen•Lorraine Olson•Martin Orbeck•Thomas Orr•Kenneth Packer•Edward Page•Jwo Pan•Panos Papalambros•Homer Parker•Donald Patterson•Felix Pawlowski•J. Raymond Pearson•John Penrose•Noel Perkins•Vernon Phelps•Walter Pierce•Christophe Pierre•R. Clay Porter•Philip Potts•David Pratt•Horace Purfield•Leland Quackenbush•Krishnan Radhakrishnan•Ravi Rao•Stillman Robinson•Don Rogers•Franklin Rote•John Rowen•Robert Ryan•Shyam Samanta•Albert Schultz•William Schultz•Frank Schwartz•Raymond Scott•Richard Scott•Leonard Segel•Steven Shaw•Allen Sherzer•Joseph Shigley•Scott Slezak•Frank Smith•Gene Smith•Hadley Smith•Homer Smith•Robert Smith•John Smoots•Louis Solomon•Richard Sonntag•Frank Sowa•William Spindler•Charles Spooner•George Springer•Wilbert Steffy•Jeffrey Stein•Robert Stevens•John Sullivan•Joseph Sweeney, Jr.•Douglas Tally•Clarence Taylor•John Taylor•William Telfer•Charles Thorpe•Stanton Tompkins•William Truckenmiller•Grétar Tryggvason•A. Galip Ulsoy•Gordon Van Wylen•William Verner•Frederick Vesper•Charles Vest•Edward Vincent•Quentin Vines•Phillip Visser•Frank Wagner•Leslie Wagner•Allen Ward•Henry Watson•Earl Webb•Philip Webb•Franklin Westervelt•Joseph Whitesell•Clyde Wilson•Alan Wineman•Ward Winer•Robert Winslow•Anthony Woo•DeVolson Wood•Shien-Ming Wu•Chin Tse Yang•Wei-Hsuin Yang•Wen-Jei Yang•Chia-Shun Yih•John Young•Paul Youngdahl•M.Y. Zarbrugh•Stanislaus Zowski

This list was compiled from a variety of sources and may not be a complete listing of all faculty.

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Mechanical Engineering and Applied Mechanics
ANNUAL REPORT

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In 1910, Felix Pawlowski, a young scientist from Poland, arrived in America with a dream. Earlier at the University of Paris, he had taken the first course in aeronautical engineering ever given and was now determined to become America's first aeronautical engineer. When he sent letters to engineering colleges around the country requesting the chance to start an aeronautics program, he received mostly negative replies. The field was too new, and there was no assurance that it would ever amount to anything.

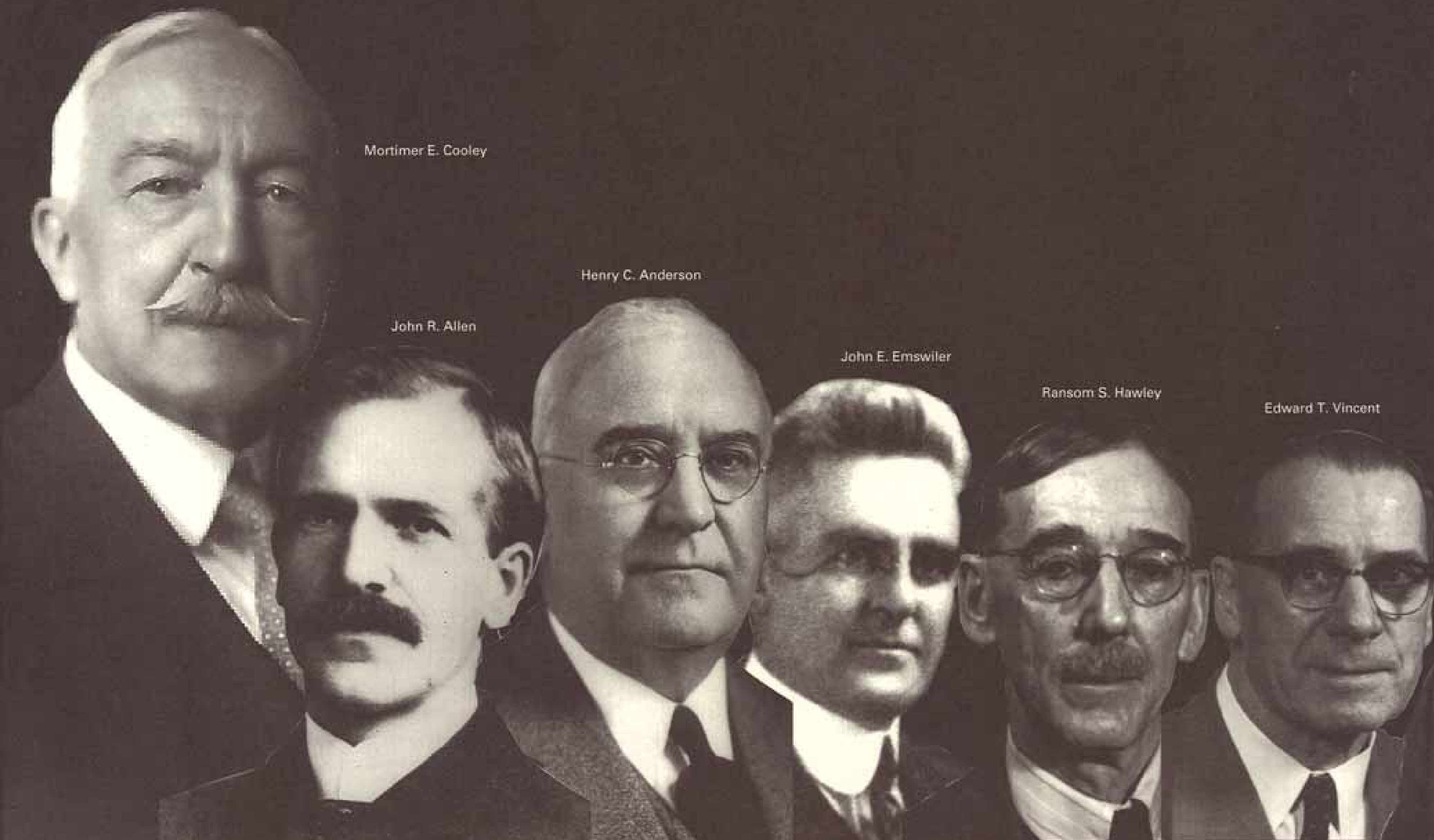
Finally, Pawlowski made contact with a leader as forward thinking as himself. That person was Mortimer Cooley, the first chairman of the Department of Mechanical Engineering at the University of Michigan. Cooley hired Pawlowski onto the faculty of Mechanical Engineering and encouraged him to create a course of study. Thus, Pawlowski became the first aeronautical engineering instructor in the country, and the program he developed, which granted its first degree in 1917, became the first program in aeronautics.

Pawlowski's story is important because it reminds us that both determination and risk-taking are important qualities in reaching for excellence—qualities just as important to our Department today as they were at the turn of the century.

Indeed, history has much to teach us and that is why we have devoted this book to looking at the achievements of our students and faculty over the last 125 years.

We hope you will take the time to look it over.

Panos Y. Papalambros
Chair,
Department of Mechanical Engineering
and Applied Mechanics



1881 Cooley | 1904 J. Allen | 1917 Anderson

1868 First ME Course Held

1882 Original Machine Lab

1885 Engineering Laboratory (Shops)

West Engineering Bldg.

1913 First Automotive Course Held

1922 East Engineering Bldg.

Mechanical Engineering at The University of Michigan 1868 to 1993

Over the last 125 years the Department has grown from a humble, two-room laboratory with one professor in 1868 to one of the top-ranked engineering programs in the country in 1993. The story of that evolution is presented in four sections dividing the years at logical breaking points. It is not a comprehensive history but one that tries to give a sampling of the activities of the Department in all four eras.

1937 Emswiler | 1940 Hawley | 1951 Vincent | 1955 W. Allen | 1956 Van Wylen | 1965 Hansen | 1966 Clark | 1974 Pearson | 1978 Pratt | 1983 Sonntag | 1992 Papalambros

Auto Lab moves to UM North Campus | 1957 G.G. Brown Bldg. North Campus | 1985 ME Completes its Move to North Campus | 1993 125th Year Anniversary

1868-1900 Laying the Foundation

University Catalogue, 1887
Mechanical Engineering:

"Prominence is given to the study of steam engineering, and in this branch, a large amount of practical work is done. The instruction is arranged to accommodate those who wish to devote their time principally to mechanical engineering proper, to steam engineering, or to marine engineering and naval architecture."

The story of the Department of Mechanical Engineering and Applied Mechanics at the University of Michigan begins 125 years ago when the engineering discipline at the University was still in its infancy. Engineering professors and students could be numbered in the dozens, and the only curriculum offered was in Civil Engineering. Seeing the need for a broader program, Professors DeVolson Wood and Stillman Robinson requested that the University offer a separate specialized course to focus on the newly developing fields of machine, power, and marine engineering. In 1868, the Regents voted to create the Mechanical Engineering program. Unfortunately, the University did not have the resources to maintain its new creation, and two years later the Mechanical Engineering program was reabsorbed into Civil Engineering, where it remained for eleven years.

During this time, students continued to receive strong and often innovative instruction in mechanical engineering. Professor DeVolson Wood described a challenging teaching technique he used in a course in 1872. "I assigned to them a problem, the character of which I was certain they were not familiar with, and asked them to solve it, make a drawing to

DEGREES CONFERRED

...about 4 per year.
A total of 141 undergraduate degrees were conferred by the Department during this 32-year period.

represent their idea, accompany it with a specification, and report it to me. (Example) After describing the construction and operation of the ordinary D valve (in a steam engine), and showing particularly that in order to open a port ...the valve...is moving in the opposite direction from the piston, I asked the class to invent such an arrangement of parts as that the valve would open the port correctly if it moved the same way as the piston... In a class of thirty there would often be fifteen or twenty different solutions..." (*An Encyclopedic Survey*, p.1257.)

In 1881, the Department finally gained an independent identity thanks to an energetic young Naval officer, Mortimer E. Cooley, an 1878 graduate of the U.S. Naval Academy. He was one of a number of naval officers appointed by Congress to university faculties. His assignment at Michigan was to establish a Mechanical Engineering program, and over the next two decades, his dynamic leadership laid the foundation for a thriving department.

Built for $2,500 in 1882, the first Mechanical Laboratory housed a foundry, forge room, brass furnace, engine room, machine room and pattern shop.

The Original ME Curriculum

Cooley quickly set to work developing the Department's curriculum, which emphasized machines powered by steam and water. Students received a smattering of liberal arts courses and a solid base in math and basic science before taking the ME courses in their junior and senior years. There was no separate naval engineering department so these courses were also included. The original curriculum consisted of: Workshop Appliances and Processes, Pattern Making, Moulding and Founding; Mechanical Laboratory Work (Shop Practice in Forging); Machinery, Machine Construction, and Drawing; Mechanism and Machine Drawing; Machinery and Prime Movers (Water Wheels and Steam Engines); Machine Design; Thermodynamics, Original Design, Estimates, Specifications, and Contracts; and Naval Architecture.

The First Mechanical Laboratory

At the time of Cooley's appointment, all engineering classes were held in the South Wing of the University Hall with no laboratory space available. To remedy that situation, Cooley used an appropriation of $2500 from the State legislature to construct and equip a two-story laboratory building.

Plans for the building were prepared by faculty member J.B. Davis. "It was a two-story structure of frame construction (24' x 36') with bricks placed edgewise between the studding. The ground floor was divided into two rooms, the foundry on the east end and the forge shop, brass furnace, and engine room on the west. The foundry also included two flasks, other necessary foundry tools, and molding sand. The shop contained the first steam equipment in the Mechanical Engineering Laboratory, a forge, anvil, tools, a

As the Engineering curriculum grew, the building that formerly housed the University's Dental College provided needed classroom space. Originally a professors' dormitory, this building stood on the site of the current William L. Clements Library.

brass furnace, and a four-horsepower vertical fire-box boiler and steam engine. The second floor was also divided into two rooms, one of which was occupied by the pattern shop and the other by the machine shop. The equipment in these rooms consisted of a wood-turning lathe built by Cooley and members of his class, and an iron lathe, salvaged from the basement of University Hall and repaired by the students. The building was heated by an old-fashioned stove on the second floor. In cold weather, ice was melted in a pail of water on top of the stove in order to increase the humidity." (*An Encyclopedic Survey*, pp.1259-60.)

In his first report to the Regents Cooley described the original course taught in the new laboratory, "Six students were permitted to take the first laboratory course held in the building. They were engaged for a large share of the time in overhauling and erecting machinery in the shop. The remainder of the time was devoted to grinding and putting in order the cutting tools, in performing some of the simpler operations at the workbench, in preparing work for the iron lathe, in wood-turning, forging, brazing, and soldering, and in running the engine." (*An Encyclopedic Survey*, p.1259.)

Cooley reminisced about this first class in his autobiography, *The Scientific Blacksmith*, published in 1947 after his retirement as Dean of the College of Engineering. "How well I remember my first class in this little shop. Six engineers were taking the course. The first lesson was at the forge. I taught them how to build a fire. Then I wanted a piece of iron to heat. At the back door there was a wagon load of scrap of different kinds of metal, and I sent the members of the class to bring me back a piece of wrought iron. Much to my surprise not one of the six could identify wrought iron, cast iron, steel, or anything else in the pile. I asked the differences between the various kinds of metal, and every last one of them knew the chemical differences and the process of manufacture, but not one of them could identify one piece of metal from another. That incident thoroughly convinced me of the need for practical work to acquaint engineers with the characteristics of the materials they would be using after graduation" (p.106).

Cooley did not remain long satisfied with the small four-room laboratory. In 1883 he convinced the University to donate to the Department the carpenter shop that had been used in the construction of the University library. It was dismantled and attached to the Mechanical Laboratory. In 1885, construction of a new laboratory building was authorized by the Regents, and the original lab, just four years old, was torn down to make room for it. Additional space was acquired for the Department in 1891 when the former dental building was given to the engineering program for classroom space.

Inspection Visits

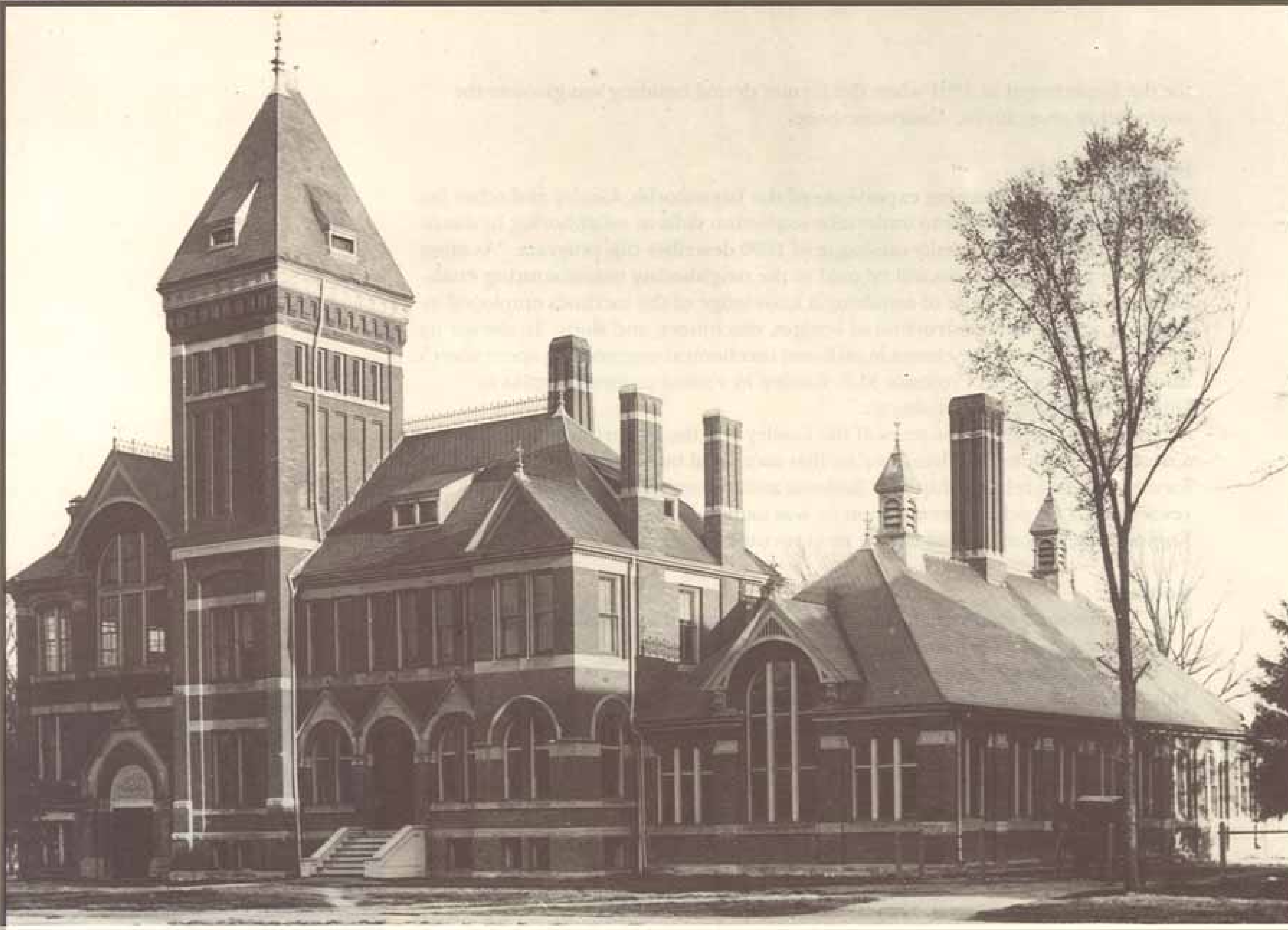
To supplement the learning experience of the laboratories, Cooley and other faculty arranged for students to undertake inspection visits to neighboring businesses. An entry in the University catalogue of 1890 describes this program. "As often as may be practicable, visits will be paid to the neighboring manufacturing establishments for the purpose of acquiring a knowledge of the methods employed in building, and in the construction of bridges, machinery, and ships. In the spring of 1886, members of the classes in civil and mechanical engineering spent a week, under the guidance of Professor M.E. Cooley, in visiting industrial works at Detroit, Cleveland, and Pittsburgh."

During the twenty-three years of the Cooley era, the Department had acquired a strong curriculum, had launched its first successful building program, and had formed a strong relationship with business and industry. In 1904, Cooley was rewarded for his achievements when he was named Dean of the College of Engineering, a post he held for the next twenty-four years.

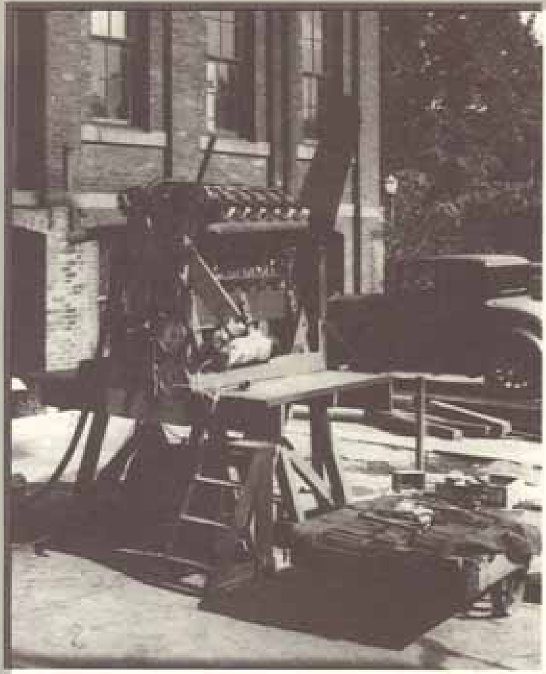
Sources:

O.W. Boston and Edward T. Vincent, "The Department of Mechanical and Industrial Engineering," in *The University of Michigan, An Encyclopedic Survey*, (Walter A. Donnelly, Editor), University of Michigan Press, Ann Arbor, 1953.
Mortimer Cooley, *The Scientific Blacksmith*, University of Michigan Press, Ann Arbor, 1947.
Announcement, College of Engineering, University of Michigan, 1895-1940.

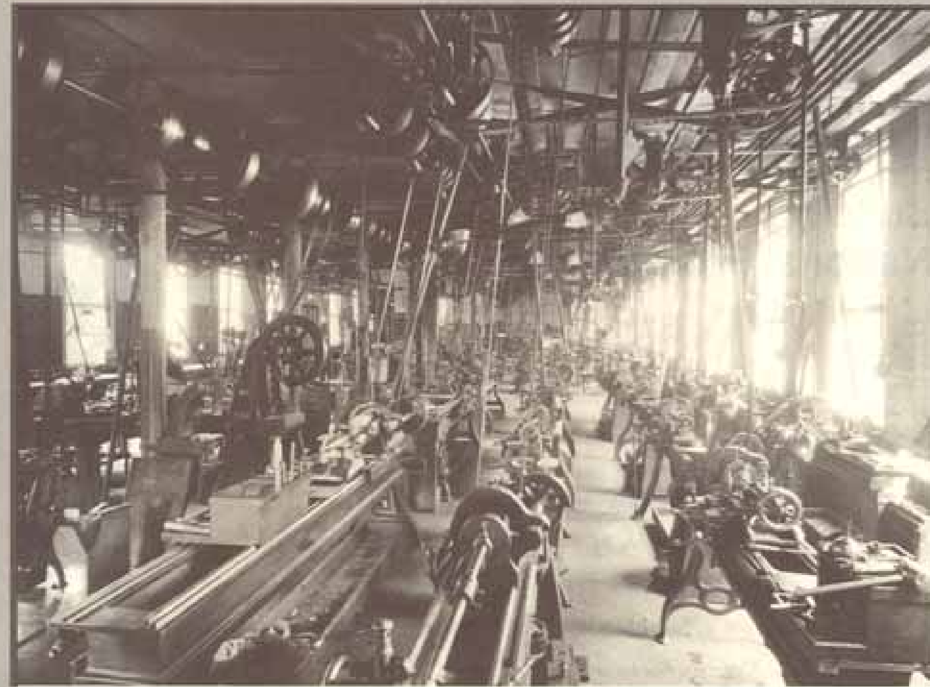
"...every last one of them knew the chemical differences and the process of manufacture, but not one of them could identify one piece of metal from another. That incident thoroughly convinced me of the need for practical work to acquaint engineers with the characteristics of the materials they would be using after graduation."
Mortimer Cooley, *The Scientific Blacksmith*



In 1885, at the urging of Mortimer Cooley, the University built the Engineering Laboratory Building. Various shops in the building and yard were used for education and research until that building (first referred to as "The Shops" and later "The Annex") was razed to make way for the Undergraduate Library in 1956. The forge and foundry (right) were converted into the University's first automotive lab in 1913.



Over the years, the courtyard between the "The Shops" and the foundry was used for experiments as well. This 800 lb. Liberty aircraft engine was used in an engine cylinder pressure study (ca. 1923).



This machine shop, located in the second floor, was used for student work in blacksmithing and machine tool work. The building included its own power plant, and line shafts powered the belt-driven machines.

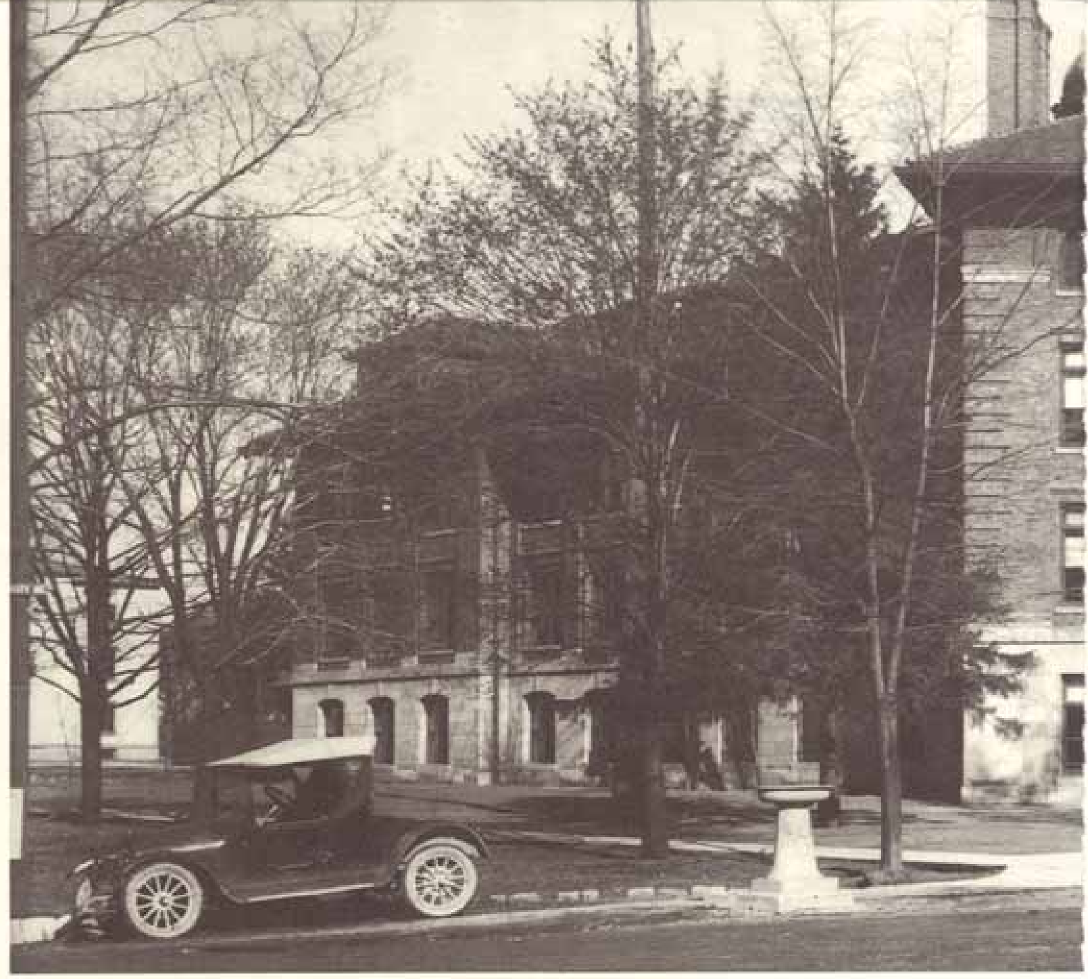
The facilities at the shops offered students exceptional opportunities in engineering training, always under the guidance of a highly respected professional staff.

1900-1940

Building National Prominence

University Catalogue, 1910
Mechanical Engineering:

"...that branch of engineering which, broadly speaking, covers the fields of heat, power, design of machinery, industrial management, and manufacturing problems."



DEGREES CONFERRED

...about 70 per year.
A total of 2780 undergraduate degrees were conferred by the Department during this 40-year period.

With a foundation well laid in the Cooley era , the Mechanical Engineering Department, as well as the entire engineering program at Michigan, was primed to step into a leading role in engineering education in the decades following the turn of the century. Drawing students from across the country and throughout the world, the engineering student body grew tenfold over the next forty years; graduate degrees were offered for the first time; laboratories were updated and equipped with modern instrumentation; and independent research projects became important academic endeavors along with the education of students. The university established stronger contacts with industry and

with other schools. Interdisciplinary programs leading to joint degrees with either law or business schools were created. The Department grew from a fledgling organization to one of the most prominent educational institutions in the country.

Curriculum

Perhaps the most important changes came in the curriculum. In the previous century, the ME program had emphasized steam power and manufacturing machinery almost exclusively, but the world of science and industry was changing and the Department changed as well. By 1940, the curriculum for the bachelor's degree had grown to include fifty-four courses with seventy-four semester hours of preparatory work, fifty hours of secondary and technical work and sixteen hours of electives. Semesters at this time were sixteen weeks long. Courses were grouped under these headings:

- Steam Power Engineering
- Internal Combustion
- Hydro-Mechanical
- Heating, Ventilation, and Refrigeration
- Industrial
- Automotive

Students conducting a test on a Fairbanks-Morse oil engine in "The Shops" in 1936.

These last two focus areas provide examples of how the Department adjusted its programs to the changing needs of industrial America.

Facilities

An advanced educational program requires advanced facilities, and the Department's growth in this area kept pace. The building that would be the symbol of Michigan engineering over the next seventy years was constructed in 1904—the West Engineering Building. Its laboratories were some of the most sophisticated in the country for that time, and five of those labs were part of the Mechanical Engineering program.

General Mechanical Engineering Laboratory: The equipment consisted of steam power machinery and apparatus; internal combustion engines; air compressors; refrigeration machinery; and heating and ventilating apparatus; as well as the auxiliary apparatus for use in testing the various machines.

Hydraulic Laboratory: This laboratory occupied a space of forty by sixty feet on two floors. A canal four feet wide and fourteen feet, six inches deep conveyed water from the naval tank to a well which furnished the suction supply for the pumps. A fifteen-inch centrifugal pump geared to a 150 hp variable speed motor returned the water through two weighing tanks, each holding 600 cubic feet to the naval towing tank. Nearby, the canal was provided with bulkheads, screens, weirs, and nozzles arranged with bulkheads dividing it into basins each 100 feet long, and by means of a sluice in the bottom connecting the canal with pumping systems.

Automotive Laboratory: Consisted of a large dynamometer room for engine testing, and a section for demonstration of automobiles, motor trucks, and their component parts. The lab was equipped with some twenty automobile, truck, tractor, and aeroplane engines of two, four, six, eight or twelve cylinders, complete operating and cutaway chassis, a chassis dynamometer, transmissions, rear axles, differentials, clutches, carburetors, ignition, starting and lighting systems, and other automobile equipment.

Physical Testing Laboratory: Materials were tested for strength in this laboratory.

Highway Lab: Tests were made on all materials used in road or pavement construction. (*Announcement*, 19-20)

Automotive Engineering

The automotive engineering program was an example of how the Department responded to an entirely new industrial direction. The Department's program in automotive studies began in concert with the beginnings of the auto industry in nearby Detroit. In 1913, the Department offered its first automotive course—Gasoline Automobiles. In 1916, Walter Lay joined the faculty with a mandate to create a laboratory and an entire automotive slate of courses. The first automotive laboratory course that he designed featured a full day's road test of a motor vehicle—either a single-cylinder Oldsmobile engine, a 1910 Krit, a 1907 air-cooled Franklin, or a 1911 Franklin engine. By 1914, at the beginning of World War I, the Mechanical Engineering Department had gained a strong reputation in automotive engineering and was called upon by the government to help in the war effort. Over the next few years, faculty trained 1081 Army personnel in automotive engine repair. Following the war, Professor Lay carried out pioneering research in cooperation with the nearby automotive manufacturers. The laboratory was one of the first to present comprehensive experimental data showing the advantages of streamlining. Another important project was a cooperative study with the State Highway Department to determine optimal highway grades, balancing cost of construction against operation cost of cars and trucks climbing the grades. Other studies were on engine heat balance, testing and improving of automotive parts, car safety, car noise, and riding comfort. By 1937, equipment in the Department's automotive laboratories consisted of motor vehicles, engines, transmissions, axles, superchargers, carburetors, mufflers, all the major units used on aircraft, motor vehicles, tractors and some marine applications of internal combustion engine power, electric dynamometers, water brakes, air meters, fuel meters, tachometers, and potentiometers.

In the 1920s and '30s researchers investigated the uses of manufactured gas. Three specific projects were issues of heat treatment, decarburization of steel, and core baking.

The continuing expansion of the Engineering Department called for the addition of another engineering classroom building across the street from West Engineering Building. The East Engineering Building, erected in 1922 provided classroom and lab space.

Industrial and Production Engineering

During this same forty-year period, industrial practices and processes in all branches of manufacturing changed dramatically, and in response, the Department created a program on the leading edge of the discipline. The changes began in 1915 when a course inspired by the Gilbreths's "scientific management" was introduced called Scientific Shop Management. It featured the study of the applications of scientific management in manufacturing plants. During World War I, this course was expanded to include two courses in the preliminary training of officers of the Ordnance Department of the Army—the first such courses offered by an American university. (The program was eventually expanded to 173 hours of study, and the first degree was awarded in 1926 to William Alden Capen who later became superintendent of the Keeler Brass Company in Grand Rapids.)

In 1921, Orlan W. Boston joined the faculty and was given the task by Dean Cooley of developing courses that would coordinate the disciplines of design, metallurgy, and production. Under Boston's leadership, the emphasis in the plan of instruction moved from that of manual training to the teaching of principles related to modern industrial practice.

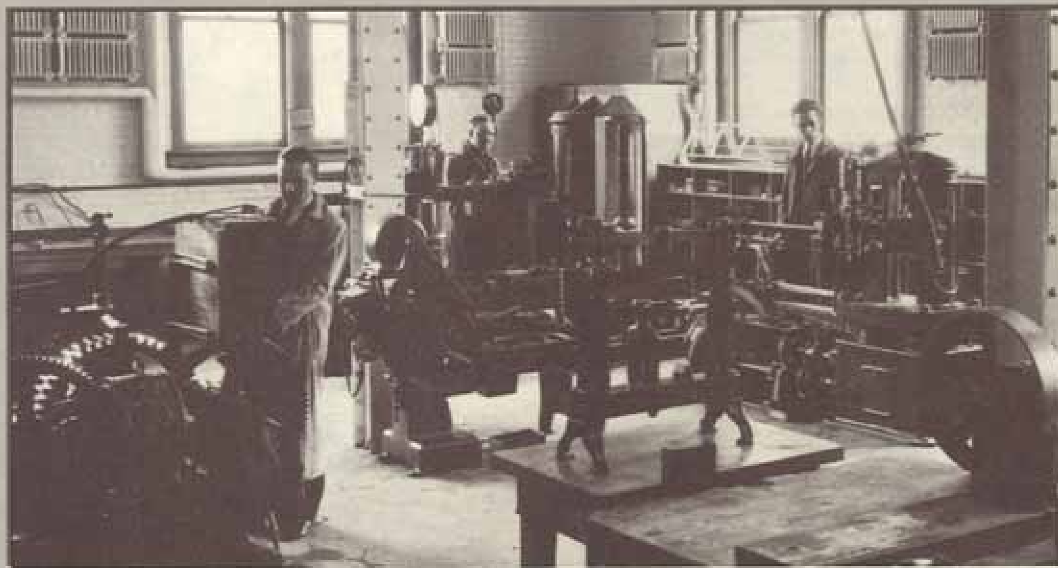
In addition to curriculum development, Boston also initiated research projects including pioneering investigations on the fundamental principles involved in the machinability of metals. In 1934, Boston was made the chair of the Department of Metal Processing within ME and in 1936 was named Custodian of the Gaging and Measuring Laboratory of the Detroit Ordnance District. By 1935-1936 enrollment in Metal Processing courses was so large that crowded sections were taught every half-day during the week.

By the end of this era in 1940, the Department was well established as one of the leading mechanical engineering programs in the country.

Sources:

O.W. Boston and Edward T. Vincent, "The Department of Mechanical and Industrial Engineering," *The University of Michigan, An Encyclopedic Survey*, (Walter A. Donnelly, Editor), University of Michigan Press, Ann Arbor, 1953.

Announcement, College of Engineering, University of Michigan, 1895-1940.



Stephen P. Timoshenko

Pioneering Researcher and Teacher

Stephen P. Timoshenko carried out research on the elastic method of stress analysis in the above laboratory as a professor in the Engineering Mechanics Department from 1927-1936. (Engineering Mechanics was later renamed Applied Mechanics and merged with Mechanical Engineering in 1979.) Timoshenko was a world recognized expert in the field of mechanics because of his original research, his teaching, and his textbooks.

The investigations he carried out while at the University of Michigan formed the foundation of the theory of the elastic behavior of solid matter. Among his other research contributions were: use of the energy method in problems of structural stability and buckling, and the formulation of the differential equation for lateral vibrations of beams, including the effects of shear and rotational inertia. He was also the first to formulate the basic differential equation for the problem of torsion of structural sections and was the first to obtain the shear center of a beam.

Timoshenko introduced scientific and mathematical approaches to the teaching of mechanics, and during his tenure at Michigan, the first bachelor's degree program in engineering mechanics in the country was established and the first doctorate degree in the field was awarded. During the course of his career, Timoshenko wrote eighteen textbooks that were translated into thirty-six languages.

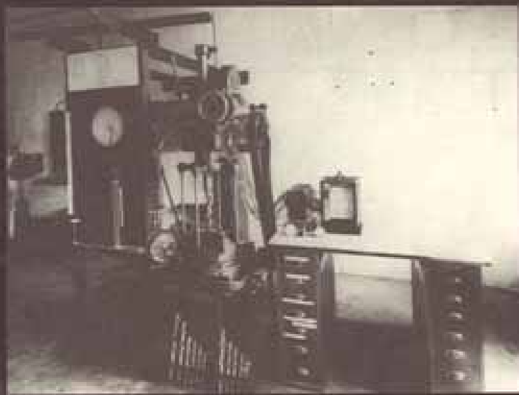
Timoshenko was the recipient of numerous honorary degrees and medals in both the U.S. and Europe, and in 1948 the ASME named a medal after him to honor his contributions to the field.

Source:

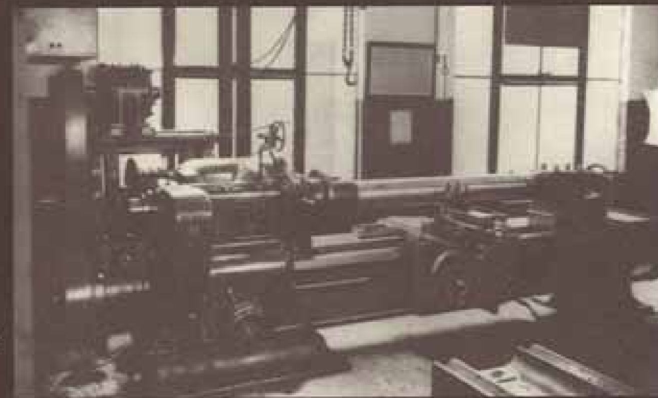
The National Cocyclopedia of American Biography, volume 57, pp 365-366, New York: James T. White and Co., 1977.

Orlan W. Boston

During his 35 years in the Mechanical Engineering Department, Boston conducted research in many areas, including the machinability of metals. He developed an exceptional curriculum in concurrent engineering that united design, metallurgy and production engineering into the modern concept of industry. This photo of Boston as an undergraduate (at left, above) was taken in 1909 in the West Engineering Building.



This drilling dynamometer set-up (left) and lathe set-up for tool life tests (right) were designed and built by O.W. Boston (ca. 1923-30) in "The Shops."



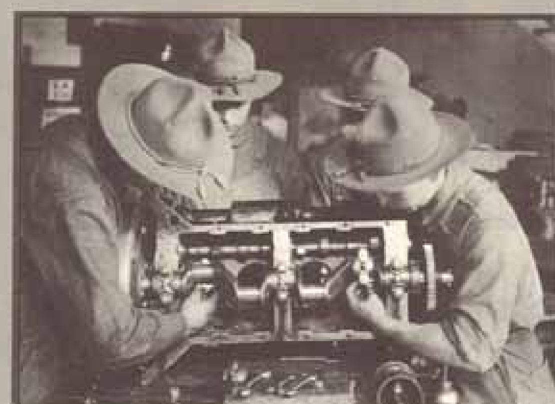
Boston was given the task of redesigning the foundry of the Engineering Laboratory. These photos (taken the spring of 1924) show the foundry as layed out by Boston assisted by H.L. Campbell and John Grennan.

Walter E. Lay
Automotive Engineering

Automotive engineering has always played a central role in the research and teaching activities of the Department of Mechanical Engineering. The University's proximity to the heart of the nation's auto industry in Detroit has made Automotive Engineering a natural focus for the Department. Facilities grew from a wooden shed attached to the engineering laboratory in the early 1900s, to the spacious, modern automotive lab constructed on North Campus in 1956. Research interests have included most areas of automotive engineering, from early studies on streamlining and engine heat balance in the twenties and thirties to pivotal investigations on fuel efficiency and emissions in the seventies. The broad range of topics more recently has included computerized control, measurements of engine performance, and reduction in variation in vehicle assembly. In 1978 the Office for the Study of Automotive Transportation was established in the Department, the only one of its kind in the nation, now one of the most influential voices in setting government transportation policy.

The Department has provided a steady flow of highly trained automotive engineers to industry throughout its history. One current measure of the excellence of our students is their performance in the two national solar car races 1991 and 1993. Undergraduate engineering students many from the Department beat out competition from dozens of other engineering programs to win both solar car races (see pg. 68).

A tireless researcher, Walter E. Lay (center, right) stands at the dynamometer controls during an analysis of the performance of automotive mufflers (ca. 1930).

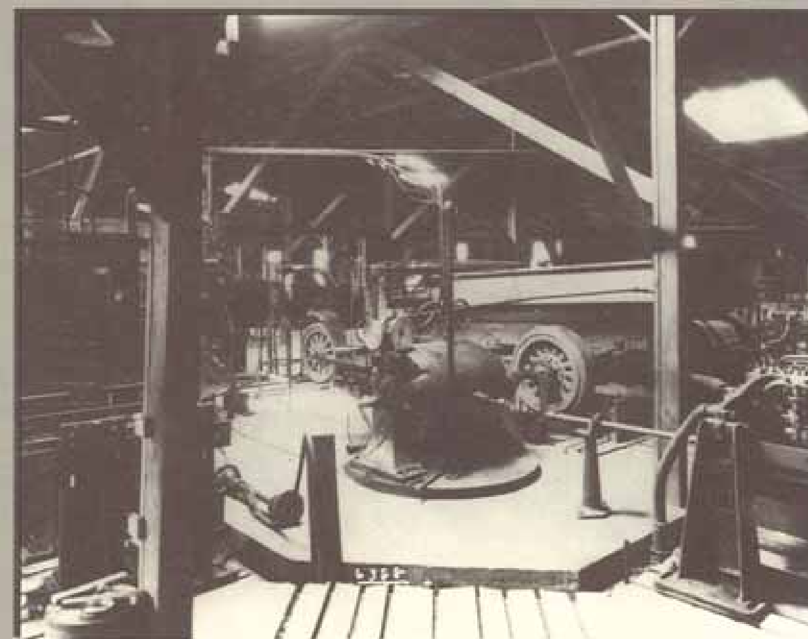


During World War I, over one thousand U.S. Army ordnance officers were trained in the new field of automotive engine mechanics by the Department.

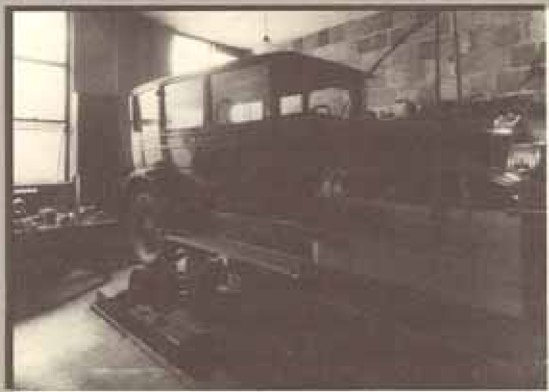
Mounted on a Chevrolet chassis, the "Blue Bird" served as one of the university's first test vehicles. Its exotic design helped to determine air resistance to motion in land vehicles, and to explore the effect of changes in vehicle shape. In the days before strain gauges, Lay suspended the shell of the "Blue Bird" on an assembly of scales to measure wind resistance while driving.

An annex to the first Automotive Laboratory at the University was added in 1928, when no other space was available for the growing program. As Prof. Jay Bolt recounts, conditions in this annex were bad. "...when it rained, water would drip through the roof for days afterward, and in the winter, snow melt would come through. Experiments often had to be covered to protect equipment and instruments."

In spite of its appearance the lab was a very useful facility. The equipment and instrumentation were well designed and state-of-the-art. The tar paper annex provided much needed laboratory space and kept unavoidable fumes and noise from the rest of the engineering building.



This large dynamometer was mounted on a turntable to provide access to several engines and projects. Dynamometers were rare and valuable research tools, always in high demand at this facility. Other "dynos" were set on rails and rolled from one test stand to another to ease the assembling of experiments and to allow for more test engines.



This early version of a chassis dynamometer permitted operation of a complete automobile at various loads and speeds. The experiment shown was an investigation of automobile noises produced during operation.

Automotive research continued at the Engineering Annex until 1956 when it was moved to North Campus to make room for a new undergraduate library. The new facility, the Walter E. Lay Automotive Laboratory, was so named by Lay's former students and assistants to honor their mentor and friend.

This mobile laboratory was donated to the automotive research laboratory in 1959 by the International Nickel Corporation.

The W.E. Lay Automotive Laboratory provides 20 engine test cells, a 5-bay vehicle laboratory, machine shops, instructional and computer labs, and offices. Student vehicle projects built here have taken high honors in competition.

1940-1970 Entering the Modern Era

University Catalogue, 1952
Mechanical Engineering:

"...all aspects of the mechanics of equipment and processes used in the rapidly developing technical era in which we live. Mech. engineers play a major role in the national space program, in the design of both conventional and nuclear power plants, in the automotive field, in heating and air conditioning, refrigeration and cryogenics ... automation, fluid machinery, production and processing machinery and consumer goods and appliances."

The three decades following World War II brought some remarkable changes to the Department reflecting changes in the worlds of science and industry. During this era, the space race began, new technologies were developing in industry, and the Cold War demanded advanced military systems. Both government and business turned to universities for expertise in meeting these challenges. For the first time, funded research projects sponsored by the National Aeronautics and Space Association (NASA), the National Science Foundation (NSF), the Department of Defense, and industry became an important focus of Department activity. The graduate program expanded dramatically as a result and undergraduate education began to incorporate new technologies and methodologies. The Department took a lead within the College in responding to these changes, creating a modern curriculum and building a research-oriented faculty.

Restructuring

Although the Department had split and merged with various engineering programs over the years, in 1956 it experienced one of its most important changes. Industrial engineering was becoming too large and prominent an area to remain as a subset within Mechanical Engineering. The first solution was to elevate it to department status within Mechanical, and the Department was renamed Industrial and Mechanical Engineering. Two years later, however, the industrial engineering component split off to become a separate entity. The faculty within that group was split, some going to the new department, called Industrial and Operations Engineering, and some staying in Mechanical as the Production Engineering group.

DEGREES CONFERRED

...about 118 per year.
A total of 3538 undergraduate degrees were conferred by the Department during this 30-year period.

Investigations of the dynamic stresses that aircraft landing gear are subjected to were conducted for the growing aircraft industry in 1952. A significant increase in sponsored research characterized this period of the Department's history.

Another change during this time was the establishment of the U-M Dearborn Campus in the late fifties. ME faculty, including Raymond Pearson, Axel Marin, Howard Colby and Gordon Van Wylen, were instrumental in the creation of the ME program at the new school.

Another program that came to life with the help of ME faculty was the Bioengineering Program in the College of Engineering. ME Professor Glenn Edmonson was its founding father, establishing the group and arranging for the original funding. The Bioengineering Program continues today as one of the strongest multidisciplinary programs in the College.

Research

The new emphasis on research during this era was felt in both traditional areas of mechanical engineering such as automotive and production engineering and newly emerging technologies such as space, nuclear, and automation engineering. Along traditional lines, one of the first ME faculty to be heavily involved with basic research was Professor Edward Vincent who investigated heat transfer in gas turbine rotor disks and wrote *Gas Turbines*—a first-of-its-kind book that brought Vincent international distinction. The production engineering group carried out major world-recognized research on surface roughness measurement and the machinability of exotic materials as requested by the War Production Board during World War II. In this group were Orlan W. Boston, Robert Caddell, Lester Colwell, Joseph Datsko, William Gilbert, and Kenneth Ludema.

Other important research included the Orthetics Research Project in the School of Medicine to develop assistive devices for the upper limbs of disabled persons. ME researchers on this project included Raymond Pearson, Robert Juvinall, Rune Evaldson, and Robert Hess. The project was sponsored by the Department of Vocational Rehabilitation and NSF at $100,000 per year. One of the first environmental impact studies having to do with control of exhaust emissions of power plants was carried out by Professor Clay Porter in cooperation with civil engineering faculty.

Research exploring newly emerging technologies started receiving strong support in the Department during Gordon Van Wylen's tenure as chair. He was the first to pursue money for basic research from government when he went to the Army Ballistic Missile Center (a precursor to NASA) in Huntsville, Alabama, and obtained funding for the project "Discharge of Cryogenic Liquids from Tanks." Throughout the sixties, faculty members Wen-Jei Yang, Herman Merte, Vedat Arpaci, and John A. Clark worked on it and other space projects that had impact on the design of the Saturn launch vehicle in the U.S. space program. Nuclear power related research was carried out in the sixties on projects funded by the government. Two examples were Frederick G. Hammitt's work on cavitation in liquid metal used in breeder reactors and Edward Lady's doctoral research on boiling at low heat flux. In another newly emerging technology,

The Willow Run Laboratories provided research opportunities for studies in aerodynamics, engine research, and aviation electronics. This supersonic wind tunnel, capable of generating streams of up to 3,000 mph., was used to study fluid flow and heat transfer behavior of sudden pressure shock waves and the flow of gases behind them. Such studies enabled researchers to explore the effects that breaking the "sound barrier" would have on vehicle design.

Professor Lester Colwell did pioneering work on numerical control of machines. The total contract research conducted in ME labs throughout the sixties was estimated at $1,100,000. The publications of the faculty from their research and teaching in these laboratories numbered about eighty, including three textbooks.

Curriculum

As research activities expanded, so did the graduate program. In the first seven decades of the Department's existence, it had conferred only twenty-one Ph.D. degrees. From 1940-1970 that number soared to 151. In line with these changes, the Department began to actively recruit faculty members with doctorate degrees.

In 1958, graduates and undergraduates in the Department received a first taste of a technology that would one day revolutionize engineering education and research. Several faculty members were released from teaching duties to participate in the Ford Foundation sponsored "Project on the Use of Computers in Engineering Education." They learned about the University's mainframe computer and how it could be used in teaching and research. Faculty began to assign key punch computer problems in classes.

In 1961 to keep pace with all of these changes, the undergraduate program was completely revamped. Chairman Gordon Van Wylen described the reorganized curriculum in the 1961 departmental annual report. "A complete reorganization of the undergraduate laboratories has been effected. Each of the undergraduate laboratories will be made an integral part of one of the classroom courses and both will be handled by the same faculty member. It is anticipated that this will make the lab work a more significant educational experience for the student and that the theoretical and experimental aspects of engineering will be more effectively related to each other. (The six courses with labs are fluid mechanics, dynamics, engineering materials, manufacturing processes, thermodynamics, and heat transfer)." This new educational approach was copied in the following years by many universities across the country.

Facilities

By the early fifties it was apparent that the old engineering buildings were no longer adequate for the level of research activity and the growth in the educational programs. ME chairmen complained that their classrooms and laboratory space in the East and West Engineering Buildings were woefully inadequate.

Some relief was provided by a partial move to new buildings on the North Campus. In 1956 the automotive laboratory was completed and occupied. The State had provided the construction costs of $1,850,000, and Michigan industries added $500,000 for equipment (including facilities for testing fifteen engines at a time). Steelcase had donated the furniture, and International Nickel Company donated a mobile laboratory. In 1958-1959, researchers in thermodynamics, heat transfer, and fluid mechanics moved to new laboratory facilities in the G.G. Brown Building on North Campus.

Researchers and students in ME also began to have access to extensive on-campus computing facilities. In 1953, the Michigan Digital Automatic Computer (MIDAC)was designed and built at the Willow Run Research Center. It was one of only twenty high-speed electronic digital computers in the country—the second in the Midwest It was said to be "some 20,000 times faster than a professional mathematician using a desk calculator,"* and in 1959, the Board of Regents authorized establishment of the U-M Computing Center on North Campus with powerful mainframe computers and a terminal system known as the MTS or Michigan Terminal System.

Time-sharing computer terminals were introduced during this era. Although they were relatively slow and difficult to use, they were an improvement over previous computing methods. These stations were used until the Computer Aided Engineering Network brought personal computers directly to offices and laboratories in the 1980s.

Centennial Year

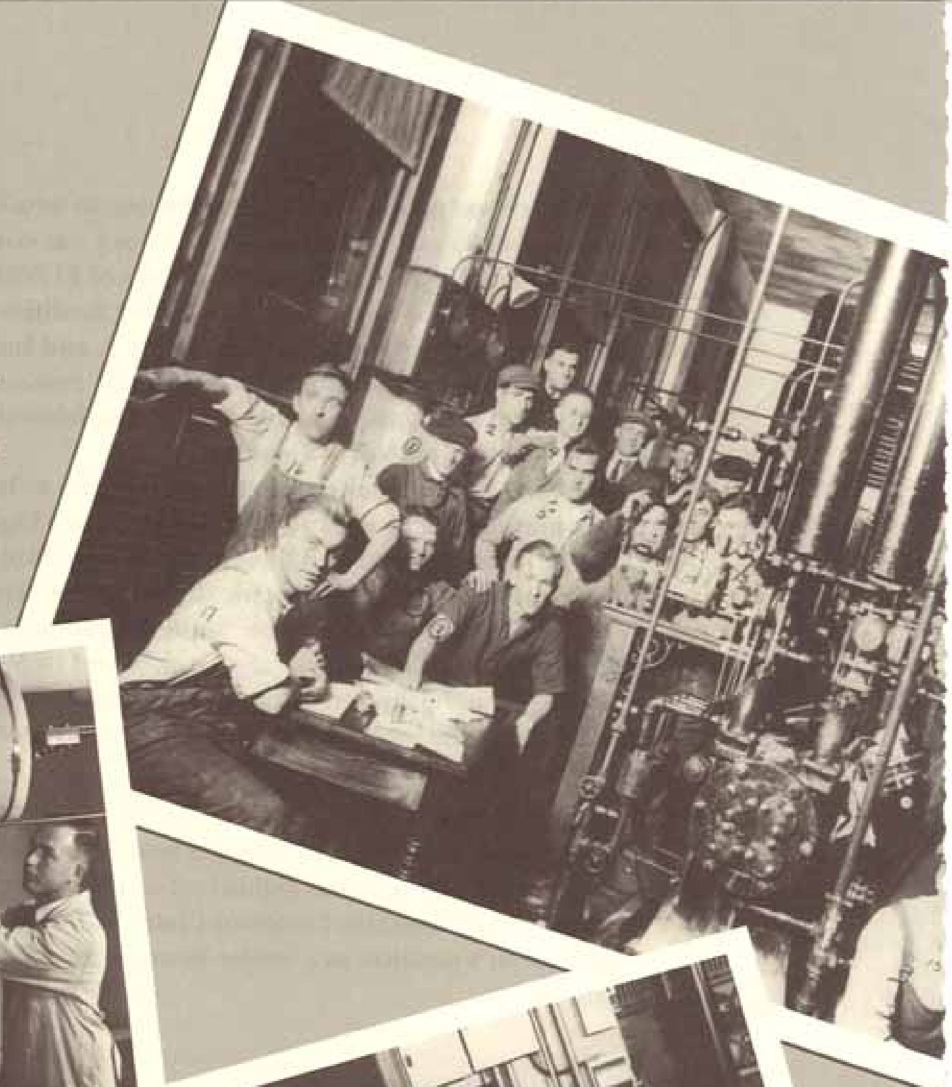
In October of 1968 the Department hosted a two-day Centennial celebration. A report on the activities was published in 1973 in both soft and hard covered versions edited by Assistant Professor Charles M. Vest. The report documented the Department's position as a leader in modern engineering education and research.

*(TechniUM + No. 18, June 1980)

The Mechanical Engineering Department provided significant support for the nation's defense efforts during the Cold War. From biomechanical studies for cockpit design to detonation combustion, researchers worked on a variety of military contracts at the Ann Arbor and Willow Run laboratories. This M47 tank was used to study tracked vehicle drive assemblies and suspension systems. Work was also done on servomechanisms and exotic propulsion systems.

The **MICHIGAN** Experience

Michigan was the first university west of the Alleghenies to offer a degree in engineering, and from the very beginning, Michigan engineers developed a reputation for a hard-nosed, no-nonsense approach to their work. Many students came long distances to study here, bringing little more than exceptional talent and the fierce determination to succeed. Then, as now, students expected the best education they could get, and MICHIGAN has always lived up to their expectations.








1970-1993 Leadership in High-Technology

Undergraduate Brochure 1990
Mechanical Engineering:

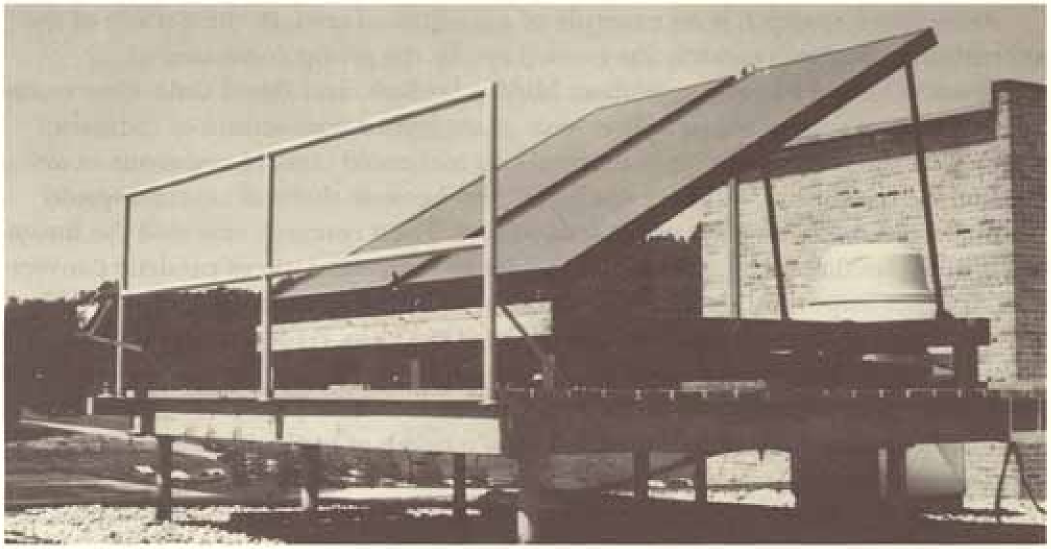
"Mechanical Engineers are involved in research and development, design, testing, manufacturing, plant operations, marketing and sales, consulting and management. Their knowledge and skills are essential to nearly every industry, including manufacturing, transportation, energy, and aerospace. They use computers to model physical systems and work on problems as diverse as automating a parts assembly process, determining fuel properties for spacecraft engines, and specifying the load characteristics of a prothesis."

When the Mechanical Engineering Department first began 125 years ago, an engineer needed to prepare for a career in railroading, surveying, shipbuilding, or manufacturing. In every era since then, the role of the mechanical engineer has evolved and expanded to include new industries and fields including automotive engineering, hydraulics, cryogenics, space technology, and nuclear power. The last twenty-five years have been no exception as the field has expanded into new areas of high technology including lasers, solar energy, automated control, acoustic emission, composite materials, and flexible manufacturing. In addition, many of the activities of the mechanical engineer have been transformed by easy access to one of the most influential developments of any era—the computer, which over the last ten years has come to permeate the everyday world of business and industry. Computers have also made it possible to explore many problems in traditional research areas that were previously inaccessible.

In response to these developments, the Department has also undergone significant change: sponsored research and graduate programs have grown rapidly; researchers have expanded beyond the university to create high-tech businesses arising from their studies; the long-awaited move to North Campus has been completed; the entire College of Engineering has been computerized; and the Department has gained strength through its merger in 1979 with the Applied Mechanics Department, acquiring the new name Mechanical Engineering and Applied Mechanics (MEAM).

DEGREES CONFERRED

...about 168 per year.
A total of 3695 undergraduate degrees were conferred by the Department during this 23-year period ·



Professor John Clark's investigation of solar energy is an example of an ongoing commitment to new fields of scientific inquiry that characterizes research in the Department of Mechanical Engineering and Applied Mechanics. Pictured here is one of two large solar arrays used in Clark's research that were mounted on the roof of the G.G. Brown Building. These panels absorbed heat directly and used a circulating liquid as a transport medium.

Research

The research focus that began in the previous thirty years came into its own in this era as total research expenditures climbed from about $500,000 a year in the early 1970s to nearly $7 million a year in 1993. This emphasis not only increased engineering knowledge but also enriched the educational experience of MEAM students. Researchers pursued interests in many areas of high-technology as well as in traditional areas.

Professor John A. Clark's work in the area of solar energy, which included two senior/graduate level courses, is an example of research in a new technological field. The energy crisis of the mid-seventies sparked a search for alternative energy sources, and solar energy was considered one of the most promising. Professor Clark established the Department's Solar Energy Laboratory in 1973. It was the chief source of technical advice and research for all the solar companies in Michigan from 1973-1985. The lab carried out research on solar collection and storage devices including concentrating collectors, wind-energy systems, photo-voltaic conversion devices, thermal recovery devices on furnaces tied into solar devices (heat grabber), and the boiling collector with refrigerant instead of water or air—the most efficient type of solar collector. Clark carried his activities into the private sector as the technical director of Star Pak Energy Systems Company, which developed and marketed the devices conceptualized in the UM solar lab. Star Pak devices were in turn described and analyzed by students in the lab using sophisticated computer modeling. This close relationship continued until the early 1980s when interest in solar energy declined and with it the solar industry in Michigan. Clark continued his interest in the field with projects in the areas of modeling the terrestrial solar flux on arbitrarily oriented surfaces, the technical and economic modeling of complete solar thermal, and energy conservation systems.

Over 2000 workstations are linked in one of the largest integrated, multi-vendor networks in the academic world, the Computer-Aided Engineering Network (CAEN). In addition to those in offices and research laboratories, seventeen CAEN labs are available to Mechanical Engineering students and faculty, twenty-four hours a day.

Automotive research is an example of a traditional area. In the decade of the seventies, important research was carried out by the group consisting of Professors Donald Patterson, William Mirsky, Jay Bolt, and David Cole. One example is a project supported by a three-year grant from a consortium of industrial firms. The purpose was to see if thermal reactors could control emissions as well as catalytic converters. Industry was interested because thermal reactors would have allowed the continued use of leaded fuel. Their research revealed the limitations of thermal reactors, paving the way for the universal use of catalytic converters. Another important development was the establishment in 1978 of the Office for the Study of Automotive Transportation (OSAT) by Professor David Cole. OSAT is the only on-going university-based group in the country that has focused on a study of the automotive industry. The fifteen-member staff has examined the auto industry from every angle, researching a range of topics from industry competitiveness and labor relations to forecasts of technical and market trends.

Automotive faculty were some of the first to carry their technology beyond the university in establishing private companies. Professors Cole, Mirsky, Patterson, and Weber (Civil) founded MI Automotive Research company for testing automotive engines and products. This firm spawned another small company, Engine Test Instrumentation, Inc., and later the group founded QED Environmental Systems to manufacture a pump design they invented for obtaining water samples around dump sites. These three firms combine to employ 150 people in the Ann Arbor area.

Other important research of the last 25 years includes work by professors James Barber (thermoelastic effects in contact mechanics and tribology), Samuel Clark (adhesion and reliability of flexible composites), Maria Comninou(crack closure and contact at interfaces), Elijah Kannatey-Asibu, Jr.(acoustic emissions), Kenneth Ludema (rheology and tribology), Christophe Pierre(the phenomena of vibration and wave localization in spatially repetitive structures with imperfections), Albert Schultz and James Ashton-Miller (biomechanics of mobility impairments in the elderly), Richard Scott (optimization of layered composite media, vibration and wave propagation in rotating elastic structures), George Springer (structure of rarefied rocket plasma), Alan Wineman (mechanical response of rubber and polymers under conditions of large deformations), S.M. Wu (dimensional measurement in manufacturing), and Wen-Jei Yang (thermal fluid phenomena in biological, anatomical and physical systems).

Detailed reports on other significant Departmental research from the last 25 years can be found on pages 50-67.

Facilities

In 1984, the ME department left the East and West Engineering Buildings on Main Campus, its home of eighty years, to take up residence in new laboratories, offices, and classrooms on the North Campus, completing the move begun in the fifties. For the first time in thirty years the Department was consolidated at one location.

Laboratory facilities within the North Campus buildings were upgraded to an unprecedented degree during this era thanks to increased research funding. The Department now supports advanced laboratories with state-of-the art computing and experimental equipment for research in the areas of automotive/combustion; biomechanics; computational mechanics; computational design; design prototyping; dynamics; computational fluid mechanics; cavitation and multiphase flow; transport, reaction and phase change in porous media; variable gravity heat transfer; optical and mechanical coordinate measuring machines in manufacturing; precision machining; tribology; welding; machine tool sensing and control; mobile robotics; and ceramic composites.

Time-sharing was the principal method of computing employed by both faculty and students until the eighties with the advent of the personal computer (PC) revolution. That revolution was brought to the College of Engineering in 1983 with the establishment of the Computer-Aided Engineering Network (CAEN). Today, CAEN operates one of the largest integrated, multi-vendor workstation networks in the academic world. Over 2000 workstations and microcomputers are distributed in faculty and graduate offices and in research and teaching laboratories throughout the College. Several distributed file systems provide over 150 gigabytes of centrally administered file storage that can be reached by any computer on the network. The system is recognized as a model distributed computing environment for engineering and computer science instruction and research.

Curriculum

An undergraduate curriculum review committee was appointed in the spring of 1992 by the new Department Chair, Panos Papalambros. The committee was charged with making a thorough review of the current curriculum and proposing necessary changes.

Issues related to electric-powered cars as well as automotive electronics, engine performance, and thermodynamics were investigated by Prof. Gene Smith.

Investigations into the improvement of power engineering have been carried out in the Department of Mechanical Engineering and Applied Mechanics since 1868. This study by Prof. Herman Merte Jr. investigated boiling behavior at a plate/tube interface. This behavior is a regular source of stress fracture of tubing inside nuclear steam generator vessels.

The review committee gathered informal input from the faculty and students, examined the curriculum at other engineering schools, and conducted two formal surveys of the alumni from the classes of '87, '82, and '72. Both surveys showed that generally the Department does well in preparing students in the engineering sciences, but less well in the nontechnical aspects of engineering. The alumni, in particular, stressed the need for a stronger communication component.

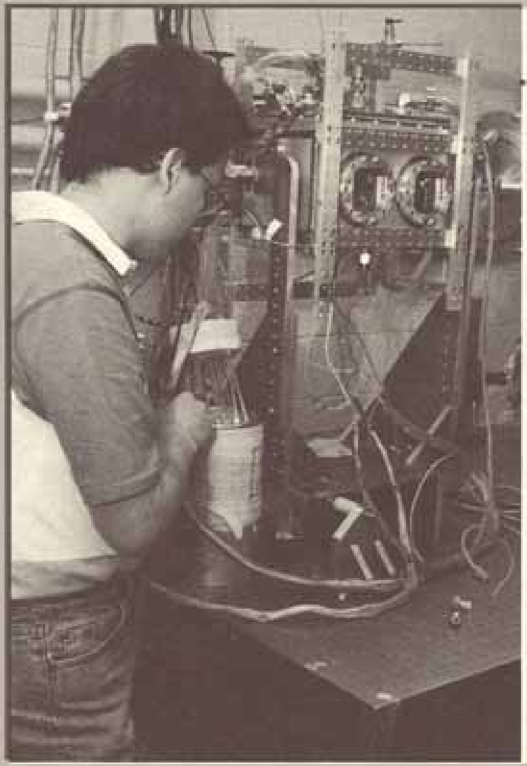
In the spring of 1993, the Committee presented to the faculty a preliminary proposal for curriculum revisions, which was given general approval. It maintained the curriculum's strong core in engineering science but also put much more emphasis on hands-on experience, creative problem solving, and communications and teamwork. Although a number of details still had to be worked out, two major changes were in progress by the fall of that year.

The first was a major reorganization of the required laboratories. Instead of single credit laboratory modules attached to a number of introductory courses, these laboratories were consolidated into two courses—a thermal/fluid laboratory already developed and a mechanical sciences laboratory course under development. In these labs, students will learn how to design, conduct, and interpret experiments. Eventually these courses will be merged into junior and senior laboratory classes, which will include a strong technical communications requirement focusing on presentations and technical report writing.

The second change was the establishment of a sophomore level class in design and manufacturing to include computer-aided design and actual hands-on experience in a machine shop. This early introduction to actually making things will allow the subsequent junior and senior design courses to put more emphasis on the completion of working prototypes. The junior and senior courses will also include life-cycle issues, such as environmental impact and disposal after useful life.

To support the work in these courses, plans have been made for a major renovation of the student machine shop. Floor space and staffing will be at least doubled, hours of operation will be expanded to evenings and weekends, and the inventory of machines will be increased by eighty percent.

Selected Research 1968-1993



Research has come to play an ever increasing role in the Department's activities over the last twenty-five years. A selection of some of the most influential studies from that era is featured in this section.

The Nuts and Bolts of Collecting Data

One of the most interesting changes that has taken place in the Department over the years is in the apparatus used for collecting data. For a long time, researchers had to rely on their ability to directly observe phenomena, measure them with simple meters and scales, and quickly log their findings in journals. The dedication of scientists working under these conditions is legendary.

As technology advanced the opportunity for creating more sophisticated data-gathering equipment presented itself. With that opportunity came a myriad of challenges including overcoming the weight and bulkiness of equipment and increasing the sensitivity of apparatus. Over the years, scientists at the University of Michigan and the Department of Mechanical Engineering have come up with some creative approaches to data gathering and analysis.

The Sanborn Recorder was a significant improvement in acquiring research data in the late 1940s. Its analogue trace, on heat sensitive paper, permitted continuous monitoring of relatively high-frequency strain gauge outputs in this machine research project.

Video technology was difficult to apply to vibrational dynamics research in 1959, but offered great promise.

Strange looking university research vehicles, like this mobile microwave laboratory of 1960, have been a common sight on the roads around Ann Arbor for over 60 years. From Walter Lay's "Blue Bird" (p. 21) to "Maize-n-Blue" (p. 68), Mechanical Engineering has always pursued innovative approaches to education and scientific inquiry.

Before miniaturization, electronic data-gathering components could be a logistical challenge in themselves, as suggested by this cart assembled by electrical engineers in 1958.

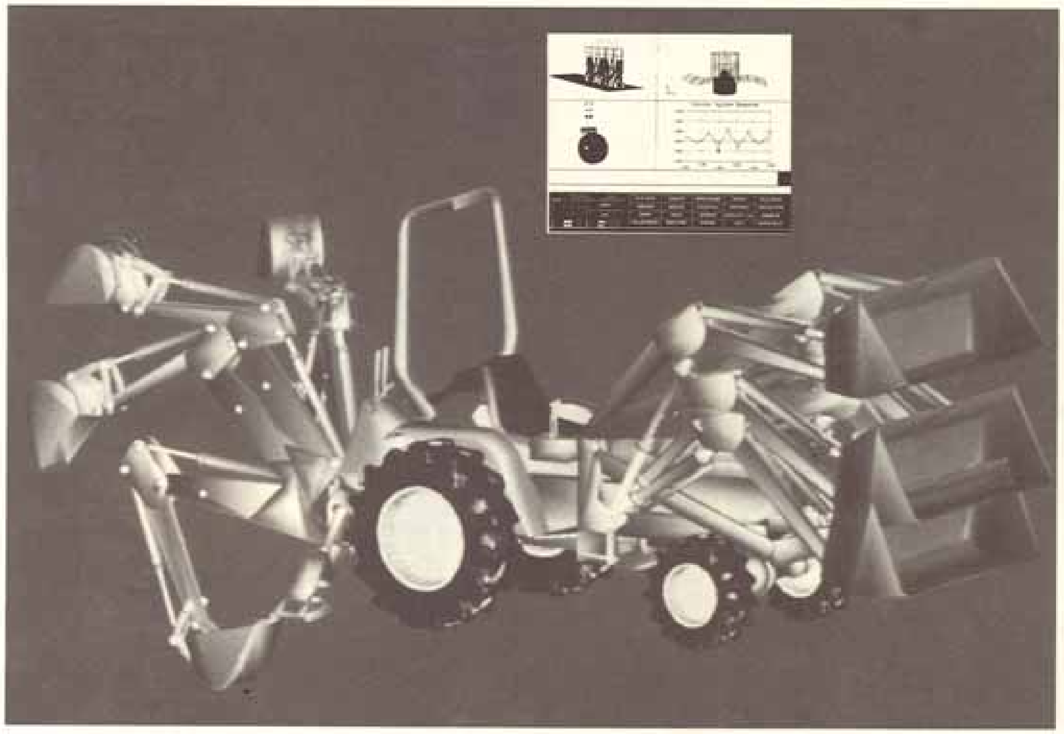
Stroboscopic photography revolutionized the study of motion and process. In this 1951 study, a researcher is using a strobe light to analyze the machining characteristics of woodcutting.

From slide rules to supercomputers, devices for scientific calculation have gone though amazing changes in the last 125 years. This researcher is using a Monroe Calculator in his examination of heat exchanger coils.

This optical pyrometer (ca. 1954) enabled a production engineering researcher to measure temperature in this induction furnace. The device utilized the human eye to compare a heating element to visible, radiating color. Before the advances in electronic imaging technology of the 1980s, many devices tried to assist natural vision in making measurable observations.

Computer-Aided Engineering and the Technology of Mechanical Dynamic System Analysis

As a graduate student and then a professor in the Mechanical Engineering Department in the sixties, seventies, and early eighties Milton Chace carried out pioneering research in the area of computer-aided engineering and the technology of mechanical dynamic system analysis (MSA technology). In 1977 Chace and his colleagues Mike Korybalski and John Angell formed a company in Ann Arbor called Mechanical Dynamics, Incorporated (MDI) to provide MSA software to Fortune 500 companies designing new mechanical products. Chace left the University in 1983 to pursue his business interests full time. MDI has been a highly successful example of technology transfer. The company has grown steadily, has several thousand clients worldwide, and has won awards for product excellence and export success.



Mechanical dynamic system analysis permits a wide range of mechanical simulations to be performed using a computerized model. This enables engineers to explore many types of mechanisms without expensive prototypes.

The ideas that led to MDI were first formulated by Chace as a graduate student in the 1960s. Chace saw that problems in mechanism design could be reduced to a clearer level of simplicity, using classical vector calculus. He found that the prediction, and simulation, of motion of planar mechanisms could be based on the solution of simple vector loop equations. He found also that there was a wonderful extension to three-dimensional mechanisms, most of which could be represented by a limited set of four-sided spatial vector loops, which he termed "vector tetrahedrons." Chace's categorization of these equations was amenable to being structured for solution by digital computer.

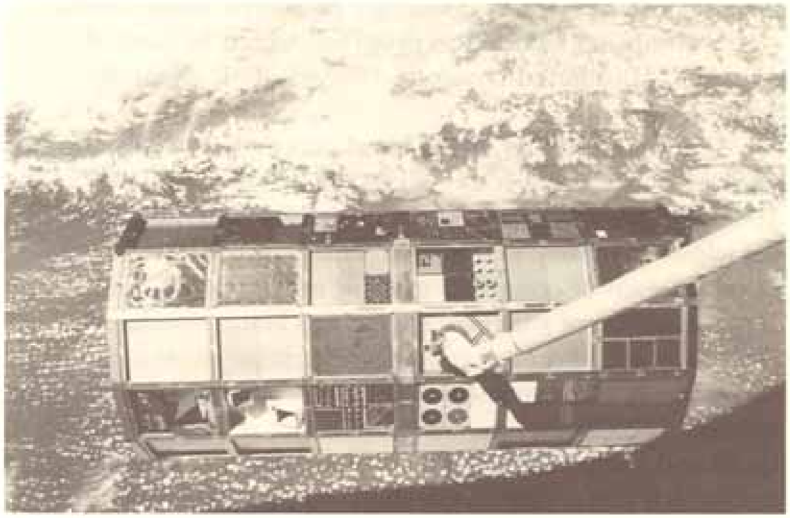
After receiving his Ph.D., Chace worked for IBM for two years and then returned to the Mechanical Engineering Department as a faculty member in 1967 to continue his research. Chace's work at IBM had shown him that comparatively few applications were ideally kinematic; most were multifreedom-dynamic involving practical effects such as impact, motor torque-speed characteristics, elasticity, etc. Different solution procedures than those used for kinematics would therefore be required.

Problems in multifreedom, large displacement, rigid-body dynamics are, in general, represented mathematically by simultaneous, nonlinear, ordinary differential equations. Applied mathematicians had long before shown that these could be solved by a stepwise process termed numerical integration. Also, by a technique of Lagrange multipliers, the constraint vector loops characteristic of kinematics could be included in the same formulation required for the dynamics conditions.

Using these methods, Chace's initial research team, which included Don Smith, Mike Korybalski, Allan Rubens, and John Angell, first developed a two-dimensional program named DRAM (Dynamic Response of Articulated Machinery), completed in 1969. It included a computer language that provided automated development of the correct differential equation set for whatever problem was modeled by the user, thus increasing practical utility and eliminating the number of errors per problem that occur with user-developed equations. Later, Ph.D. student Nicholae Orlandea succeeded in creating a prototype three-dimensional computer simulation program, which he named ADAMS (Automated Dynamic Analysis of Mechanical Systems).

MDI was launched in 1977 and proceeded to develop successively more advanced versions of DRAM and ADAMS. By 1981 ADAMS was able to simulate fully detailed highway vehicles in dynamic maneuvers. The company also developed a means of computer graphic output of a schematic representation of whatever system was being simulated. Engineers could now reasonably determine most of the performance of a contemplated mechanical system design without having to devote the time and expense to physically build and test it. They could also investigate design alternatives much more thoroughly than with testing alone. This significantly enabled industry efforts toward concurrent and simultaneous design, especially in the highly competitive automotive industry. MDI is now the world's largest developer and supplier of mechanical systems simulation software with clients in over 30 countries.

High-Toughness / High-Performance Composite Materials



After five years, the Long-Duration Exposure Facility (LDEF) was retrieved from orbit. The specimens aboard the facility, including Prof. Felbeck's, were exposed to the rigors of spaceflight longer than any other terrestrial material.

In the late 1960s and early 1970s Anthony G. Atkins, then a visiting Associate Professor and David K. Felbeck, Professor, conducted a research and development program that led to graphite-epoxy composite materials of improved properties. Prior to that time, very high strength had been achieved in these materials, but at the price of very low toughness. Such brittle materials therefore had somewhat restricted applications as engineering materials. Under NASA sponsorship, Felbeck and Atkins applied basic knowledge regarding the origins of toughness in materials to this class of potentially very useful composites. With very high strength and stiffness (elastic modulus), such materials would be highly desirable for applications to space vehicles if their toughness could be improved.

Early research by Atkins and Felbeck, on boron-epoxy composites, demonstrated that by applying a coating of low-strength resin to a fraction of the surface of boron fibers, the resultant composite would have increased toughness. When applied to pre-preg layers of commercial graphite-epoxy, the procedure consists of adding very thin layers of Mylar between the layers of pre-preg. The Mylar layers contain a matrix of fine punched holes, so that when cured, adjacent pre-preg layers of composite would bond over a fraction of the total interfacial area. Using these procedures, Felbeck and Atkins demonstrated that high-performance composites could be produced with about six times the fracture toughness of ordinary composites, while experiencing reductions of strength and elasticity of less than about 10%.

Working with Atkins and Felbeck during this period were Ph.D. students Roger Heimbuch (who later received the first Departmental Distinguished Alumnus Award), Theodore U. Marston, and Li-Chung Jea.

When NASA first proposed in the early 1980s a one-year recoverable orbiting satellite for scientific experiments, Felbeck submitted a proposal, subsequently funded, to fly selected samples of toughened graphite-epoxy composite materials in order to learn whether detrimental changes would occur as a consequence of space exposure in near-earth orbit.

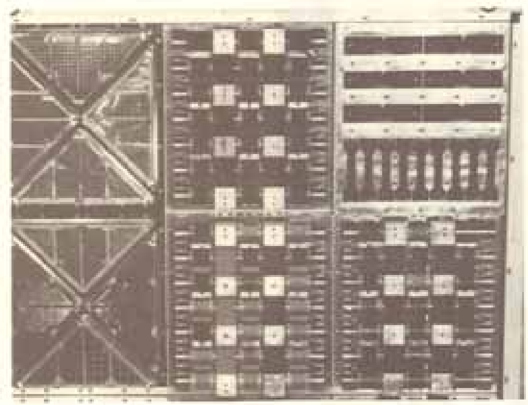
Felbeck's experiment consisted of one set of tensile specimens of toughened graphite-epoxy composite material with a range of cross-ply angles and a fraction of interlaminar contact, as well as a set of toughness specimens with the same set of variables. To isolate the effect of time after manufacture of the specimens, two identical ground control sets of specimens were produced in addition to the flight specimens, one set to be tested at the approximate time of launch and one set to be tested following recovery. The experimental frame was designed and fabricated by William H. Durrant; specimens were manufactured by Stephen B. Culp; and both men participated in the specimen test program.

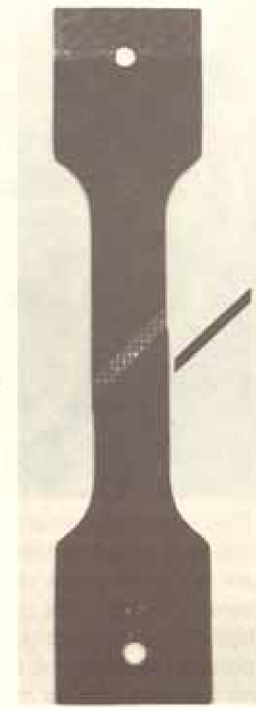
The samples were prepared to be contained aboard the Long Duration Exposure Facility (LDEF), an eleven-ton cylindrical frame 10 m long, containing on its outer surface fifty-seven experiments prepared by researchers in government, private industry, universities, and eight foreign countries.

LDEF was launched in April 1984 on board the space shuttle Challenger. The initial deployment was at an altitude of 481 km in an orbital plane approximately five degrees from the ecliptic. All experiments were intended for subsequent recovery so no data were transmitted during the orbiting period.

Recovery was originally planned for a year later but was first delayed by scheduling and launching problems. Then, before recovery could take place, the Challenger shuttle blew up during launch, halting all shuttle launches for several years. Recovery of LDEF was for some time considered a low priority by NASA until unanticipated large solar activity during 1989, which caused expansion of the atmosphere with consequent rapidly increasing loss of altitude by LDEF. With a fiery re-entry estimated to occur in February or March 1990, LDEF was recovered by the space shuttle Columbia in January 1990 at an altitude of 33 km.

Although only a limited number of specimens was feasible, the results of this 5.8 year orbiting experiment show that the toughened graphite-epoxy composite, if properly coated for protection from atomic-oxygen erosion, is sufficiently durable for use during near-earth space missions of the order of at least five years.





Prof. Felbeck's graphite-epoxy composite specimens (above, at upper right) were only supposed to be in orbit for a year. When the LDEF was finally retrieved, the specimens proved that the material is sufficiently durable to handle near-earth missions for relatively long periods of time. (At right is a close-up view of one of the tensile specimens.)

Holographic Interferometry and Computed Tomography

by David Watt

The pattern of light and dark fringes in this digitally processed interferogram allows researchers to examine flow characteristics of a transparent fluid jet. The lighter areas represent the highest wavelength distortion due to maximum density. Holographic Interferometry provides a nonintrusive tool for measuring density, and even chemical gradients, within transparent media.

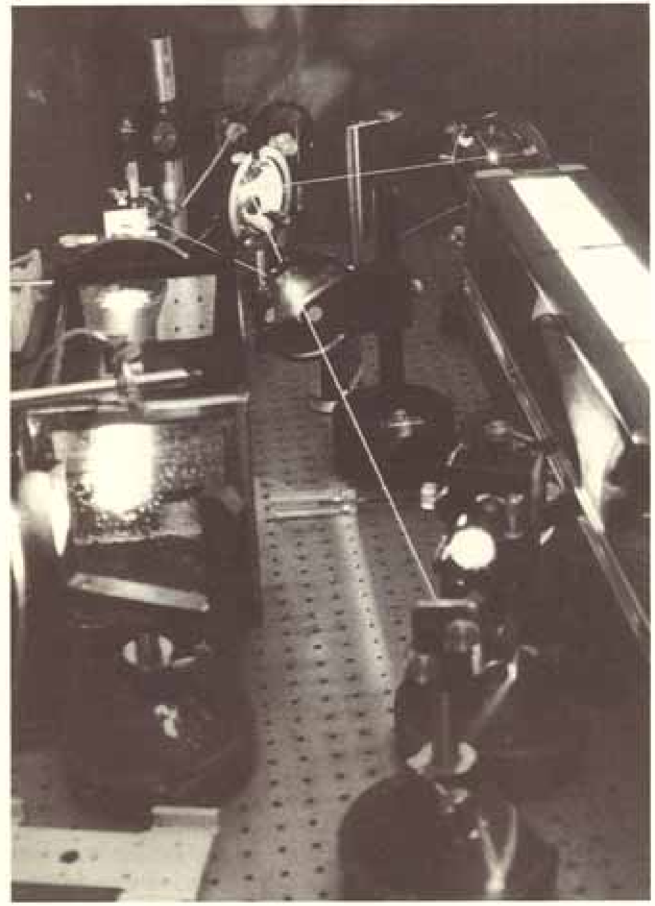
In the 1970s, Professor Charles Vest was carrying out research in the area of experimental and theoretical convection heat transfer, and although he continued to direct research in this area, his best known work concerned the use of holographic interferometry and computed tomography. This work followed closely on the development of the laser and the discovery of laser holography.

Holographic interferometry is based on the interference between two holographic images of an object. When the object has been altered, for instance by the presence of a crack, the resulting image is overlain with a striking pattern of bright and dark fringes. These fringes can be interpreted to identify qualitatively the nature of the modification of the object, or they may be used to obtain quantitative measurements. The advantages of holographic techniques over conventional methods are that they do not require contact with the object and that measurements at a large number of points on the object can be obtained from a single image.

Vest's group did a great deal of work on both the development of this technique (especially on the interpretation of interferograms and the application of digital and electronic augmentation techniques) and the practical applications of it, studying fields as varied as microcrack formation, flow in stratified media, natural convection heat transfer, nondestructive testing, and the formation of spots on animal coats. In 1979, Vest published a well-known book on the field of holographic interferometry and its applications.

The work on holographic measurement of temperature fields in natural convection heat transfer led directly to Professor Vest's work on computed tomography. In heat convection studies, an expanded beam of laser light is passed through a transparent fluid, and an interference fringe pattern is generated that contains information concerning the fluid's density. In the early 1970s, Vest and his students began to consider the experimental information available from multiple beams traversing the fluid in a variety of directions. They quickly realized that given an adequate number of viewing directions, three-dimensional measurements of the density could be obtained mathematically from interferometric measurements. The mathematical procedure for obtaining these measurements is called tomographic inversion and is similar to the procedure used to obtain medical images from CAT and MRI scanners.

The implications of this work were to provide a powerful imaging method that could be used to validate important predictions in combustion, aerodynamics, and heat transfer. Between 1970 and 1987, Vest and his students worked on the computational and experimental aspects of this problem. Experimental studies in convection heat transfer, transonic aerodynamics, and turbulent shear flows and a number of algorithmic studies were also carried out. The work of Vest, his students, and some of his contemporaries laid the groundwork for a number of studies currently being carried out using tomographic methods in combustion and hypersonic flow.

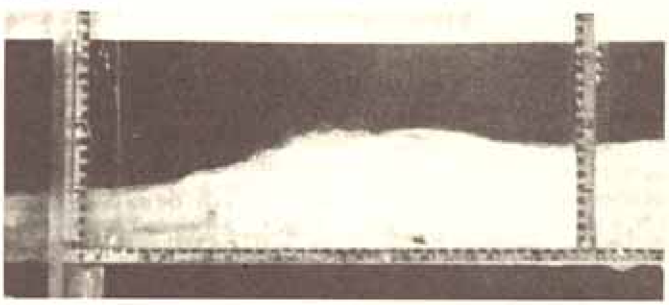


Using the set-up above, an interferogram (far left) is first obtained on a holographic plate. The gradient boundaries are too indistinct for direct measurement so the image is digitally processed into a more sharply defined image (preceding page). Processed images from several viewpoints give a measurable three-dimensional map of the transparent jet. A realistic visualization of the transparent turbulent jet (near left) can be achieved by further processing the gradient into an absolute phase image.

Chia-Shun Yih's Fluid Mechanics

Professor Chia-Shun Yih was the Stephen P. Timoshenko Distinguished University Professor in the Mechanical Engineering and Applied Mechanics Department from 1968 until his retirement in 1988. He is one of the most honored professors in the Department's history, a member of the U.S. National Academy of Engineering and of the Academica Sinica in China. His contributions form a significant segment of the literature on the mechanics of fluid flows. The following summary of his contributions was taken from the introduction to Yih's most recent book *Selected Papers*. The introduction was written by Yih's long-time friend and colleague C.C. Lin.

This photo shows the interfacial surge and almost horizontal free-surface between two fluids from Yih's work on hydraulic jump with C.R. Guha.



Chia-Shun Yih's contributions to the literature of fluid mechanics have been important and extensive. With his bountiful love for nature, it is not surprising that some of his most significant contributions deal with fluid flows that are ubiquitous in our environment. The field of stratified flows itself is rich in physical phenomena. This richness owes its origin to the interplay of the heterogeneity of the fluid medium and the gravitational field. This fact was noted by Yih in the preface to his book *Stratified Flows*, 1980, which first appeared in 1965 under the title *Dynamics of Nonhomogeneous Fluids*. This book, which is primarily based on Yih's original contributions to the field, has since become a classic reference for all serious students and researchers.

While much of Yih's success owes to his physical insight, it is perhaps equally true that he is always able to use precisely the right mathematical tool. For example, in the paper "Gravity waves in a stratified fluid," Yih made use of Sturm's second comparison theorem to obtain the result that the phase speed decreases as the wave number increases, in small-amplitude wave motion of a heterogeneous liquid with a free surface. He has also been very successful in introducing ingenious mathematical transformation of variables to enable certain general classes of difficult problems of wavy motions with finite amplitudes to be solved with relative simplicity.

For example, in his paper "A class of solutions for steady stratified flows," the use of a more general form of transformation of variables led Yih to an elegant theorem in three-dimensional shallow-water theory. The theorem states that "so long as the shallow water theory is valid, a class of steady stratified flow with a free surface originated from rest can be found corresponding to each irrotational steady free-surface flow of a homogeneous fluid originated from rest."

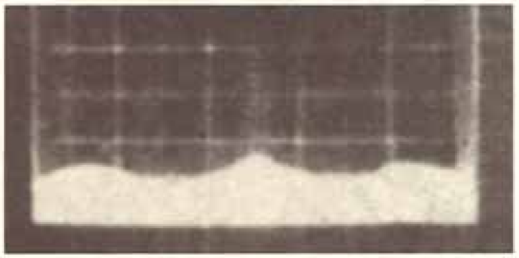
The subject of internal hydraulic jumps of great importance to environmental and hydraulic problems was first treated by Yih and Guha in 1955. That paper has been referred to in nearly every paper written on that subject since.

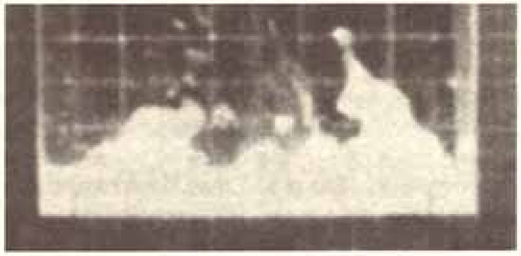
In the field of hydrodynamic stability, his investigations include results that are applicable generally and examinations of how specific fluid properties may affect the instability of the flows. His solutions to many stability problems involved the utilization of new techniques or adapting those in other contexts.

Yih has also worked on surface waves in fluids of homogeneous density. His papers on patterns of ship waves give two formulae in closed form from which the patterns can be determined simply, be they of gravity waves, gravity-capillary waves, or internal waves. From Yih's formulae, all the known results of Kelvin, Havelock, and others for all sorts of waves can be obtained readily, without the rather obscure reasoning initiated by Lord Kelvin. These formulae have brought the theory of ship waves within the reach of fourth-year undergraduates.

Yih's work on jets, plumes, and diffusion stems from his early work on convective plumes caused by a point source of heat. The similarity solutions for straight turbulent jets were well-known in the nineteen thirties. Guided by a dimensional analysis, Yih worked with Hunter Rouse in 1947-48 on the experimental determination of the velocity and temperature distributions in a round turbulent plume caused by a point source of heat. But it was not until 1977 that Yih was able to give the eddy viscosity an expression on dimensional arguments and thus to give analytical solutions for both round and plane turbulent plumes for certain turbulent Prandtl numbers. The eddy viscosity was assumed constant in any plane normal to the plume axis. Yih was able to apply that same sort of analysis to jets and plumes in a transverse wind. One interesting analytical result is the double-helix structure of jets and plumes in a transverse wind, which one can observe in a chimney plume on a windy day.

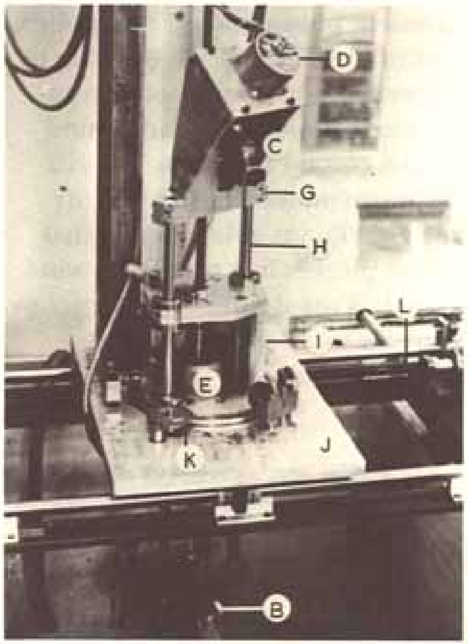
These two photos show the effect of acceleration on an unstable free-surface. The instability at top shows the free-surface at near g^0 and then a few milliseconds later. This study with S.P. Lin first appeared in 1964.

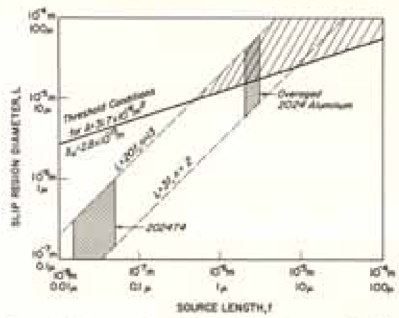




Ultrasonic Imaging and Acoustic Emission

by Professor Kenneth Ludema





The photograph at top (courtesy of C.J.H. Vanden Broek, 1980) shows a scanning apparatus for detecting acoustic emissions across a fluid-metal interface using narrow beam insonification. The graph shows the minimum slip region for a 2024 aluminum alloy. The heavy solid line shows the level at which detectable emissions occurred.

As a student of physics and later as a Professor of Mechanical Engineering at the University of Michigan, Julian Frederick was instrumental in the development of two of the most important technologies of our age: ultrasonic imaging and acoustic emission. He wrote a widely used text on these subject entitled *Ultrasonic Engineering*, and he was a founding member of the American Acoustic Society.

Frederick began his work in ultrasonics as a research associate in the Physics Department under the tutelage of Professor F. Firestone. Firestone's research team discovered the phenomenon of magnetostriction, which was the foundation for ultrasonic detection technology. During his tenure in Firestone's lab, Frederick helped to develop materials for magnetostriction and worked on high frequency electronic circuits for creating electromagnetic fields. He was also part of the team that developed the use of sound waves to detect cracks in metal, a technology that has expanded from those early beginnings to have widespread application in industry.

In 1957, Frederick left Firestone's laboratory to join the faculty of Mechanical Engineering. Over the next twenty-five years, he carried out research to develop and refine fundamental knowledge and applications in the field of ultrasonics. Some of his early studies were in the areas of manufacturing and medicine. For example, Frederick worked in collaboration with researchers in the University of Michigan Medical School to detect hard regions in heart muscle using ultrasonics. This was one of the first studies on ultrasonic detection in medical applications, a technology that has now become widespread.

In the early 1960s, Frederick began to investigate the fundamental causes of noise emission, turning his research toward the passive detection of sounds generated in solids. This activity has become known as acoustic emission.

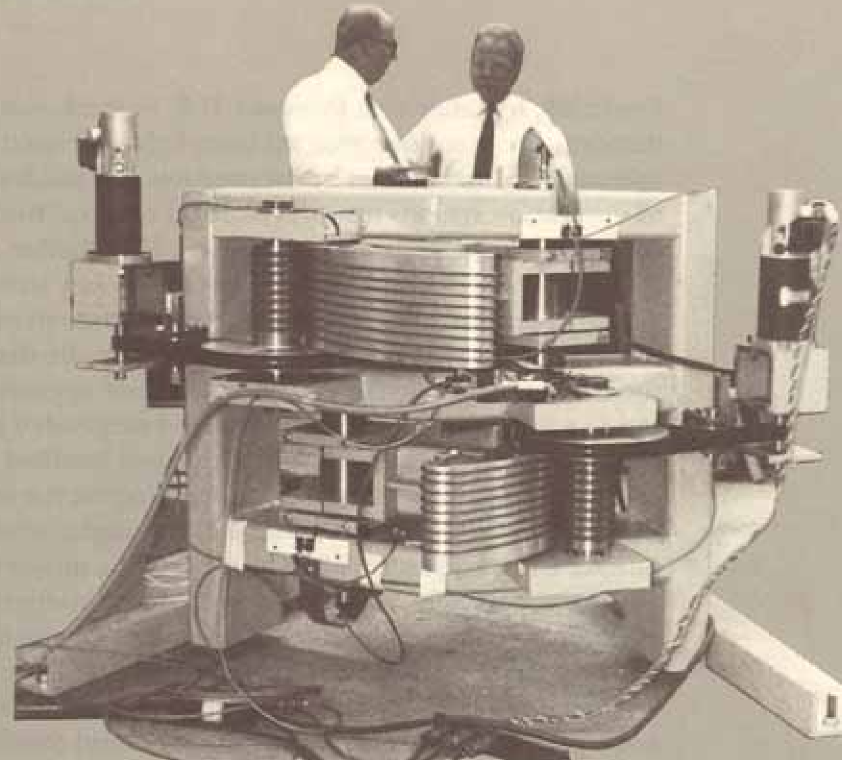
Frederick, together with Professor D.K. Felbeck, was able to demonstrate that noise emitted from lightly stressed aluminum alloys was caused by the creation and sudden growth of dislocation systems from Frank-Read sources. Working with graduate students A.B.L. Agarwal, N.G. Sankar, and R.C. Bill, Frederick and Felbeck developed very sensitive displacement sensors that could detect displacement of approximately 2 fm, which is 105 times smaller than the diameter of the aluminum atom. They constructed their apparatus inside a very heavy, very thick, insulated suspended cubical chamber, about 4 mm on a side, which was installed in the basement of the East Engineering Building on the main campus. Their best work was done late at night, when the outside truck and automobile traffic was at a minimum. Using these sensors, they were able to detect sudden bursts of dislocation motion over areas as small as 10 mm in diameter. This was the first known independent proof that dislocation generation by bursts actually occurred. Nowadays, any noise produced by a metal, even the very loud emissions from growth of a crack, are referred to as acoustic emission, but the early use of this term implied extreme sensitivity. Professors Frederick and Felbeck and their students published four papers on several aspects of this important discovery.

In the 1960s and 1970s, Frederick turned his attention to work on crack detection in metals with principal applications in the detection of cracks in the steel enclosures and pipes in nuclear reactors. One requirement of this application was to find a way for nuclear-power plant technicians with relatively little training to obtain good data about possible cracks. The most difficult part of the operation was to hold the ultrasonic transducer tightly and flat against the metal surface that was being examined. It was useful to place a "spot" of petroleum jelly in the contact region, but even this had limitations. Frederick developed ways to use water as the bridge between the transducer and the metal surface, which turned out to relax the requirements for flat and tight contact.

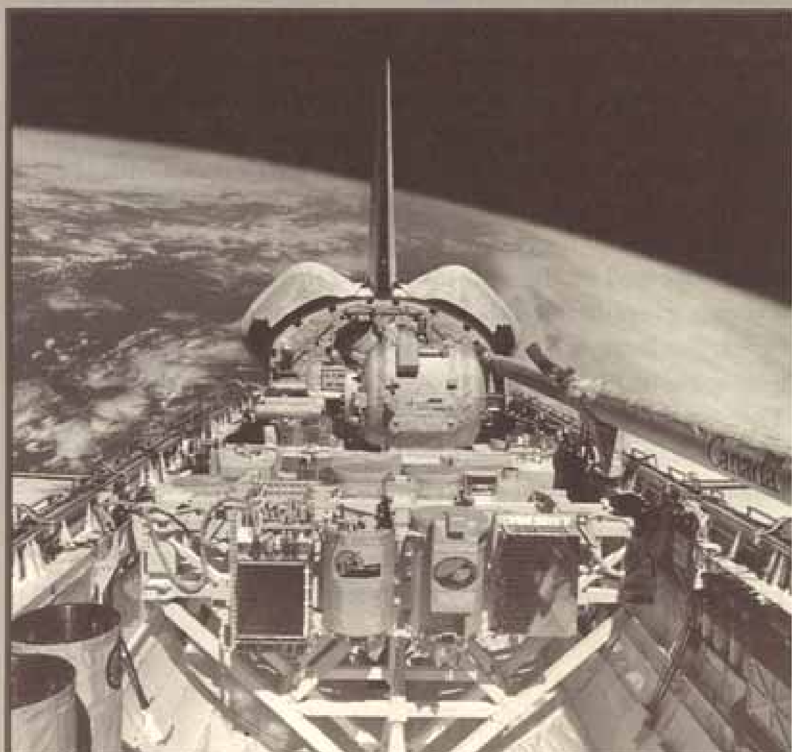
Once the transducer could be easily moved, the idea arose to obtain data from several transducer locations and, thereby, get images of a crack from different angles of view. Further, several transducers could be aimed at the same location on the metal from some distance. This technique is known as the Synthetic Aperture Method. This led to a project sponsored by the U.S. Nuclear Regulatory Commission, Division of Reactor Safety Research to develop new and improved methods for visualizing cracks and other discontinuities in structures and materials. Images of the cracks created by ultrasonic waves were displayed by using computer graphic techniques in pseudo three-dimensional types of displays. A key objective of the research was to develop techniques for obtaining greater accuracy in characterizing the cracks being evaluated. The work was carried out with the use of an Interdata 7/32 computer having 256k bytes of core memory and 20 megabytes of storage. Data were acquired and processed by the computer and the results displayed on a vector graphic display. As better computers were developed, the images improved. In 1978, Frederick reported gray-scale indicating the strength of signals from the crack. The strength in turn indicated the separation of the crack walls. Further work continued on color representation in image reconstruction up to the time of Frederick's retirement in 1982. As an emeritus, Frederick remained active and was working on a second book, this one on Acoustic Emission in Non-Destructive Testing, when he died in 1983.

Looking to the Future

Mechanical Engineering at the University of Michigan continues to chart new territories in engineering science. This section highlights a few of the scientific and technological challenges MEAM researchers are currently exploring.

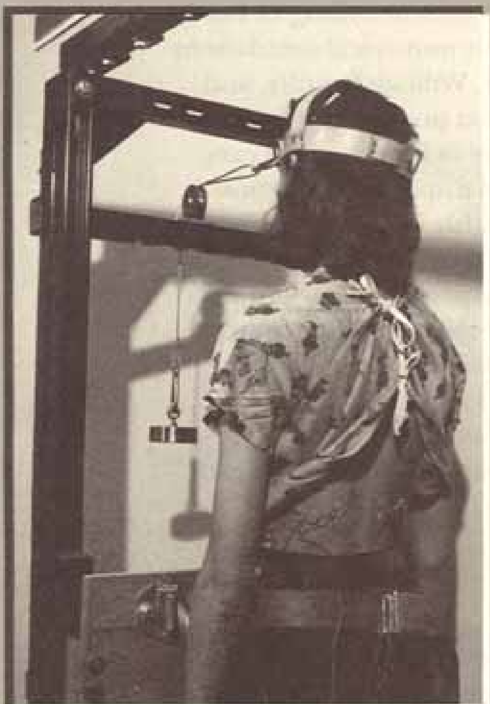


This prototype of a multi-arm milling machine, designed by Profs. Allen Ward and Jeffrey Stein, is the first of a new generation of "novel" machining centers. It allows greater mobility for machining complex geometries quickly and accurately.



Prof. Herman Merte's experiment in pool boiling in microgravity was one of a group of NASA "get-away specials" (G.A.S.) flown on shuttle flight STS-47 in April, 1993. This "G.A.S. Can" package permitted nine tests to be conducted in a prototype pool boiling vessel.

Investigators in the MEAM biomechanics lab examine many characteristics of human posture, muscular control, and structural stability. Areas of study include geriatric mobility impairments, obstacle avoidance strategies, and human scoliosis.



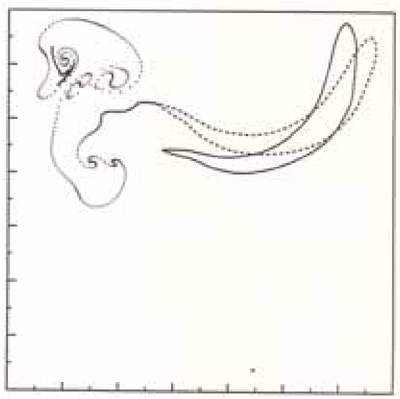
Prof. Noboru Kikuchi has hypothesized that his homogenization method of design may lead to advanced materials composed of microstructures similar to human trabecular bone and other natural materials. For example, the microstructures of a car's skin could be designed to carry fluids just as veins circulate blood, providing a more uniform heat to the interior and providing a means for self-repair of rust spots or damage due to accidents.

Prof. Noel Perkins has developed techniques for studying the dynamic behavior of slack cables in active use. This apparatus developed with the help of graduate assistant Chris Lee will be used for examining cables underwater.

Fluid Mechanics

Over the last two decades, powerful new computers and algorithms have made it possible for researchers to increase their knowledge of the fundamental physics of fluids. The MEAM fluid mechanics group is at the forefront of this important area of research, making significant contributions to the understanding of fundamental structures and processes of fluid flows using direct numerical simulations and experimental studies. Professors Rayhaneh Akhavan, William Schultz, and Grétar Tryggvason have developed theoretical models that provide a better understanding of fluid behavior in applications as diverse as flows around cars, ships and fish; combusting flows in turbomachinery; and dispersion of atmospheric pollutants. Professor Steven Ceccio carries out highly innovative experimental studies of basic fluid processes (particularly cavitation) with applications in hydromachinery, such as hydroelectric turbines, high-speed pumps, and ship propulsion systems. The group carries out sponsored projects totalling approximately $850,000 for agencies including the Office of Naval Research, the Gas Research Institute, Kimberly-Clark, National Aeronautics and Space Administration, the National Science Foundation, the Naval Research Laboratories, and the Air Force Office of Scientific Research. The selected projects described below are illustrative of the group's work.

This numerical simulation shows a carangiform fish moving from an at-rest position to 34/250 sec. Initially the tail moves laterally without significant forward movement. The solid line traces show experimental profiles, and the dotted lines are the numerical simulation.



A Numerical Study of Fish Swimming

Associate Professor William Schultz

Until this study, understanding of fish locomotion has been driven by hydromechanical models based on thrust and resistance. This theory, however, is inappropriate for a wide range of swimming modes and for questions of stability. This study introduces a more general numerical model for fish swimming in an unbounded fluid. The swimming of neutrally-buoyant fish is simulated assuming it is surrounded by an infinite two-dimensional inviscid flow with the wake represented by discrete point vortices. For a fish shape that is a prescribed function of time, we predict the motion of the center of mass and the orientation angle from conservation of linear and angular momentum. Our fully-computational, two-dimensional inviscid model requires no slender-body assumptions nor "adjustable" parameters required in slender-body theory. The numerical model compares well to an observed fast-start (acceleration from rest) of a rainbow trout and to a turning maneuver of a rudd (Weihs 1972). We study the effects of body shape and deformation on swimming speed and power for carangiform motions. Steady swimming results show that the predicted maximum speed occurs when the swimming wavelength is equal to the fish length—the velocities are appropriate for observed stride lengths. The simulated swimming power with a simple viscous force model compares favorably to expectations based on measured metabolic rates. Simulations with varying viscous forces suggest that the inviscid wake-induced drag may be more important than viscous drag since power predictions are reasonable. The trends of swimming power with tail-beat amplitude show excellent agreement with trends from the slender-body theory of Lighthill (1975) in the range where the slender-body theory is valid. The effects of the body thickness agree qualitatively with the conclusions of Newman & Wu (1973) and Newman (1973 a,b).

Modeling of Bubbles and Drops

Associate Professor Grétar Tryggvason

The dynamics of flows containing two fluids separated by a sharp interface, such as a bubble or drop, are of the utmost importance for both natural and technological processes, such as boiling heat transfer, air entrainment in casting (porosity), spray combustion, spray painting, and rain. Professor Tryggvason is carrying out research to simulate multi-phase flows fully and thereby lead to a better understanding of phenomena that take place at the smallest scales within these flows. To examine the small scale processes in multiphase flows is extremely difficult. The small time and spatial scale makes measurement difficult, and the change in phase usually eliminates visual access to the interior of the flow. Full numerical simulations of the flow can in principle give all the necessary information, since the governing equations are (for the most part) well known. In practice, however, this is one of the difficult areas of computational fluid dynamics. Progress has been slow, and almost all current studies make a number of simplifications, such as inviscidness, Stokes flow, two-dimensionality or axisymmetry. Tryggvason has developed a numerical technique that allows accurate and efficient simulation of flows that take into account physical phenomena in the fluids, including viscosity, inertia, and surface tension. In Tryggvason's immersed boundary technique, fluid is resolved on a stationary mesh, and the interface is represented by a moving mesh of lower dimension. It allows for the prediction of the performance of the process in much greater detail than was possible before. The method has several advantages over previous methods: it handles the colliding interfaces easily; it is relatively simple; and it is easy to code and to vectorize. The method, therefore, allows for relatively easy simulation of fully three-dimensional phenomena.

Turbulence Control in Wall-Bounded Flows

Assistant Professor Rayhaneh Akhavan

Overcoming the large drag coefficients associated with turbulent flows has remained a main goal of turbulence research for several decades. In fact, turbulent-drag reduction is currently considered a major "barrier problem" to further optimization of most aerodynamic and hydrodynamic bodies. Turbulent drag accounts for nearly 50% of the drag of most underwater bodies. Over the years, a variety of turbulence-control and drag-reduction measures for wall-bounded flows have been devised. For most of these techniques; however, drag reduction is quite modest, on the order of 5-10%. Professor Akhavan and her students Wen-Je Jung, Norberto Mangiavacchi, and Amid Ansari have devised a method that may reduce drag by a much higher percentage. Research on the structure of turbulent boundary layers over the past two decades has revealed that production of turbulence in wall-bounded flows occurs in well-organized (coherent) structures in a quasi-periodic manner. Through the use of direct numerical simulations, Akhavan's team has found that the internal dynamics of these coherent structures can be utilized to obtain turbulence control and drag reduction in wall-bounded flows. In numerical experiments performed on the San Diego Supercomputer Center 64-node Intel iPSC/860 hypercube, Akhavan and her team have discovered that by exposing a turbulent boundary layer to spanwise oscillations at selected frequencies, turbulent drag can be reduced by more than 40%. The oscillations can be introduced either by the spanwise motion of the wall or by superimposing a spanwise oscillatory pressure gradient on the flow. These results indicate a simple and effective means of control of turbulence in wall-bounded flows. Further optimizations for practical applications are currently under study.

Experimental Studies of Cavitation in Fluid Flows

Assistant Professor Steven Ceccio

When the absolute pressure of a liquid is reduced below the vapor pressure gas and vapor cavities may form in a process known as cavitation. The presence of cavitation can seriously effect the performance of hydromachinery, such as hydroelectric turbines, high-speed pumps, and ship propulsion systems. Cavitation can reduce performance, create noise and vibration, and cause fatigue and erosion. By understanding the physical processes that lead to cavitation, we can delay its onset and help to mitigate its effects. Professor Ceccio's research group is studying the fluid mechanics of cavitation inception. Cavitation first occurs when small microbubbles within the fluid are swept into low pressure zones and explosively grow. In turn, their growth can alter the nearby flow, further inducing cavitation. The inception process can be intermittent, making it difficult to study systematically. In order to carry out studies of cavitation Ceccio has developed electrical probes, which can be used to detect and quantify the dynamic process of cavitation inception. Once detected, a variety of techniques can be used to record the cavitation process, including high-speed photography and acoustic probes. Cavitation inception usually occurs in complex, three-dimensional flow fields. To study such flows, Ceccio has been working with Professor Luis Bernal of the Aerospace Engineering Department to implement a holographic particle imaging velocimetry system (HPIV). With HPIV, flow velocities are determined after the motions of many small tracer particles are detected and recorded. Holograms are used to simultaneously record the motions of many particles within a sampled flow volume, and these images are digitally analyzed to produce a set of velocity vectors within the flow field.

The fluid mechanics of cavitation is investigated in Prof. Steven Ceccio's laboratory. Cavitation is an important phenomenon because it adversely affects the functioning of hydromachinery. This blow-down apparatus induces cavitation by generating intense short duration surges through a three-inch diameter test section.

Heat Transfer

MEAM heat transfer faculty carry out research on a diversity of topics including Efficient Drying versus Pulse Combusters (Professor Vedat Arpaci), Flame Spread Over Charring Materials (Associate Professor Arvind Atreya), Thermocapillary Flows in Welding and Crystal Growth (Professor Michael Chen), Forced Convection Boiling in Microgravity (Professor Herman Merte, Jr.), and Visualization of Flows in Torque Converters (Professor W.-J. Yang). Research funding for the group totals approximately $800,000 from sponsors including GE Aircraft, Ford Motor Company, the Gas Research Institute, the National Aeronautics and Space Administration, Whirlpool Corporation, the Department of Energy, and the National Science Foundation. Below is a sampling of projects being carried out by heat transfer faculty.

Microscales, Irreversibility, Radiation, Acoustics, Chaos

Professor Vedat Arpaci

Microscales of complex (hydromagnetic, radiating, reacting, pulsating) turbulent flows are an emerging research area with significant practical applications. On fundamental grounds, the turbulent dissipation of all forms of energy (mechanical, chemical, nuclear, electromagnetic, radiative) into thermal energy is a measure of irreversibility characterized by these scales. On technological grounds, the foundations of the so-called "empirical" heat and mass transfer correlations for turbulent flows can be interpreted in terms of these scales.

In a joint research program between the University of Michigan and the Sandia National Laboratories, the Sandia experimental data demonstrating the increased efficiency of heat and mass transfer via pulse combustion is theoretically interpreted by the Michigan models based on the microscales.

In a joint research program between the University of Michigan and NASA-Lewis Research Laboratories, the Lewis data on the surface-tension driven turbulent motion in evaporating droplets is also theoretically interpreted by the Michigan models based on these scales. A computational program based on a Godunov projection method that evaluates the nonlinear (inertial, convective) terms with high precision complements the modeling effort.

A research program supported by the Ford Motor Company involves Michigan doctoral students gathering turbulent data on Ford engines and supporting the data by models based on the appropriate microscales.

The present research interests of Professor Arpaci include also the radiative and acoustical properties of interacting particles in sooty, seeded, polluted, smudgy media, which have important technological as well as environmental applications. These interests also include chaotic thermocapillary driven flows, which find important space applications.

Formation and Oxidation of Soot and NOx in Diffusion Flames

Associate Professor Arvind Atreya

Soot and NOx formation processes are of considerable interest to practical combustor designers because they control the combustion efficiency, pollutant formation, and thermal radiation in combustion systems. While all these aspects are important in large industrial furnaces and combustors, flame radiation plays a particularly important role because thermal radiation is the primary mode of energy transfer in these systems. Higher flame radiation increases the efficiency of energy transfer, while lower flame radiation results in higher flame temperature which increases the production of NOx and also requires equipment capable of handling high temperature exhaust gases. Thus, the technical problem is to reduce the flame temperature and hence the NOx production rate by promoting flame radiation. This can only be accomplished by increasing the soot production rate in such a way that it is completely oxidized before leaving the flame zone. NOx and soot formation processes therefore are intimately linked.

This research focuses on determining the soot formation and oxidation rates in counterflow diffusion flames and developing a model for a radiating flamelet for use in turbulent diffusion flames. The effect of variables used in controlling furnace flames, namely, the preheat temperature, the chemical composition of the reactants, the strain rate and dilution by products of combustion on soot formation, is also being investigated. In addition, NOx measurements and modeling are included in the study .

Researchers in Prof. Arvind Atreya's laboratory evaluate fire suppressants and the basic mechanisms of fire suppression using one-dimensional laminar diffusion flames produced in this stagnation point flow apparatus.

Transport, Reaction and Phase Change in Porous Media Laboratory

Professor Massoud Kaviany

Porous media, such as powders, foams, fabrics, soils, coals, fiberglass insulations, and concretes all undergo nonisothermal processes in their fabrication and usage. The fluid filling in the pores of these media can be gaseous or liquid or

Steam injection into a packed column of glass particles, steam condensation, and the propagation of this condensation front are observed using this experimental apparatus in Prof. Massoud Kaviany's laboratory. This is part of a study concerning decontamination of soils using steam injection.

both, and the fluid can be multicomponent. The heat transfer aspects of porous media become important when there is an exothermic chemical reaction (combustion), a phase change among any phase pairs of gas, liquid and solid, or a simple change in the sensible heat. Applications in mechanical engineering are vast including the areas of climate control, energy conservation, energy harvesting, environmental cleanup, heat exchangers, manufacturing, materials, and processing.

The scientific-engineering treatment of transport, reaction, and phase change in porous media addresses the fundamentals of conduction, convection, radiation, and chemical reactions at the pore level. Since porous media of finite size are of interest, these processes must also be studied at the interface of the porous media with bounding media (a fluid or solid). The presence of a bounding surface drastically changes the distribution of the phases in two-phase flows and the velocity distribution in single-phase flows.

Professor Kaviany has addressed these problems by the direct simulation of the processes (conduction, convection, radiation, phase change, and reaction) at the pore level. These direct simulations have been deterministic and statistical (Monte Carlo simulation in the case of radiation using geometric optics). The anisotropy of the effective medium properties adjacent to the interfaces has been formulated, and the transfer coefficients have been developed.

The goal of his research and instruction in this area has been to identify critical technologies and obtain sponsorship from the firms or institutions in need of these technologies. He then formulates and performs fundamental research that can address (and in some cases directly solve) these problems. He also organizes the findings in a manner useable by the students and other researchers.

Manufacturing

During the last decade, MEAM has developed one of the strongest manufacturing automation groups in the world—specializing in research in automated monitoring, sensoring, and control as applied to machinery. Twelve manufacturing faculty members carry out educational and research activities in ten laboratories. A broad range of technology developed by the group has been transferred for use in industry. The research program supports approximately seventy graduate students and has funding totalling approximately $3 million. Sponsors include the U.S. Air Force, Chrysler Corporation, the U.S. Department of Energy, Ford Motor Company, General Electric, General Motors, Kodak, the Michigan Strategic Fund, the National Science Foundation, and the Office of Naval Research. Below is a sampling of research projects currently underway in the manufacturing laboratories.

Tool-Wear Estimation in Machining

Professor Galip Ulsoy

The purpose of this research is to develop on-line tool-wear estimation methods for machining processes. The real-time estimation of tool wear in machining operations is important for scheduling tool changing times and for adaptive process control and optimization. However, tool wear cannot be measured directly during cutting. Professor Ulsoy has developed an approach that permits estimation of tool wear under varying cuttings (e.g., changes in depth-of-cut, feed and speed), as would be required in many production situations. The method uses force measurement during cutting together with a process model. The model is the basis for an adaptive state estimator, which simultaneously estimates model parameters and the model states (i.e., state of wear of the tool). This force-based estimation is intermittently calibrated by the use of a computer vision system for direct optical wear measurement between parts. For production situations where a single tool-edge produces many parts, the vision system can be used by itself. On the other hand, if a single part is produced by one or more tool edges, then the force-based system only can by used. The two are used in conjunction for production situations where a tool produces several (e.g., 10) but not many (e.g., 100) parts. Laboratory tests for a turning operation with varying cutting conditions show excellent results. The maximum error in the flank wear estimate is less than 30μm.

Prof. Galip Ulsoy's real time tool-wear instrumentation is evaluated on a turret lathe in the MEAM machine tool laboratory. The method uses force measurements during cutting, together with a process model.

Cross coupling control developed by Prof. Yoram Koren allows this milling machine to produce more accurate contour machining.

Variable-Gain, Cross-Coupling Control for Multiple Axes

Professor Yoram Koren

Unlike traditional CNC controllers, where each axis of a machine tool is controlled independently, the U-M CNC controller uses the cross-coupling control method, which makes all the axes utilize each other's actual position information simultaneously, so that the tool can produce considerably more accurate curves. In our lab demonstrations, the cross-coupling control method reduces contour errors of 2-D and 3-D curves by up to an order of magnitude (i.e., 10:1) compared to traditional CNC controllers. The concept of the cross-coupling control method for 5-axis machine tools has already been developed and will be implemented and evaluated on a 5-axis milling machine in the near future.

Strategies for Automating the Modeling Process

Associate Professor Jeffrey L. Stein (with Yih-Tun Tseng and Bruce Wilson)

Many solutions for manufacturing design and control problems require the development of a dynamic model of the machine or machine process. Unfortunately, no software tools (or in any other tools, for that matter) exist to help manufacturing engineers to develop these models. The purpose of this research is to develop software tools to assist in automating the modeling process. Professor Stein's group has identified the basic structure of the general modeling process that is used by engineers to create valid, proper, quantitative models of physical systems, where proper is defined as a model of necessary yet sufficient complexity. They have proposed several strategies that could serve as the basis for an artificial intelligence (AI)-based computer environment for automating the modeling process. These are (1) decomposing: the process of transforming real systems into a collection of objects or components and assigning them motion attributes, which can be accomplished with a user-interactive dialogue with the computer; (2) mapping: the process of associating physical objects (components) with ideal phenomena (basic physics), which is a totally automated strategy based on associating energy phenomena with each identified motion of the components; (3) structured modeling: a systematic and, thus, totally automated process of lumping the energy phenomena, defining state variables, and assembling the model based on motion constraints; (4) modifying: a heuristic-based strategy for altering decomposing and structured modeling processes that have failed to meet modeling specifications. This strategy is imbedded in a program called COMMA

(COMputer Modeling Assistant), which demonstrates the feasibility of designing an automated modeling program. They have also developed a less general, but more powerful program MBA (Model Building Assistant), which is focused on automating the synthesis of lumped-parameter models of machine tool drive systems and is a useful tool for designing such systems.

Precision Engineering in Machining

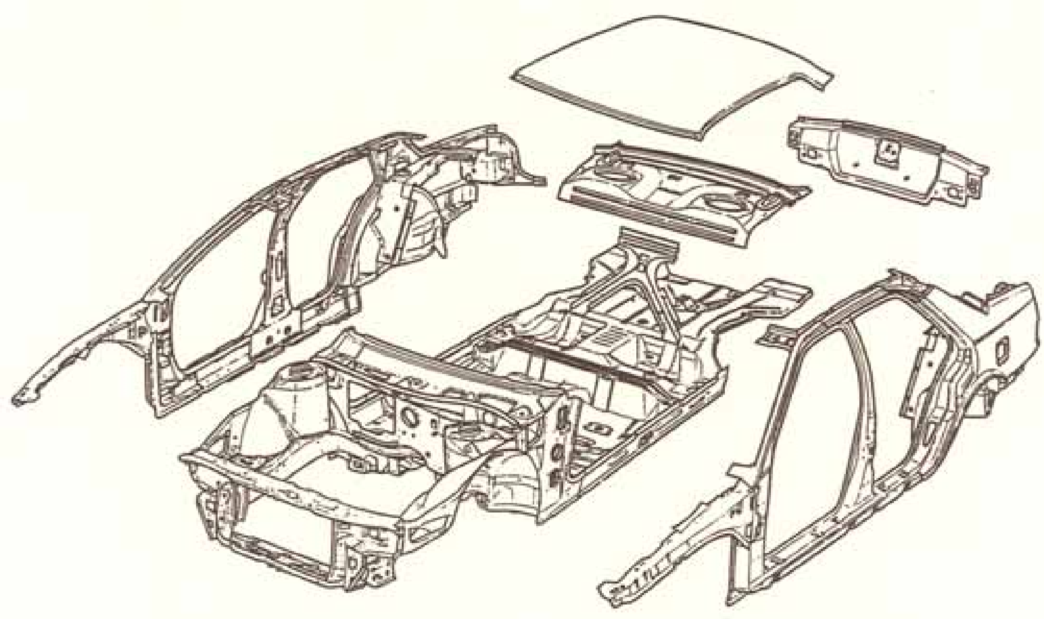
Associate Professor Jun Ni

The objective of this research is to achieve greatly improved machining accuracy through the use of sensing, modeling, and control methods. Ni's group has three on-going projects: (1) On-line control of hole quality in boring operations. A real-time sensing system is built into the boring bar structure to sense the machined cylindrical surface during machining. The processed signatures are used to actuate the boring cutter via a piezoelectrical translator so that the compensation can be achieved on line. (2) Feasibility study of chatter prevention and suppression. Rather than detecting the machining chatter after the fact, this project focuses on the feasibility of preventing the chatter during its onset. The key is the early identification of the chatter before it fully develops. (3) Real-time generation of NC tool path. An innovative method of generating the NC cutter path is being developed. CAD models in the IGES format can be used directly on line to generate the NC tool path instead of the conventional off-line approach.

The 2mm Program

Assistant Research Scientist S. Jack Hu

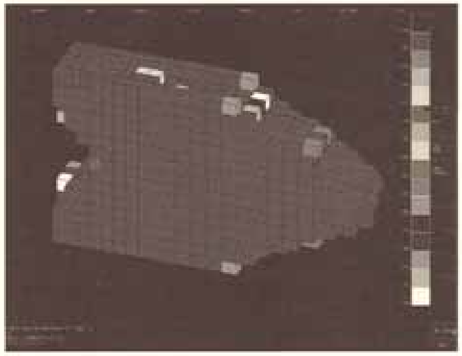
An automobile body provides the basis for the complete assembly of a vehicle. Improper dimensions of a car body will introduce problems in final assembly, as well as problems in the complete vehicle, such as fit and finish, wind noise, water leakage, closing effort, and so forth. In this research, Dr. Hu's group is working with a number of automobile manufacturers to advance their automobile body manufacturing techniques and process control methodologies to achieve world-class quality. The aim is to reduce variations on critical dimensions to within 2mm. A second objective of the program is to improve the scientific understanding of the sheet metal assembly processes and to establish a technical infrastructure for future sheet metal process control and assembly systems. To achieve these objectives, researchers are assigned to different stamping and assembly plants, variation reduction teams are formed in each plant, and problems in stamping and assembly are identified and solved one by one.



In the 2mm program, MEAM researchers work with industry to reduce variation in vehicle body assembly.

Design

The seven full-time professors who comprise the Department's design group are nationally recognized for their contributions in a broad range of leading-edge research. Their efforts emphasize close interaction with industry and include topics such as geometric modeling; techniques for optimizing conceptual designs; computational methods of designing complex mechanical devices; automated process planning; machine design; artificial intelligence applications to design; design education; design management; and computer graphics. The budget for design research exceeds $500,000 annually and comes from both industrial and governmental sources including the National Science Foundation, the Office of Naval Research, Ford Motor Company, the Army, General Motors, Nissan, Suzuki, General Electric, Chrysler Corporation, Horiba, Applicon-Schlumberger, and the Air Force Office of Scientific Research. The reports below feature three of the many important research projects being carried out by this group.



MEAM design researchers can create complex, superior designs for components using the homogenization method in Project Maxwell.

Project MAXWELL

Professor Noboru Kikuchi, Professor Panos Papalambros, and Assistant Professor Debasish Dutta

Project MAXWELL aims at bringing together two innovative research efforts underway at the University of Michigan and at Carnegie Mellon University. MEAM researchers are synthesizing a new, mathematically rigorous method for the concurrent design of form and material composition called the homogenization method. Carnegie Mellon researchers are developing a novel method for the rapid fabrication of such designs by thermal spray shape deposition called MD* (recursive Mask and Deposit). Bringing these two efforts together in an integrated methodology will allow for the manufacture of superior products not possible before. Such parts will possess superior structural and mechanical properties (e.g., lower weight to stiffness ratio) and will satisfy packaging and other manufacturing requirements (e.g., ease of assembly). The current application domain is in automobile design and manufacture and includes sheet metal/composite panels, brackets, suspension components, and special structures for side impact energy absorption.

The homogenization method is based on the observation that topological design is necessary in addition to size and shape design. If topological changes are not allowed, size and shape optimization procedures can improve a design by

The topological modifications made possible by the homogenization method can improve a design by 30 - 50%.

approximately 5-15%. Topological modifications, however, can often yield 30-50% improvement. In the homogenization method, the topology and shape problem is formulated as a new optimization problem involving material distribution. Given a solid with a prescribed volume, microscale voids are generated within the design domain where a solid structure is not required for supporting loads. Therefore, instead of designing the shape and physical dimensions of the cross section of a structure, infinitely many microscale voids are generated within the configuration wherever the stress is small. If a portion in the domain is highly stressed, the homogenization method prevents the creation of microscale holes and that portion remains solid. Furthermore, the orientation of noncircular voids has a significant effect on the overall material response. Therefore, in the new optimization problem, the design variables are the density of microscale voids and their orientation over a specified domain. By removing material completely from portions of the domain densely packed with voids, the optimum shape of the structure is identified, while its topology is determined by accounting for the number of "global" holes.

The design images produced by the homogenization method are transformed into realistic manufacturable designs using advanced geometric modeling and image processing techniques. The designs are then implemented using Carnegie Mellon University's MD* layered manufacturing process.

Design of Compliant Mechanisms for Microelectromechanical Systems (MEMS)

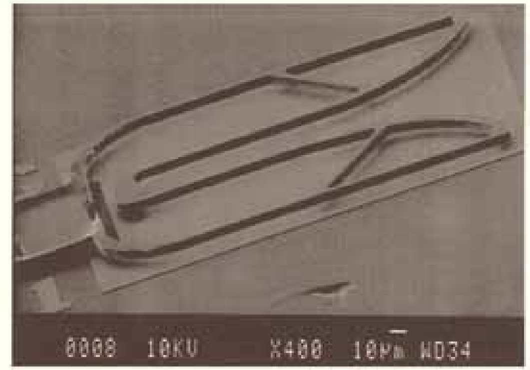
Associate Professor Sridhar Kota

Graduate Research Assistant G. K. Ananthasuresh

The study of microelectromechanical systems (MEMS) is a fast growing area of research that has an immense potential for applications on the micro level. This research addresses the design aspects of such systems. Through MEMS it is possible to integrate movable mechanical elements with electronic circuits and sensors and then fabricate the entire assembly using the same process. Developments in the past decade have been truly revolutionary. Microfabrication technologies have been developed that can build electrostatic motors, linear actuators and resonators, springs, grippers, and gears, all of which are in the size range of a few tens of microns to a few hundreds of microns. These technologies are limited, however, by exigencies in fabrication and design at the micro level that are nonexistent at the macro level. One such difficulty is the virtual loss of the third dimension, since most of the microstructures are fabricated using integrated-circuit-chip-based micromachining techniques that are predominantly two dimensional. Also, to justify the cost, MEMS should be batch-produced with minimal or no assembly. These difficulties can either be surmounted with further breakthroughs in microfabrication technologies or circumvented with novel designs. This research is aimed at the latter. We are introducing a novel class of mechanical designs that require no assembly, called compliant mechanisms for MEMS applications.

Compliant mechanisms are single-piece flexible structures that deliver the desired mechanical motion by undergoing elastic deformation as opposed to the rigid body motions of conventional mechanisms. Since the motion is dependent on geometry and applied forces, these mechanisms are treated in the light of kinematics and continuum mechanics. Compliant mechanisms have many attractive features including ease of manufacture, non-mechanical actuation, elimination of the need for accessories, less friction, less wear, less noise, etc. Potential applications include simple parts of machinery, hand-held instruments, robotic grippers, measuring instruments, and transducers at both the micro and macro levels.

As yet there is no systematic method for synthesizing compliant mechanisms. The objective of this research is to evolve such a method by extending Professor Noboru Kikuchi's newly developed design technique called homogenization. The application of homogenization to the synthesis of micro-compliant mechanisms enables the synthesis problem to be solved up to the fabrication detail starting from functional specifications only.



This micrograph shows an actual compliant crimping mechanism with a built-in electrostatic linear actuator that was designed using the homogenization method. This device, about 100x100 microns in size and 10 microns in thickness, was systematically synthesized and then fabricated by Prof. Sridhar Kota in collaboration with colleagues at the U-M Center for Integrated Sensors and Circuits Laboratory.

The Set-Based Concurrent Engineering Project

Assistant Professor Allen Ward

Design is usually considered an iterative process, in which a solution is posed, analyzed, and then modified. The set-based concurrent approach is an alternative that can be demonstrated with a simple problem such as arranging a meeting among a group of people. The iterative approach is to identify a time, then call everyone to see if they can make the time. If someone can't, the time must be modified. The set-based approach is to pick the week in which the meeting must take place and ask people to identify the times during the week that are already committed. Picking a time is then easy. Similarly, the Toyota Motor Company requires its suppliers to develop a set of possible subsystem designs for each product, exploring the trade-offs before establishing the specifications.

Good engineering designers have always applied this sort of approach, but it has received little theoretical attention. Fully effective application requires ways to represent sets of possible solutions and allows high levels of design automation, as well as the efficient exploration of truly novel design concepts. Current activities include: (1) the development of a national electro-mechanical catalog selection system, operating over "electronic highways", which will accept a schematic from a design and return a nearly optimal selection of bids for sub-systems; (2) development of new, fundamental mathematics for design synthesis (rather than analysis); (3) studies of US and Japanese design practices, and the development of training material based on "best practice"; (4) development of new classes of computer-controlled machine, which may reduce life cycle costs for milling machines by up to 40%; (5) development of CAD software allowing automotive stylists and body and stamping engineers to quickly find the "intersection" of marketable, rigid, and manufacturable designs.

Robotics

Robotics has been identified as one of seven key technologies that will drive global economic competitiveness over the next few decades. MEAM has taken a leadership role in this critical area through work carried out by Professor Yoram Koren and Dr. Johann Borenstein in the Mobile Robotics Laboratory and in the Humechtronics Laboratory. Their work includes basic theoretical advances in areas such as navigation, obstacle avoidance, mapping, and environmental exploration as well as applications for business and government. The group's research funding totals approximately $425,000 from sponsors including NSF, Colding International, and Cybernet Systems. Below is a sampling of projects from the robotics laboratories.

Error Eliminating Rapid Ultrasonic Firing

Associate Research Scientist Johann Borenstein

Ultrasonic sensors are subject to noise and sporadic false readings, just like any other sensor system. In most operating environments, environmental ultrasonic noise is fairly rare. However, robots with multiple ultrasonic sensors may introduce their own noise, a phenomenon known as crosstalk. When operating a mobile robot under such real-world conditions, it is impractical to base the decision for an obstacle maneuver on a single (possibly erroneous) sensor reading that seems to indicate the presence of an object. A more practical approach combines multiple range samples. When traveling at a high speed, it is crucial to quickly and repeatedly gather multiple samples in time to avoid a collision. Fast sampling of multiple sensors, however, introduces even more ultrasonic noise and increases the occurrence rate of crosstalk. To overcome this problem, we have developed a method that will allow rapid sampling of all sensors while reducing erroneous readings by a factor of 1-2 orders of magnitude. Moreover, our method will completely eliminate crosstalk. This method, called error eliminating rapid ultrasonic firing (EERUF), can be implemented in software and will work with a modified off-the-shelf ultrasonic sensor interface board.

The obstacle-avoidance system of the CARMEL robot developed by MEAM researchers allows for high-speed obstacle avoidance. (see page 69 for more on CARMEL).

Analysis of Potential Field Methods for Mobile Robot Obstacle Avoidance

Professor Yoram Koren and Associate Research Scientist Johann Borenstein

Potential field methods are rapidly gaining popularity in obstacle avoidance applications for mobile robots and manipulators. While these methods are particularly attractive because of their elegance and simplicity, substantial shortcomings inherent to these techniques have been identified. Koren and Borenstein have devised a mathematically based method for systematically examining these problems in qualitative and theoretical terms. The heart of their analysis is a differential equation that combines the robot and the environment into a unified system. The equation permits the analytical formulation of a stability condition that states that for every environment/robot configuration there is a speed at which motion becomes unstable (when potential fields are utilized).

Multi-Degree-of-Freedom Vehicle for Constraint Environments

Associate Research Scientist Johann Borenstein

This multi-degree-of-freedom vehicle was developed with innovative features that permit smooth and accurate operation.

Multi-degree-of-freedom (MDOF) vehicles have many potential advantages over conventional (i.e. 2-DOF) vehicles but are difficult to control because of their over-constrained nature. These difficulties translate into severe wheel slippage or jerky motion under certain driving conditions. To overcome this problem, the Mobile Robotics Laboratory is developing a new concept (patent pending) in the kinematic design and the method of control for MDOF vehicles and mobile robots. Experimental results show smooth and accurate motion. Dead-reckoning accuracy is substantially better than that reported in the literature for other MDOF vehicles. It was found equal to or even better than that of comparable 2-DOF vehicles.

NavBelt for the Blind

Associate Research Scientist Johann Borenstein and Dr. Shraga Shoval

The NavBelt is a robotic device that alerts a blind user to obstacles in the environment. The device consists of a belt with eight electronic sensors worn around the waist, a computer to process the information from the sensors worn as a backpack, and headphones to receive the signals from the computer. The sensors send out signals in a 120 degree arc at a five meter range that bounce off obstacles.

The computer picks up the signal, interprets it and sends a stereophonic beeping sound to the headphones alerting the user. The beeps can tell where an object is, how far away, its size, whether it is moving, and how it relates to other obstacles.

Mechanical Snake Robot

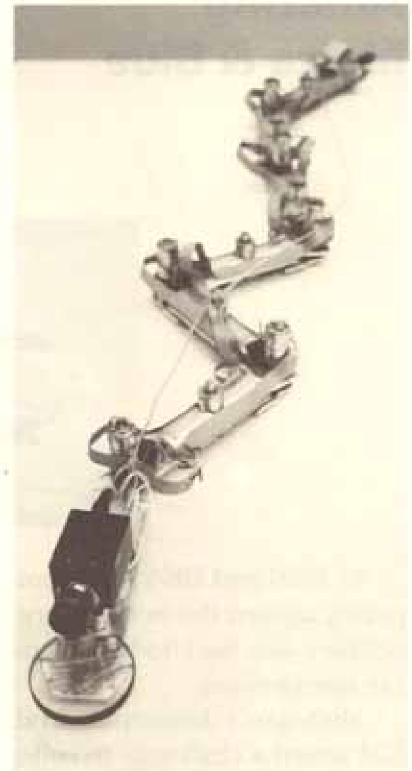
Professor Yoram Koren and Assistant Research Scientist Yansong Shan

The mechanical snake robot is designed with two special features that allow it to operate in natural outdoor environments or in cluttered indoor environments where robots usually cannot function. Its first unique feature is the method of locomotion. Most snake robots move on wheels, which inhibits flexibility. The U-M snake mimics the motion of a live snake using a design with seven links using caster balls and DC motors for the forward motion and solenoids that contact the floor for static points. The second feature is a method of control called obstacle accommodation that allows the snake to touch obstacles in the environment safely instead of having to avoid them completely.

The HoverBot

Associate Research Scientist Johann Borenstein

The HoverBot is an electrically powered flying robot similar to a model helicopter. It is designed with four rotors instead of one to provide greater stability. Without expensive autopilots, any conventional helicopter will tip over and crash unless constantly and actively stabilized by the pilot. Model helicopters will tip over even faster than large ones because their time constant is shorter. On-board controllers are impractical because they add too much weight. Preliminary tests on the four-rotor design indicate that it provides stability without additional weight.



The mechanical snake robot is designed to operate in settings that are too hazardous or too constricted for humans to enter.

Amazing Maize & Blue

In 1990 and 1993 Michigan engineering students competing against the best undergraduate engineers in the country won back-to-back national championships in solar car competition.

Michigan's dominance in this event began in 1988, when GM issued a challenge to college students across the country to design and build solar cars to race from Florida to Michigan in Sunrayce '90.

Over the next two years a team of about one hundred student Wolverines toiled almost around the clock to create their car, and in June of 1990, they arrived at the starting line with Sunrunner, ready to take on the competition from 32 other student built cars from around the country. As the race progressed over the next seven days, Sunrunner pulled into the lead and stayed there, crossing the finish line with a 90-minute lead over the second place car.

Five months later in November of 1990, Sunrunner competed in the World Solar Challenge in Australia finishing third in the world. The following summer, Sunrunner was retired from competition and put on exhibit in the Henry Ford Museum in Dearborn Michigan.

Soon thereafter, the call went out from GM for Sunrayce '93 and a new team of Michigan students went to work. Starting from scratch, the team began to build Michigan's second solar car, Maize & Blue. One change in the rules for the '93 race was that cars were not allowed to use space-grade solar cells as Sunrunner had; only the less efficient standard cells were allowed. Therefore, when Maize & Blue lined up at the start in Texas for the 1000 mile race to Minneapolis, she had one less advantage than Sunrunner had. Using a daring strategy and synchronized teamwork, the Michigan students pulled into the lead on the fifth day of the race and finished in first place, 90 minutes ahead of the second place car.

Maize & Blue will be seeking more honors in the World Solar Challenge in Australia in the fall of 1993.

CARMEL wins the 1992 Artificial Intelligence Robotics Competition

The CARMEL robot developed in the MEAM Mobile Robotics Laboratory took first place in the Artificial Intelligence Robotics Competition held July, 1992 in San Jose, California. Three MEAM Ph.D. candidates, Ulrich Raschke, Shraga Shoval and Liqiang Feng, were on the U-M team, and Dr. Johann Borenstein, the head of the Mobile Robotics Laboratory, acted as team consultant. In the competition, CARMEL impressively outperformed eleven competing mobile robots from other universities and from industry. Among the entrants were robots from IBM, Carnegie Mellon University, and MIT.

In one stage of the competition the robots were required to find a number of objects as quickly as possible. CARMEL was the only entrant to find all of the objects and finished in only 9-1/2 minutes, way ahead of the next closest robot from Carnegie Mellon, which took 28 minutes.

According to Borenstein, CARMEL's exceptional performance can be attributed to two of the robots features: (1) CARMEL has an on-board computer, which allows fast processing of sensor data and motor commands, and (2) CARMEL has a VFH obstacle avoidance method which allows obstacle avoidance at high speeds. VFH was developed by Borenstein and Professor Yoram Koren.

The student leader of the project was David Kortenkamp (EECS) and the academic and administrative supervisor was Dr. Terry Weymouth (EECS).

As a result of the victory, CARMEL was selected to receive a Best of What's New award for 1992 from *Popular Science* magazine. The awards recognize the year's 100 top products, technologies, and scientific achievements as determined by the editors of the magazine. The winners were featured in a 24-page cover story in the December, 1992 issue of *Popular Science.*

1992-1993 Annual Report

MEAM has many accomplishments to its credit in 1993. These include the completion of a renovation of facilities, a major revision of the undergraduate curriculum, and the attainment of a top-five ranking among all ME programs in the country.

One noteworthy initiative is in the area of automotive research. In June, the Department was awarded funding for a major research project: *The Center for Automotive Structural Durability Simulation.* The initial grant is for $1.2 million for two years from the Ford Motor Company.

The Center is an exciting development for the Department because it is a cross-disciplinary team project that aims at both fundamental research and specific deliverables for the automotive industry. Professor Panos Papalambros will serve as the Center's director and Professor Jwo Pan as its associate director. This Center is the type of effort that will be critical over the coming decade as the nation shifts research priorities from a defense focus to a civilian one that can contribute to global economic competitiveness.

Another MEAM achievement arising from these same priorities is involvement in the COE's newly created Program in Manufacturing (PIM), a nondepartmental, degree-granting program focusing on students returning from industry for advanced degrees. MEAM Professor Galip Ulsoy is the chair of the new program, and many of its activities will be carried out in MEAM laboratories. The first degree offered will be the Masters in Manufacturing Engineering, a joint effort with the business school designed to provide a broad education within engineering and business disciplines.

Please take the time to review all of the achievements of our faculty and students contained on the following pages.

MEAM Student Leaders, Honors, Fellowships

Student Societies

Michael Lefebvre—President, *Society of Automotive Engineers*
Angela Martens—President, *Pi Tau Sigma*
William Rockwell—President, *Michigan Student Society of Professional Engineers*
Karen McClure—President, *American Society of Mechanical Engineers*
Bernadette Lois—President, *Epieans*

Student Awards

J.A. Bursley Award
Karen Kenreich
Michael Rutz

Distinguished Achievement Award
Undergraduate
Kathryn Laberteaux
Andrew Filip
Keith Cook
Graduate
Eric Mockensturm
Marlin Kruse

Outstanding Student Leader Award
Christina DeGnore
Galen Gornowicz
Bernadette Lois
Yolanda McKay

Charles Barth Prize
Cory Culbertson

Arlen R. Hellwarth Prize
Christina DeGnore

The Ivor K. McIvor Award
Taein Yeo
Honorable Mention
Whie Chang
Ernst Mayer

A.D. Moore Award
Sharon Smolinski

Vulcan Award
Lori J. Park

1992-1993 Student Fellowships

Amoco
Byron Newberry

Benton
Robert Landers

Department of Defense
Diana Rincon

Devlieg
Kenneth Lipka

Fulbright
Guy Babbit

National Science Foundation
Kathleen Derwin
Matthew Castanier
Amy Lerner
Eric Mockensturm
Ann Tassin

Rackham Merit Fellowships
Marcus Darden
Todd Easler
Evaristo Gonzalez
Matthew Grogan
Kim LeBrane
David Ortiz
Jose Ruiz
Charisse Russell

Rackham Predoctoral
G.K. Ananthasuresh

Regents
Rustom Bhiladvala

USX Marathon
Douglass Hargett

Whirlpool
Joe Borneo

Enrollment and Degrees Granted

Enrollment (Fall 1992)

Doctor of Philosophy	170
Master of Science in Engineering	173
Bachelor of Science	801
NonCandidate for Degree	1
Total	**1145**

Degrees Awarded

Doctor of Philosophy	52
Master of Science in Engineering	100
Bachelor of Science	256
Total	**408**

Doctoral Degrees Conferred

Fall (December) 1992

Huseyin Akcay
Chair - P. Khargonekar (EECS)
Robust Linear System Identification

Randall Beikmann
Co-Chairs - N. Perkins and A. Ulsoy
Static and Dynamic Behavior of Serpentine Belt Drive Systems

Suhyun Choi
Co-Chairs - C. Pierre and A. Ulsoy
Vibration Localization in Rotating Shafts

Liqiang Feng
Chair - Y. Koren
Adaptive Mobile Robot Motion Control

Mian-Ju Gu
Chair - A. Schultz
Biomechanical Analysis of Postural Balance in Young and Elderly During Perturbed Stance

Craig Hoff
Chair - W-J Yang
The Effect of Distributed Flow Leakage on Pulse Propagation in Viscoelastic Arteries

Jiann-Lin Hwang
Chair - G. Brereton
An Experimental Study of the Fluid Mechanics of Turbulent Pipe Flow When Subjected to Forced Oscillation at High Frequencies

Hyun-Yong Jeong
Chair - J. Pan
A Macroscopic Constitutive Law for Porous Solids with Pressure-Sensitive Matrices and its Implications for Plastic Flow Localization and Crack-Tip Behavior

Myoungseob Kim
Chair - J. Pan
A Study of Crack-Tip Fields and Fracture in Elastic-Plastic Materials

Kevin Kirk
Chair - H. Merte
A Study of the Relative Effects of Buoyancy and Liquid Momentum in Forced Convection Nucleate Boiling

Christopher Lee
Chair - N. Perkins
Modal Interactions in the Nonlinear Oscillations of Elastic Cables

Jinkoo Lee
Chair - G. Johnson
Tolerance Optimization Using Genetic Algorithm and Approximated Simulation

Bor-Tsen Lin
Chair - A. Ward
Inductively Defined Formalisms for Design Inferences on Sets of Intervals

Hai-Ping Lin
Chair - N. Perkins
Theoretical and Experimental Investigations of Slack Cable/Mass System Dynamics

Donald Malen
Co-Chairs - W. Hancock and R. Scott
Engineering for the Customer: Decision Methodology for Preliminary Design

Gary Snavely
Chair - P. Papalambros
An Abstraction-Based Methodology for Mechanical Configuration Design

William Waldron
Chair - A. Wineman
Influence of Normal Stress Effects on Finite Shear Deformations of Compressible Nonlinear Isotropic Solids

Winter (May) 1993

Abdulghaffar Aljawi
Co-Chairs - C. Pierre and A. Ulsoy
Vibration Localization in Dual-Span Axially Moving Elastic Systems

Engin Atik
Co-Chairs - J. Stein and B. Fijan
Disturbance Rejection in the Heel Contact Phase of Gait

Zine El Abidine Ben Aoun
Chair - J. Pan
Influences of Pressure-Sensitive Yielding and Non-Singular Stress on Plane-Stress Elastic-Plastic Crack-Tip Fields

Hsieh-Ching Chen
Co-Chairs - A. Schultz and J. Ashton-Miller
Tripping Over Obstacles: Biomechanical Analysis of How Young and Old Try to Avoid It

Sung-Hoon Choa
Chair - K. Ludema
Characterization of the Boundary Films Formed in Sliding on Steel Surfaces at High Temperatures

Woosuk Choi
Chair - G. Johnson
Vibration of Roller Chain Drives with and without a Tensioner

Shin Fann
Chair - W-J Yang
Numerical and Experimental Studies on Transport Phenomena in Rotating Channels with Throughflow

Umesh Gandhi
Co-Chairs - J. Ni and S.M. Wu
Application of System Identification in Improving Crashworthiness Analysis

Mohammad Hassani
Co-Chairs - D. Talley and C. Borgnakke
An Imaging Method for Analyzing Spherical and Non-Spherical Particles

Peisen Huang
Co-Chairs - S.M. Wu and J. Ni
Laser Optical Measurement Systems and Their Application to the On-line Error Compensation of Coordinate Measuring Machines

Insik Jang
Chair - G. Hulbert
Automatic Time Step Control Algorithms for Structural Dynamics

Steven Donald Jones
Chair - A.G. Ulsoy
Quantification and Reduction of Dynamically Induced Errors in Coordinate Measuring Machines

Wen-Je Jung
Chair - R. Akhavan
Response of Wall Turbulence to High Frequency Streamwise and Spanwise Oscillations

Youngil Kim
Co-Chairs - R. Sonntag and C. Borgnakke
Generalized Equation of State for Refrigerants with Applications

Ali Kodal
Chair - G. Brereton
A New Orthogonal Decomposition Method for Turbulent Flows

Shyh-Shyan Lin
Chair - D. Patterson
Piston/Ring Assembly Friction Measurement and Modeling

Chong Jin Ong
Co-Chairs - D. Dutta and E. Gilbert
Penetration Distances and Their Applications to Path Planning

Ki Ook Park
Co-Chairs - W. Schultz and K. Ludema
An Asymtotic Analysis for Compressible Gas Lubrication of Rough Surfaces

Kyoungkuhn Park
Co-Chairs - R. Sonntag and C. Borgnakke
Generalized Thermodynamic Properties of Refrigerants

Leonard Pomrehn
Chair -P. Papalambros
A Recursive Opportunistic Optimization Tool for Discrete Optimal Design

Chinmo Roan
Co-Chairs - S.M. Wu and J. Hu
Identification, Monitoring, and Diagnosis for Dimensional Control of Automobile Body Assembly

Sukhendu Samajdar
Co-Chairs - J. Barber and S. Samanta
Bulk Processing, Microstructure and Property of a Superconductive Ceramic-Metal Microcomposite System: YBa2Cu307-8-Ag.

Yansong Shan
Chair - Y. Koren
Robot Obstacle Accommodation: Mechanics, Control, and Applications

Terrence Wagner
Chair - P. Papalambros
A General Decomposition Methodology for Optimal System Design

Taein Yeo
Chair - J. Barber
Thermoelastic Contact Stability: Analytical and Numerical Methods

Faruk Yigit
Chair - J. Barber
Stability Analysis of Thermoelastic Contact with Solidification of Casting

Byung Ok Yoon
Chair - B. Karnopp
Dynamic Analysis and Optimal Design of Overhead Cam Systems

Faculty News and Professional Service

Professional Service

Arvind Atreya
- Program Subcommittee, International Symposium on Combustion
- Subcommittee for Fire and Combustion, ASME
- U.S./Japan Panel on Fire Research (Associate Member)

James Ashton-Miller
- Board of Editors, *Journal Orthopaedic Research*
- Executive Committee, Bioengineering Division, ASME
- Terminology Subcommittee on 3-D Description of Scoliosis, Scoliosis Research Society

James Barber
- Elasticity Committee, ASCE
- Editorial Board, *Journal of Thermal Stresses*

Giles Brereton
- Organizer, 1993 International Symposium on Particles on Surfaces, Fine Particle Society
- Faculty Adviser, ASME Student Section

Michael Chen
- Director, Thermal Transport and Thermal Processing Program, NSF.
- Associate Editor, *Applied Mechanics Reviews*
- Session Chair, Thermal Fluid Issues in Manufacturing, National Heat Transfer Conference

David Cole
- Energy Engineering Board, National Research Council
- U.S./Canada Free Trade Act Select Panel.
- International Coordinating Committee, SAE
- Membership Service Board, SAE
- Advanced Powerplant Committee, SAE
- Organizer, U-M Automotive Management Briefing
- Organizer, Symposium on North American Free Trade Strategies for Auto Suppliers.

Maria Comninou
- Executive Board, Technology and Society Division, ASME

Debasish Dutta
- Geometric Modeling and Applications Subcommittee, 1993 Design Automation Conference, ASME
- Co-organizer, Symposium on Concurrent Engineering, 1992 ASME WAM
- Organizer, Invited Session on Automated Assembly, Workshop on Intelligent Manufacturing Systems, IFAC

Steven Goldstein
- Special Study Section, NIH
- Program Committee, Orthopaedic Research Society
- Committee on Biomedical Engineering, AAOS
- Editorial Consultant, *Journal of Biomechanics*
- Associate Editor, *Journal of Orthopaedic Research.*
- Associate Editor, *Journal of Biomechanical Engineering.*

Gregory Hulbert
- Computer Technology Committee, Pressure Vessels and Piping Division, ASME
- Committee on Computing, Applied Mechanics Division, ASME
- Junior Awards Committee, Applied Mechanics Division, ASME

Glen Johnson
- Vice-chair and Executive Committee Member, Design Division, ASME WAM
- Program Representative, Design Division, ASME
- Chair, Design Automation Committee, Design Division, ASME
- Computer Aided Design Committee, Computer Division, ASME
- Editor for Computer Aided Design and Optimization, *Mechanism and Machine Theory*

Elijah Kannatey-Asibu, Jr.
- Executive Committee, Production Engineering Division, ASME
- Associate Technical Editor, *ASME Journal of Engineering for Industry*

Bruce Karnopp
- Advisor, U-M Student Solar Car Team

Massoud Kaviany
- Vice Chairman, Theory and Fundamental Research Committee, Heat Transfer Division, ASME

Noboru Kikuchi
- Computational Methods in Applied Mechanics Committee, ASME

Yoram Koren
- Keynote Speaker, CIRP Annual Assembly, France
- Associate Editor, *CIRP Proceedings on Manufacturing Systems*
- Associate Editor, *SME Journal on Manufacturing Systems*

Herman Merte
- Advisory Committee on Educational Credentials, Board of Professional Engineers, State of Michigan
- Space Station Science and Applications Advisory Subcommittee, NASA

Panos Papalambros
- Editorial Boards:
  - *Journal of Artificial Intelligence in Design and Manufacturing*
  - *International Journal of Engineering Design*
  - *Journal of Global Optimization*
  - *Journal of Engineering Optimization*
  - *Journal of Japan Society of Mechanical Engineers*

Noel Perkins
- Technical Committee on Vibration and Sound, ASME
- Co-organizer, Symposium on Structural Dynamics of Large-Scale and Complex Systems, 14th ASME Conference on Mechanical Vibration and Noise

Christophe Pierre
- Associate Editor, *ASME Journal of Vibration and Acoustics.*
- Structures and Dynamics Committee, ASME Intl. Gas Turbine Institute
- Vibration and Sound Committee, ASME
- Co-organizer, Symposium on Structural Dynamics of Large-Scale and Complex Systems, 14th ASME Vibration and Noise Conference
- Visiting Researcher, Institute for Computational Mechanics in Propulsion NASA Lewis Research Center

Albert Schultz
- Honors Committee, Bioengineering Division, ASME

William Schultz
- Fluids Committee, Applied Mechanics Division, ASME

Steven Shaw
- Contributing Editor, *Nonlinear Dynamics*
- Editorial Board, International *Journal of Bifurcation and Chaos*
- Dynamics of Structures and Systems Committee, Applied Mechanics Division, ASME

Louis Soslowsky
- Officer, International Shoulder Group
- Joint Biomechanics Committee, Bioengineering Division, ASME
- Solid Biomechanics Committee, Bioengineering Division, ASME

Jeffrey Stein
- Associate Editor, *Journal of Dynamic Systems Measurement and Control*
- Chairman, Symposium on Automated Modeling, ASME, WAM
- Chairman, Technical Panel on Modeling and Identification, Dynamic Systems and Control Division, ASME
- Organizer, Panel Discussion on Fundamental Research in Manufacturing for National Competitiveness, ASME, WAM

Grétar Tryggvason
- Associate Editor, *Journal of Computational Physics*
- Visiting Researcher, Institute for Computational Mechanics in Propulsion NASA Lewis

Galip Ulsoy
- Honors Committee, Dynamic Systems and Control Division, ASME
- Organizer, Symposium on Control of Manufacturing Systems, 1992 American Control Conference
- Associate Editor, *ASME Journal of Dynamic Systems Measurement and Control*
- Editorial Board, *Mechanical Systems and Signal Processing*
- Proposal Review Panels, NSF
- Visiting Researcher, Vehicle Lateral Control Systems, Scientific Research Laboratories, Ford Motor Company, Dearborn, MI.

Anthony Woo
- Manufacturing Board, ASME
- Fellowship Committee, NIST/NSF/ASA
- Organizer, Symposium on Concurrent Design 1992 WAM, ASME
- Associate Editor,
  - *ASME Transactions Journal for Engineering for Industry*
  - *Journal of Design and Manufacturing*
  - *International Journal of Computation Geometry and Applications*
  - *International Journal of Computer Applications in Technology*
  - *Visual Computer*
  - *Journal of Manufacturing Systems*

Wen-Jei Yang
- President, Pacific Center of Thermal-Fluids Engineering.
- HTD K-10 and K-17 Committees, ASME
- Editor, *Journal of Flow Visualization and Image Processing*

Promotions

Johann Borenstein
Assistant Research Scientist to Associate Research Scientist

John Holmes
Assistant Professor to Associate Professor

Sridhar Kota
Assistant Professor to Associate Professor

Jun Ni
Assistant Research Scientist to Associate Professor

Noel Perkins
Assistant Professor to Associate Professor

Steven Goldstein
Adjunct Associate Professor to Professor

New Faculty

Arvind Atreya
Associate Professor
Atreya is a graduate of Harvard University and was on the faculty of Michigan State University for nine years. His research interests include combustion, fire, heat transfer, and mass transfer.

Yansong Shan
Assistant Research Scientist
Shan received his Doctorate degree in 1992 from the University of Michigan. His dissertation was entitled "Robot Obstacle Accommodation: Mechanics, Control and Applications."

In Memoriam

Professor Emeritus William Mirsky died January 22, 1993, following an illness of several months. He received his doctorate from the University of Michigan in 1956 and was on the faculty for 35 years before retiring in 1988. Among his interests as a faculty member were the creative revision of courses, research on combustion and air pollution, and the application of computers in engineering education.

Professor Sam Wu died October 28, 1992, due to complications during open heart surgery. Professor Wu joined the MEAM faculty in 1987 after a 25-year career at the University of Wisconsin. During his tenure here, he founded and acted as director of the NSF-I/UCR Center for Mechanical and Optical Coordinate Measuring Machines and was the director of the Manufacturing Research Laboratory. Professor Wu was a world-recognized scholar in the areas of statistics and manufacturing, and during his 30-year career, he mentored 125 Ph.D. students, a world record for a university professor.

Faculty Publications 1992

Journal Articles

Assistant Professor Rayhaneh Akhavan

Jung WJ, Mangiavacchi N, and Akhavan R, "Suppression of Turbulence in Wall-Bounded Flows by High Frequency Spanwise Oscillations," *Phys Fluids* A 4[8]:1605-1607.

Professor Vedat Arpaci

Al-Nimr MA and Arpaci VS, "Radiative Properties of Interacting Particles," *ASME J Heat Transfer* 114:950-956.

Dec JE, Keller JO, and Arpaci VS, "Heat Transfer Enhancement in the Oscillating Turbulent Flow of a Pulse Combustor Tailpipe," *Intl J Heat Mass Transfer* 35[9]:2311-2325.

Evren-Selamet E, Arpaci VS and Borgnakke C, "Simulation of Laminar Buoyancy-Driven Flows in an Enclosure," *Numer Heat Transfer Part* A 22:401-420.

Associate Research Scientist James Ashton-Miller

Ashton-Miller JA, He Y, Kadhiresan VA, McCubbrey D, and Faulkner JA, "An Apparatus to Measure In Vivo Biomechanical Behavior of Dorsi- and Plantarflexors of the Mouse Ankle," *J Appl Physiol* 72:1205-11.

Ashton-Miller JA, McGlashen KM, and Schultz AB, "Trunk Positioning Accuracy in Children from 7 to 18 Years Old," *J Orthop Res* 10:217-225.

Schultz AB, Alexander N, and Ashton-Miller JA, "Biomechanical Analyses of Rising from a Chair," *J Biomech* 25:1383-91.

Associate Professor Arvind Atreya

Agrawal S and Atreya A, "Wind-Aided Flame Spread over an Unsteadily Vaporizing Solid," *24th (Intl) Symp on Combust*, The Combst Inst, p 1685.

Atreya A and Mekki K, "Heat Transfer During Wind-Aided Flame Spread on a Ceiling Mounted Sample," *24th (Intl) Symp on Combust*, The Combst Inst, p 1677.

Zhang C, Atreya A, and Lee K, "Sooting Structure of Methane Counterflow Diffusion Flames with Preheated Reactants and Dilution by Products of Combustion," *24th (Intl) Symp on Combust*, The Combst Inst, p 1049.

Professor James Barber

Barber JR, "Generalized Beam Theory Applied to Shear Stiffness," *Intl J Solids Structures* 29:1453-1455.

Barber JR and Sturla FA, "Application of the Reciprocal Theorem to Some Problems for the Elastic Half-space," *J Mech Phys Solids* 40:17-25.

Ben Ammar F, Kaviany M, and Barber JR, "Heat Transfer during Impact," *Intl J Heat Mass Transfer* 35:1495-1506.

Cho C, Holmes JW, and Barber JR, "Distribution of Matrix Cracks in a Uniaxial Ceramic Composite," *J Amer Ceram Soc* 75:316-324.

Li N-Y, Hector Jr. LG, and Barber JR, "Theories of Thermoelastic Instability during Solidification Based on the Neumann Temperature Solution," *J Therm Stresses* 15:265-293.

Lu X, Barber JR and Comninou M, "Stress Concentration Due to an Array of Hemispherical Cavities at the Surface of an Elastic Half-space," *J Elasticity* 28:111-122.

Associate Research Scientist Johann Borenstein

Borenstein J and Raschke U, "Real-time Obstacle Avoidance for Non-Point Mobile Robots," *SME Trans Robotics* Res 2:2.1-2.10.

Assistant Professor Giles Brereton

Brereton GJ, "Stochastic Estimation as a Statistical Tool for Approximating Turbulent Conditional Averages," *Phys Fluids* A, 4[9]:2046-2054.

Brereton GJ and Bruno BA, "Manipulation and Removal of Micron Particles by Focused Acoustic Waves," *Intl J Engin* Res 2:3-15.

Brereton GJ and Kodal A, "A Frequency-Domain Filtering Technique for Triple Decomposition of Unsteady Turbulent Flow," *J Fluids Engin* 114[1]:45-51.

Assistant Professor Steven Ceccio

Ceccio SL and Brennen CE, "Dynamics of Attached Cavities on Bodies of Revolution," *J Fluids Engin* 114:93-99.

Professor Maria Comninou

Lu X, Barber JR and Comninou M, "Stress Concentration Due to an Array of Hemispherical Cavities at the Surface of an Elastic Half-space," *J Elasticity* 28:111-122.

Professor Walter Debler

Debler W, "A Simple Method for Determining Laminar Boundary Layer Evolution," *Intl Mech Engin Ed* 20[1]:33-38.

Assistant Professor David Dowling

Dowling DR and Jackson DR, "Narrow-band Performance of Acoustic Phase-conjugate Arrays in Dynamic Random Media," *J Acoustical Soc Amer* 91[6]:3257-3277.

Waggoner AP, Radke LF, Buonadonna VR and Dowling DR, "Cloud Clearing with a CO2 Laser in a Cirrus Cloud Simulation Facility," *Appl Optics* 31[27]:5871-5877.

Assistant Professor Debasish Dutta

Dutta D and Srinivas YL, "Reconstructing Curved Solids From Two Polygonal Orthographic Views," *Computer Aided Des* 24[3].

Levin J and Dutta D, "Computer-Aided Process Planning for Parallel Machining," *J Manufact Systems* 11[2].

Professor Steven Goldstein

Buchholz B, Armstrong TJ, Goldstein SA, "Anthropometric Data for Describing the Kinematics of the Human Hand," *Ergonomics* 35[3]:261-273.

Carpenter JE, Fish DN, Huston LJ, and Goldstein SA, "Pull-Out Strength of Five Suture Anchors," *Arthroscopy* 8[3]:399.

Choi K and Goldstein SA, "The Fatigue Properties of Human Trabecular Bone Tissue," *J Biomech* 25[2]:1371-1381.

Goldstein SA, et al, "Aggrecan Core Protein as Expressed in Membranous Bone of the Chick Embryo: Molecular and Biomechanical Studies of Normal and Nanomelia Embryos," *J Biologic Chem* 267[8]:5592-5598.

Goldstein SA, et al, "Proximal Femur Bone Density and its Correlation to Fracture Load and Hip Screw Penetration Load," *Clin Orthop and Related Res* 283:244-251.

Matthews LS and Goldstein SA, "The Prosthesis-Bone Interface in Total Knee Arthroplasty," *Clin Orthop* 276:50-55.

Assistant Professor Mehrdad Haghi

Haghi M and Anand L, "A Constitutive Model for Isotropic, Porous, Elastic-Viscoplastic Metals," *Mech of Matl* 13:37-53.

Assistant Professor Scott Hollister

Hollister S, Kikuchi N, Goldstein S, "Do Bone Ingrowth Processes Produce a

Globally Optimized Structure?," *J Biomechanics*, 26:391-407.

Ko C, Kohn D, Hollister S, "Micromechanics of Implant /Tissue Interfaces," *J Oral Implantology*, 18:220-230.

Associate Professor John Holmes

Cho C, Holmes JW, and Barber J, "Distribution of Matrix Cracks in a Uniaxial Composite, " *J Am Ceram Soc* 75[2]:316-24.

Holmes JW and Cho C, "Experimental Observations of Frictional Heating in a Fiber Reinforced Ceramic," *J Am Ceram Soc* 74[4]:929-38.

Holmes JW and Cho C, "Frictional Heating in a Unidirectional Fiber-Reinforced Ceramic Composite," *J Matl Sci Lett* 11:41-44.

Holmes JW, "A Technique for Elevated Temperature Creep and Tensile Fatigue Testing of Fiber-Reinforced Ceramics," J Compos Matl 26[6]:915-932.

Park Y and Holmes JW, "Finite Element Modeling of Creep Deformation in Fiber-Reinforced Ceramic Composites," *J Matl Sci* 27:6341-6351.

Assistant Professor Gregory Hulbert

Hulbert GM, "Explicit Momentum Conserving Algorithms for Rigid Body Dynamics," *Computers and Structures* 44:1291-1304.

Hulbert GM, "A Second-Order Accurate Explicit Subcycling Algorithm for Unsteady Heat Conduction," *Numer Heat Transfer* 22:199-209.

Hulbert GM, "Discontinuity-Capturing Operators for Elastodynamics," *Computer Meths in Appl Mech and Engin* 96:409-426.

Hulbert GM, "Time Finite Element Methods for Structural Dynamics," *Intl J Numer Meths in Engin* 33:307-331.

Associate Professor Glen Johnson

Hammond CR and Johnson GE, "Functional Dependence and the Method of Alternate Formulations in Optimal Design," *Trans ASME J Mech Des* 114[4]:596-602.

Santangelo A and Johnson GE, "Optimal Wing Configuration of a Tethered Satellite in Free Molecular Flow," *AIAA J Spacecraft and Rockets* 29[5]:668-670.

Associate Professor Elijah Kannatey-Asibu, Jr.

Chung J and Kannatey-Asibu Jr. E, "Acoustic Emission from Plastic Deformation of a Pure Single Crystal," *J Appl Physics* 72[5]:1812-1820.

Purvis AL, Kannatey-Asibu Jr E, and Pehlke R, "Numerical Simulation of Solidification and Thermal Stresses During Solidification of a Restrained Bar Test Casting," *Trans Amer Foundrymen Soc* 100:593-600.

Rhee S and Kannatey-Asibu Jr. E, "Observation of Metal Transfer in Gas Metal Arc Welding," *Welding J* 71:381-s—386-s.

Associate Professor Bruce Karnopp

Karnopp B, Fisher F, and Yoon B, "A Strategy for Moving a Mass from One Point to Another," *J Franklin Institute* 329[5]: 881-892.

Professor Massoud Kaviany

Ben-Ammar F, Kaviany M, and Barber JR, "Heat Transfer During Impact," *Intl J Heat Mass Transfer* 35:1495-1506.
Kim C-J and Kaviany M, "A Fully Implicit Method for Diffusion-Controlled Solidification of Binary Alloys," *Intl J Heat Mass Transfer* 35:1143-1154.

Kim C-J and Kaviany M, "A Numerical Method for Phase-Change Problems with Convection and Diffusion," *Intl J Heat Mass Transfer* 35:457-467.

Rogers JA and Kaviany M, "Funicular and Evaporative-Front Regimes in Convective Drying of Granular Beds," *Intl J Heat Mass Transfer* 35:469-480.

Sahraoui M and Kaviany M, "Slip and No-Slip Velocity Boundary Conditions at Interface of Porous, Plain Media," *Intl J Heat Mass Transfer* 35:927-943.

Singh BP and Kaviany M, "Modeling Radiation Heat Transfer in Packed Beds," *Intl J Heat Mass Transfer* 35:1397-1405.

Associate Professor Robert Keller

Merte Jr. H, Ervin JS, Keller RB, and Kirk K, "Transient Pool Boiling in Microgravity", *Intl J Heat Mass Transfer* 35:659-674.

Professor Noboru Kikuchi

Hollister SJ and Kikuchi N, "A Comparison of Homogenization and Standard Mechanics Analyses for Periodic Porous Composites," *Computational Mechanics* 10:73-95.

Ma Z-D, Kikuchi N, Cheng H-C, and Hagiwara I, "Topology and Shape Optimization Methods for Structural Dynamic Problems," *Recent Advances in Structural Problems*, PVP-248/ NE-10: 133-143.

Tezuka A and Kikuchi N, "Finite Element Discretization by Using the H-Adaptive Method-III: Error Measure and Convergence," *Trans JSME, Series A*, 58[555]: 2199-2205.

Torigaki T and Kikuchi N, "Appropriate Remeshing for Finite Element Impact Analysis with Consideration of Error and Computing Efficiency," *Nucl Engin and Design* 138:53-64.

Professor Yoram Koren

Davidove G, Shavit A, and Koren Y, "Estimation of Dynamical-Varying Parameters by the Internal Model Principle," *IEEE Trans Automatic Control* 37[4]:498-503.

Feng L, Fainman Y, and Koren Y, "Estimation of the Absolute Position of Mobile Systems by an Optoelectronic Processor," *Trans IEEE Systems, Man, and Cybernetics* 22[5]:953-964.

Koren Y and Lo C, "Advanced Controllers for Feed Drives," A keynote paper, *CIRP Annals 2:689-698.*

Associate Professor Sridhar Kota

Esterline A and Kota S, "A General Paradigm for Routine Design: Theory and Implementation," *Artificial Intelligence Engin Design, Analysis, and Manuf (AIEDAM)* 6[2]:73-93, Academic Press Limited.

Gomes E and Kota S, "A Knowledge-Based System for Nondestructive Testing of Polymeric Composite Components," *Res Nondestructive Evaluation* 4:37-54, Springer-Verlag, NY.

Kota S, "Automatic Selection of Mechanism Designs from a Three-Dimensional Design Map," *ASME J Mech Design* 114[3]:359-367.

Kota S and Chiou S-J, "Conceptual Design of Mechanisms Based on Computational Synthesis and Simulation of Kinematic Building Blocks," *Res in Engin Design* 4:75-87, Springer-Verlag, New York.

Lee C-L, Iyengar G, and Kota S, "Automated Configuration Design of Hydraulic Systems," *Artificial Intelligence in Design*, pp 61-82, Kluwer Academic Publications.

Professor Kenneth Ludema

Ajayi OO and Ludema KC, "The Effect of Microstructure on Wear Modes of Ceramic Materials," *Wear 154:371.*

Professor Herman Merte

Ervin JS, Merte Jr. H, Keller RB, and Kirk K, "Transient Pool Boiling in

Microgravity," *Intl J Heat Mass Transfer* 35:659-674.

Associate Professor Jun Ni

Chen JS, Yuan JX, Ni J, and Wu SM, "Compensation of Non-rigid Body Kinematic Effect on a Machining Center," *Trans NAMRI* 20:325-329.

Ni J, Huang PS, and Wu SM, "A Multi-Degree-of-Freedom Measuring System for CMM Geometric Errors," *ASME Trans J Engin for Indust* 114[3]:362-369.

Professor Panos Papalambros

Chirehdast M and Papalambros P, "A Note on Automated Detection of Mobility of Skeletal Structures", *Computers and Structures* 45[1]:197-207.

Associate Professor Noel Perkins

Cheng S-P and Perkins NC, "Closed-form Vibration Analysis of Sagged Cable/Mass Suspensions," *ASME J Appl Mech* 59[4]:923-928.

Cheng S-P and Perkins NC, "Free Vibration of a Slack Cable Supporting a Discrete Mass," *J Acoustical Soc Amer* 91[5]:2654-2662.

Hwang S-J and Perkins NC, "Critical and Super-critical Stability of an Axially Moving Beam, Part I: Modeling and Equilibrium Analysis," *J Sound and Vib* 154[3]:381-396.

Hwang S-J and Perkins NC, "Critical and Super-critical Stability of an Axially Moving Beam, Part II: Vibration and Stability Analyses," *J Sound and Vib* 154[3]:397-410.

Lee CL and Perkins NC, "Nonlinear Oscillations of Suspended Cables Containing a Two-to-one Internal Resonance," *J Nonlinear Dynamics* 3:465-490.

Perkins NC, "Modal Interactions in the Nonlinear Response of Elastic Cables Under Parametric/External Excitation," *Intl J Nonlinear Mechs* 27[2]:233-250.

Associate Professor Christophe Pierre

Bouzit D and Pierre C, "Vibration Confinement Phenomena in Disordered, Mono-Coupled, Multi-Span Beams," *ASME J Vibration and Acoustics* 114:521-530.

Choi SH, Pierre C, and Ulsoy AG, "Consistent Modeling of Rotating Timoshenko Shafts Subject to Axial Loads," *ASME J Vibration and Acoustics* 114:249-259.

Pierre C and Murthy DV, "Aeroelastic Modal Characteristics of Mistuned Blade Assemblies: Mode Localization and Loss of Eignstructure," *AIAA J* 30[10]:2483-2496.

Professor Albert Schultz

Alexander NB, Shepard NT, Gu MJ, and Schultz AB, "Postural Control in Young and Elderly Adults When Stance is Perturbed: Kinematics," *J Gerontol: Med Sci* 47:M79-87.

Ashton-Miller JA, McGlashen KM, and Schultz AB, "Trunk Positioning Accuracy in Children 7 to 18 Years Old," *J Orthop Res* 10:217-225.

Closkey RF, Schultz AB, and Luchies CW, "A Model for Studies of the Deformable Rib Cage," *J Biomech* 25:529-539.

Schultz AB, "Mobility Impairment in the Elderly: Challenges for Biomechanics Research," *J Biomech* 25:519-528.

Schultz AB, Alexander NB, and Ashton-Miller JA, "Biomechanical Analyses of Rising From a Chair," *J Biomech* 25:1383-1391.

Associate Professor William Schultz

Schumack M, Schultz WW, and Boyd JP, "Taylor Vortices between Elliptical Cylinders," *Physics Fluids* A 2:2578-2581.

Professor Richard Scott

Argento A and Scott RA, "Dynamic Response of a Rotating Beam Subjected to an Accelerating Distributed Surface Force," *J Sound and Vib* 157:221-231.

Beale DG and Scott RA, "The Stability and Response of a Flexible Rod in a Quick Return Mechanism: Large Crank Case," *J Sound and Vib.*

Bebhoud A and Scott RA, "Whirling Motions of a Beam Generated by In-Plane Pulses," *J Sound and Vib* 152:183-188.

Wiens GJ, Zarraugh MY, and Scott RA, "Effects of Geometric Parameters on Manipulator Dynamic Performance," *J Mech Des* 114:137-142.

Assistant Research Scientist Ahmet Selamet

Arpaci VS and Sealmet A, "Entropic Efficiency of Energy Systems," *Progress in Energy and Combust Sci* 18:429-445.

Selamet A, "Visible and Infra-red Sensitivity of Rayleigh Limit and Penndorf Extension to Complex Refractive Index of Soot," *Intl J Heat and Mass Transfer* 35[12]:3479-3484.

Associate Professor Steven Shaw

Shaw SW, et al., "Applications of Modern Geometric Methods for Dynamical Systems to the Problem of Vessel Capsizing with Water-on-Deck," *Intl J Bifurcation and Chaos* 2:101-115.

Shaw SW and Haddow A, "On Rollercoaster Experiments for Nonlinear Oscillators," *Nonlinear Dynamics* 3:375-384.

Shaw SW and Sharif-Bakhtiar M, "Effects of Nonlinearities and Damping on the Dynamic Response of a Centrifugal Pendulum Vibration Absorber," *ASME J Vibration and Acoustics* 114:305-311.

Assistant Professor Louis Soslowsky

Soslowsky LJ, et al, "Tensile Properties of the Inferior Glenohumeral Ligament," *J Orthop Res* 10:187-197.

Soslowsky LJ, et al, "Quantitation of In Situ Contact Areas in the Glenohumeral Joint: A Biomechanical Study," *J Orthop Res,* 10:524-534.

Soslowsky, LJ, Flatow, EL, Bigliani LU, and Mow VC, "Articular Geometry of the Glenohumeral Joint," *Clin Orthop and Related Res* 185:181-190.

Professor John Taylor

Taylor JE, "A Global Extremum Principle for the Analysis of Solids Composed of Softening Material," *Intl J Solids and Structures.*

Associate Professor Grétar Tryggvason

Dahm WJA, Frieler CE and Tryggvason G, "Vortex Structure and Dynamics in the Near Field of a Coaxial Jet," *J Fluid Mech* 241:371-402.

Song M, Bernal LP and Tryggvason G, "Head-on Collision of a Large Vortex Ring with a Free Surface," *Phys of Fluids* A 4:1457-1466.

Tryggvason G, Abdollahi-Alibeik J, Willmarth W and Hirsa A, "Collision of a Vortex Pair with a Contaminated Free Surface," *Phys of Fluids* A 4:1215-1229.

Unverdi SO, Tryggvason G, "A Front Tracking Method for Viscous Incompressible Flows," *J Computer Phys* 100:25-37.

Unverdi SO, Tryggvason G, "Computations of Multi-Fluid Flows," *Physica* D 60:70-83.

Professor Galip Ulsoy

Choi SH, Pierre C, and Ulsoy AG, "Consistent Modeling of Rotating Timoshenko Shafts Subject to Axial Loads," *ASME J Vibration and Acoustics* 114[2]:249-259.

Park JJ, and Ulsoy AG, "On-Line Tool Wear Estimation Using Force Meas. and a Nonlinear Observer," *ASME J Dynamic Systems, Measurement, and Control* 114[4]:666-672.

Professor Alan Wineman

Wineman A, Dai F, and Rajagopal KR, "Non-Uniform Extension of a Non-Linear Viscoelastic Slab," *Intl J Solids and Structures* 29:911-930.

Wineman A and Negahban M, "Modeling the Mechanical Response of a Material Undergoing Continuous Crystallization," *Intl J Engin Sci* 30:953-962.

Wineman A and Negahban M, "The Evolution of Anisotropies in the Elastic Response of an Elastic-Plastic Material," *Intl J Plasticity* 8:519-542.

Wineman A and Rajagopal KR, "Circular Shearing and Torsion of Generalized Neo-Hookean Materials," *IMA J Appl Math* 48:23-37.

Wineman A and Rajagopal KR, "Flow of Electrorheological Fluids," *Acta Mechanica* 91:57-75.

Wineman A and Rajagopal KR, "A Constitutive Equation for Non-Linear Solids Which Undergo Deformation Induced Microstructural Changes," *Intl J Plasticity* 8:385-395.

Wineman A and Rajagopal KR, "Shear Induced Redistribution of Fluid Within a Uniformly Swollen Non-Linear Elastic Cylinder," *Intl J Engin Sci* 0:1583-1595.

Professor Wei-Hsuin Yang

Yang WH and Tyan T, "Analysis of Metal Cutting Process," *Intl J Numer Meths Engin* 34:365-389.

Professor Wen-Jei Yang

Yang W-J and Fann S, "Hydrodynamically-Thermally Developing Laminar Flow Through Rotating Channels Having Isothermal Walls," *Numer Heat Transfer* 19.

Yang W-J, Fann S, and Mochizuki S, "Heat and Fluid Flow at Entrance Regions of Rotating Iso-heat Flux with Laminar Throughflow," *Intl J Numer Meths Heat and Fluid Flow.*

Yang W-J and Inada S, "Effects of Heating Surface Materials on a Liquid-Solid Contact State in a Sessile Drop-Boiling System," *J Heat Transfer* 114.

Yang W-J and Lou Z," A Computer Simulation of the Non-Newtonian Blood Flow at the Aortic Bifurcation," *J Biomech* 26[1]:57-89.

Yang W-J and Lou Z, "A Computer Simulation of the Blood Flow at the Aortic Bifurcation with Flexible Walls" *J Biomechanical Engin* 114.

Yang W-J, Lou Z, and Stein PD, "Errors in Estimation of Arterial Wall Shear Rates that Result from Curve-Fitting of Velocity Profiles," *J Biomech* 25.

Yang W-J and Torii S, "Melt-Particle Mixing in Gas-Stirred Ladles with Throughflow", *Experiments in Fluids* 11.

Yang W-J and Uemura T, "Shadowgraphs of an Organic Liquid Droplet Evaporating on a Glass Plate," *Photographic J Flow Visualization* 9, Articles No. 39-40.

Yang W-J, Zhang N, and Yang GW, "Two Tier Model for Nucleate Pool Boiling on Microconfigured Composite Surfaces," *Intl Communications Heat and Mass Transfer.* 19[6]:767-779.

Conference Proceedings:

Assistant Professor Rayhaneh Akhavan

Akhavan R, Jung W J and Mangiavacci N, "Turbulence Control in Wall-Bounded Flows by Superimposed Spanwise Oscillations," *4th European Turbulence Conf,* Delft, Netherlands.

Ansari A, Mangiavacchi N, and Akhavan R, "Structure and Dynamics of the Small Scales in a Numerically Simulated Planar Turbulent Jet," *45th Ann Meet Div Fluid Dyn, Amer Phys Soc,* Tallahassee, FL. Abstract in *Bull Amer Phys Soc* 37[8]:1740.

Mangiavacchi N, Ansari A, and Akhavan R, "Interscale Energy Transfer in a Numerically Simulated Planar Turbulent Jet," *45th Ann Meet Div Fluid Dyn, Amer Phys Soc,* Tallahassee, FL. Abstract in *Bull Amer Phys Soc* 37[8]:1740.

Jung WJ and Akhavan R, "Suppression of Turbulence in Wall-Bounded Flows by High Frequency Spanwise Oscillations," *45th Ann Meet Div Fluid Dyn, Amer Phys Soc,* Tallahassee, FL. Abstract in *Bull Amer Phys Soc* 37[8]:1738.

Professor Vedat Arpaci

Arpaci VS, "Buoyant Turbulent Flow Driven by Internal Energy Generation," *Thermal Hydraulics of Advanced and Special Purpose Reactors,* HTD 209:11-18 (FB Cheung and PF Peterson eds) WAM, ASME, Anaheim, CA.

Arpaci VS, "A Thermal Mesomicroscale for Turbulent Forced Convection," *Fundamental Issues in Small Scale Heat Transfer,* HTD 227: 69-74 (Y Bayazitoglu and PF Peterson, eds) WAM, ASME, Anaheim, CA.

Assistant Professor Ellen Arruda

Arruda EM and Boyce MC, "The Anisotropy of Large Deformations in Polycarbonate," *13th RISO Intl Symp Metallurgy and Materials Sci Modeling of Plastic Deformation and its Engineering Applications.*

Arruda EM and Boyce MC, "The Roles of Temperature and Strain Rate in the Development of Anisotropy during Large Strain Deformations of Glassy Polymers," *29th Ann Meet, Soc of Engin Sci.*

Associate Research Scientist James Ashton-Miller

Ashton-Miller JA, et al, "Maintenance of Balance, Gait Patterns, and Obstacle Clearance in Alzheimer's Disease," *45th Ann Meet, GSA,* Wash., D.C.

Ashton-Miller JA, et al, "Accuracy of Foot- Ground Clearance Estimation in Healthy Adults," *45th Ann Meet, GSA,* Wash., D.C.

Ashton-Miller JA, Schultz AB, Alexander NB, and Grenier J, "Assessment of Mobility in the Elderly," *N Amer Cong Biomechanics,* Chicago.

Professor James Barber

Barber JR, "Instability of Unidirectional Solidification due to Pressure-Dependent Thermal Contact Resistance at the Mould/Casting Interface," *Contact Mechanics Intl Symp,* Lausanne, Switz.

Li NY, Hector Jr LG, and Barber JR, "Theories of Growth Instability during Solidification of Metals: Part II, Stress Function Approach," *Intl Conf Transport Phenomena in Processing,* HI.

Yigit F and Barber JR, "Effect of Thermal Capacity on the Development of Sinusoidal Perturbations during the Unidirectional Solidification of Pure Metals," HTD-218/AMD-139:141-150, *ASME WAM,* Anaheim, CA.

Associate Research Scientist Johann Borenstein

Borenstein J, "Compliant-linkage Kinematic Design for Multi-Degree-of-Freedom Mobile Robots," *SPIE Symp Advances in Intelligent Systems, Mobile Robots VII,* Boston, MA, November.

Borenstein J and Koren Y, "Noise Rejection for Ultrasonic Sensors in Mobile Robot Applications," *IEEE Conf Robotics and Automation,* pp. 1727-17, Nice, France, May.

Assistant Professor Giles Brereton

Brereton GJ and Bruno B, "Streaming Motion in the Vicinity of an Acoustic Wave Focused at a Surface," *ASME Fluids Engineering Division Meeting, Los Angeles*, 133:257.

Brereton GJ and Kodal A, "Application of the Turbulence Filter to Decomposition of Complex Turbulent Flow, " *ASME Fluids Engineering Division Meeting*, 133:139, Los Angeles.

Brereton GJ and Kodal A, "The Turbulent Filter: A Decomposition Technique for Complex Turbulent Flow," *Bull Am Phys Soc* 37:10.

Bruno BA and Brereton GJ, "Removal of Micron Particles from Surfaces with Focused Acoustic Waves," *23rd Ann Meet Fine Particle Soc, 4th Symp Particles on Surfaces: Detection, Adhesion and Removal*, 2:95, Las Vegas.

Hwang J-L and Brereton GJ, "Turbulence in Fully Developed Pipe Flow with High Frequency Streamwise Oscillatory Forcing," *Bull Am Phys Soc* 37:10.

Spears RJ and Brereton GJ, "Potential Intravascular Oxygenation with Oxygen Clathrate Hydrate," *65th Amer Heart Assoc Scientific Sess*, New Orleans.

Assistant Professor Steven Ceccio

Kuhn De Chizelle Y, Ceccio SL, Brennen CE and Gowing S, "Scaling Experiments on the Dynamics and Acoustics of Traveling Bubble Cavitation," *3rd Intl Conf Cavitation*, Cambridge, U.K.

Kuhn De Chizelle Y, Ceccio SL, Brennen CE, and Shen Y, "Cavitation Scaling Experiments with Headforms: Bubble Acoustics," *19th Symp Naval Hydrodynamics*, Seoul, Korea.

Kuhn De Chizelle Y, Ceccio SL, Brennen CE, and Shen Y, "Cavitation Scaling Experiments with Headforms: Bubble Dynamics," *2nd Intl Symp Propeller and Cavitation ISPC*, Hangzhou, China.

Kuhn De Chizelle Y, Ceccio SL, Brennen CE and Shen Y, "Cavitation Scaling Experiments with Axisymmetric Bodies," *23rd Amer Towing Tank Conf*, pp. 167-173, New Orleans, LA.

Professor Michael Chen

Li JW, and Chen MM, "The Added Mass and the Modified Bassestt Forces of Stokes Flow over Regular Arrays," *Division of Fluid Dynamics Meeting*, American Physical Society, Tallahasse, FL.

Chen MM, "Research Opportunities at the National Science Foundation," *National Heat Transfer Conference*, Aug. 10-12, San Diego, CA

Assistant Professor Debasish Dutta

Dutta D and Srinivas YL, "Motion Planning in Three Dimensions With Cyclides," *Computer Graphics Intl 1992*, Tokyo, June.

Dutta D and Woo TC, "Algorithms for Multiple Disassembly and Parallel Assemblies," *ASME WAM, Symp Concurrent Engineering*, Anaheim, CA.

Gelston S and Dutta D, "Boundary Surface Recovery from Skeleton Elements Part I: Curves and Part II: Surfaces," *ASME Design Automation Conf*, Phoenix, AZ.

Levin J and Dutta D, "On the Effects of Parallelism on Computer-Aided Process Planning," *ASME Computers In Engineering Conf*, San Francisco, CA.

Srinivas YL and Dutta D, "Blending and Joining with Cyclides," *ASME Design Automation Conf*, Phoenix, AZ.

Wentland K and Dutta D, "Offset Curves in Sheet Metal Design," *ASME WAM, Symp Concurrent Engineering*, Anaheim, CA.

Research Scientist Robert Ervin

Chen K and Ervin RD, "Worldwide IVHS Activities: A Comparative Overview," *Intl Congr Transp Electronics*, pp. 339-349, Dearborn, MI, SAE, Warrendale.
Ervin RD and Fancher PS, "Rationalizing the Study of Active Safety Technologies," *1992 Annual Meeting IVHS Amer*, 2:751-784, Newport Beach, IVHS America.

Ervin RD, MacAdam CC, Gilbert K, and Tchoryk P Jr., "Quantitative Characterization of the Vehicle Motion Environment (VME)," *Vehicle Navigation and Information Systems Conf, 1991*, SAE Transactions 100, Warrendale, SAE, 1992.

Professor Steven Goldstein

Wong M, Bonadio J, and Goldstein SA, "The Effect of Reduced Mechanical Loading on the Growth and Morphogenesis of the Chick Embryo Long Bone," *38th Ann Meet Orth Res Soc*, Wash., D.C.

Goldstein SA, et al, "Biomechanical Assessment of the Extracellular Matrix of Bones: The Contribution of Collagen Type I," *7th Meet European Soc Biomech*, Rome, Italy.

Goldstein SA, et al, "Relationships Between Regional Material Properties, Density, and Architecture of the Human Proximal Femur," *ASME, WAM*, Anaheim, CA

Assistant Research Scientist Shixin (Jack) Hu

Hu S and Wu SM, "Identifying Sources of Variation in Automobile Body Assembly Using Principal Component Analysis," *Transactions of NAMRI*, pp. 311-316.

Assistant Professor Gregory Hulbert

Hulbert GM and Chung J, "A New Explicit Time Integration Method for Structural Dynamics: The Explicit Generalized- α Method," in *New Methods in Transient Analysis* (P Smolinski, WK Liu, G Hulbert and K Tamma, eds), ASME, New York, AMD 143:73-78.

Hulbert GM and Jang I, "Adaptive Time Integration Algorithms for Structural Dynamics," in *Adaptive, Multilevel and Hierarchical Computational Strategies* (AK Noor, ed), ASME, New York, AMD 157:223-233.

Associate Professor Glen Johnson

Conwell JC, Johnson GE, and Peterson SW, "Design and Constructions of a Machine to Evaluate the Forces in Roller Chain Drives," *Advancing Power Transmission into the 21st Century* 2:703-710, ASME, DE-Vol. 43-2, NY.

Conwell JC, Johnson GE, and Peterson SW, "Experimental Investigation of the Forces in a Link Side Plate During Normal Operation of a Roller Chain Drive," *Advancing Power Transmission into the 21st Century* 2:711-716, ASME, DE-Vol. 43-2, New York.

Conwell JC, Johnson GE, and Peterson SW, "Experimental Investigation of the Impact Force that Occurs when a Roller Seats on the Sprocket During Normal Operation of a Roller Chain Drive," *Advancing Power Transmission into the 21st Century* 2:717-722, ASME, DE 43-2, New York.

Kim MS and Johnson GE, "Mechanics of Roller Chain - Sprocket Contact: A General Modeling Strategy," *Advancing Power Transmission into the 21st Century 2:689-696*, ASME, DE43-2, New York.

Kim MS and Johnson GE, "Mechanics of Roller Chain - Sprocket Contact: Observations About Contact Phenomena and Load Distribution," *Advancing Power Transmission into the 21st Century* 2:697-702, ASME, DE43-2, NY.

Associate Professor
Elijah Kannatey-Asibu, Jr.

Kannatey-Asibu Jr E, "Gaussian-Line Dual Laser Beam Welding," *1st Intl Conf Transport Phenomena in Processing*, Honolulu, HI.

Associate Professor Bruce Karnopp

Karnopp B and Yoon B, "A Strategy for Moving Mass Systems from One Point to Another without Inducing Residual Vibration," *14th Canadian Congress Applied Mechanics*, Kingston, Ontario.

Professor Massoud Kaviany

Sahraoui M and Kaviany M, "Slip and No-Slip Temperature Boundary Conditions at Interface of Porous, Plain Media: Convection, Part 1: Formulation and Part 2: Results," in Fundamentals of Heat Transfer in Porous Media - 1992, *28th National Heat Transfer Conf*, ASME HTD 193:25-47,San Diego, CA.

Professor Noboru Kikuchi

Kikuchi N, "Multiloading Shape Topology Optimization of Elastic Structures Using the Homogenization Method," *1st European Conf Numer Meths in Engin.*

Ma Z-D, Cheng H-C, Kikuchi N, and Hagiwara I, "Topology and Shape Optimization Technique for Structural Dynamic Problems," *IUTAM Symp Optimal Design with Advanced Materials*, pp 1-15.

Professor Yoram Koren

Lo CC and Koren Y, "Evaluation of Servo-Controllers for Machine Tools," *Amer Control Conf(ACC)*, pp 800-801, Chicago, IL.

Associate Professor Sridhar Kota

Ananthasuresh GK, Kota S, Crary SB, and Wise KD, "Design and Fabrication of Microelectromechanical Systems," *ASME Design Technical Conf.*

Crary S, Ananthasuresh GK, and Kota S, "Prospects for Microflight Using Micromechanisms," *IFToMM-jc Intl Symp Theory of Machines and Mechanisms* 1:273-276, Nagoya, Japan.

Iyengar G, Lee C-L, and Kota S, "Towards an Objective Evaluation of Alternate Designs," *ASME Design Technical Conf* DE 42:19-25.

Kota S and Chuenchom T, "Generalized Synthesis of Adjustable Mechanisms," *ASME Design Technical Conf* DE 46:253-260.

Kota S and Bidare S, "Systematic Synthesis and Applications of Novel Multi-degree-of-Freedom Differential Systems," *ASME Design Technical Conf* DE 46.

Kota S and Chiou SJ, "Design Representation and Computational Synthesis of Mechanical Motions," *ASME Design Technical Conf* DE 42:365-372.

Professor Herman Merte

Kirk K, Merte H Jr. and Keller RB, "Low Velocity Nucleate Flow Boiling at Various Velocities," *Symp Fluid Mechanics Phenomena in Microgravity* ASME AMD 154/ FED142:1-10, Anaheim, CA.

Merte H Jr., "Low Velocity Forced Convection Nucleate Boiling at Various Orientations Relative to Earth Gravity," *Engin Conf Pool and External Flow Boiling Heat Transfer*, Santa Barbara, CA., March 22-27, (VK Dhir and AE Bergles, eds) ASME, N.Y.

Straub J, Winters J, Picker G, Merte H Jr. and Kono A, "Study of Vapor Bubble Growth in a Superheated Liquid," *VIII European Symp Mater and Fluid Sciences in Microgravity*, Brussels, Belgium, April 12 - 16.

Associate Professor Jun Ni

Chen YD, Tang XJ, Ni J and Wu SM, "Automatic Digitization of Free-Form Curves by Coordinate Measuring Machines," *ASME WAM*, Anaheim, CA.

Chen YD, Tang XJ, Ni J and Wu SM, "Curve Modeling by Data Reduction Method," *ASME WAM*, Anaheim, CA.

Chen JS, Yuan J, Ni J, and Wu SM, "Thermal Error Modeling for Volumetric Error Compensation," *ASME WAM*, Anaheim, CA.

Hong SY, Ni J, and Wu SM, "Analysis of Drill Failure Modes by Multi-sensors on a Robotic End Effector," *USA-Japan Symp Flexible Automation*, San Francisco, CA.

Hong SY, Ni J, and Wu SM, "Preventive Diagnosis of Minor Machine Failure by DDS Spectrum Analysis," *USA-Japan Symp Flexible Automation*, San Francisco, CA.

Lu E, Ni J, and Wu SM, "An Integrated Lattice Filter Adaptive Control System for Time-Varying CMM Structural Vibration Control, Part I: Theory and Simulation," *ASME WAM*, Anaheim, CA.

Lu E, Ni J, and Wu SM, "An Integrated Lattice Filter Adaptive Control System for Time-Varying CMM Structural Vibration Control, Part II: Experimental Implementation," *ASME WAM*, Anaheim, CA.

Professor Panos Y. Papalambros

Chirehdast M, Kikuchi N, Papalambros P, and Diaz AR, "Generalized Layout Problems in Structural Optimization," *NSF Design and Manufacturing Systems Grantees Conf*, Atlanta, GA.

Chirehdast M, Gea HC, Kikuchi N, and Papalambros P, "Structural Configuration Examples of an Integrated Optimal Design Process," *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Lo C and Papalambros P, "On Global Feasible Search for Global Design Optimization with Application to Generalized Polynomial Models," *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Lo C and Papalambros P, "A Convex Cutting Plane Algorithm for Global Solution of Generalized Polynomial Optimal Design Models." *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Pomrehn LP and Papalambros P, "Constraint Activity Revisited: Application to Global and Discrete Design Optimization," *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Pomrehn LP and Papalambros P, "Discrete Optimal Design Formulations with Application to Gear Train Design," *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Pomrehn LP and Papalambros P, "Infeasibility and Non-optimality Tests for Solution Space Reduction in Discrete Optimal Design," *Advances in Design Automation-1992*, D. Hoelzel (ed.), ASME, New York.

Chirehdast M, Kikuchi N, Papalambros P, and Diaz AR, "Recent Developments of an Integrated Structural Optimization System," *Third National Congress on Mechanics*, Athens, Greece.

Dutta D, Kikuchi N, Papalambros P, Prinz F, and Weiss L, "Project MAXWELL: A Methodology for Material Composition and Fabrication of Structural Components," *Solid Free-Form Fabrication Symp*, Austin, TX.

Chirehdast M, Gea HC, Kikuchi N, and Papalambros P, "Further Advances in an Integrated Structural Optimization System (ISOS)," *4th AIAA/USAF /NASA/OAI Symp on Multidisciplinary Analysis and Optimization*, Cleveland.

Associate Professor Noel Perkins

Beikmann RS, Perkins NC, and Ulsoy AG, "Free Vibration Analysis of Automotive Serpentine Belt Accessory Drive Systems," *CSME Mech Engin Forum*, pp 118-123, Montreal.

Cheng S-P and Perkins NC, "Structural Dynamics of Suspended Cables Supporting Arrays of Offset Bodies Part I: Out-of-Plane Response, (invited paper) *2nd Intl Offshore and Polar Engin Conf* 2:327-334, San Francisco, CA.

Cheng S-P and Perkins NC, "Structural Dynamics of Suspended Cables Supporting Arrays of Offset Bodies Part II: In-Plane Response, (invited paper) *2nd Intl Offshore and Polar Engin Conf* 2:335-341, San Francisco, CA.

Lee CL and Perkins NC, "Three-Dimensional Oscillations of Suspended Cables Involving Simultaneous Internal Resonances," (invited paper) *ASME WAM, Nonlinear Vibration Symp* DE-50/ AMD-144:59-67.

Associate Professor Christophe Pierre

Castanier MP and Pierre C, "Individual and Interactive Mechanisms for Localization and Dissipation in a Mono-Coupled Nearly Periodic Structure," *33rd AIAA/ASME Structures, Structural Dynamics and Materials Conf*, Dallas,TX.

Chen W-J and Pierre C, "Vibration Localization and Wave Conversion Phenomena in a Multi-Coupled, Nearly Periodic, Disordered Truss Beam," *Dynamics Specialists Conf*, AIAA 92-2115, Dallas, TX.

Murthy DV and Pierre C, "Stochastic Sensitivity Measure for Mistuned High-Performance Turbines," *4th Intl Symp Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC-4)*, Honolulu, HI.

Shaw SW and Pierre C, "On Nonlinear Normal Modes," (invited paper) *ASME WAM, Nonlinear Vibrations* DE 50/AMD144 (RA Ibrahim, et al, eds).

Murthy DV, Pierre C, and Ottarsson G, "An Efficient Constraint to Account for Mistuning Effects in the Optimal Design of Engine Rotors," *4th AIAA/ USAF/NASA Symp Multidisciplinary Analysis and Optimizations*, Cleveland.

Associate Professor William Schultz

Eggers K and Schultz WW, "Investigation on Time-Harmonic Disturbances for Inner-Kelvin-Angle Wave Packets," *7th Intl Workshop on Water Waves and Floating Bodies*, Val de Reuil, France.

Schultz WW, Cao Y, and Messiter A, "Waves on a Prescribed Surfactant Field," *GAMM Annual Meeting*, Leipzig, Germany.

Professor Richard Scott

Haering WJ, Ryan R and Scott RA, "A New Flexible Dynamic Formulation for Beam Structures Undergoing Large Overall Motion," *33rd Structures, Structural Dynamics and Materials Conf*, AIAA 92-1102, Dallas, TX.

Assistant Research Scientist Ahmet Selamet

Selamet A, "Mean Coefficients of Radiation in Sooty Media in Light of the Lorenz-Mie and Lorentz-Drude Theories," *SAE Congress*, Detroit, MI.

Associate Professor Steven Shaw

Shaw S and Pierre C, "On Nonlinear Normal Modes," *Nonlinear Vibrations*, ASME DE-50/AMD-144:1-5 (RA Ibrahim, NS Namachchivaya, and AK Bajaj, eds)

Assistant Professor Louis Soslowsky

Ateshian GA and Soslowsky LJ, "Human Knee Joint Anatomy and Cartilage Thickness," *38th Ann Meet Orthop Res Soc*, Washington, D.C.

Soslowsky LJ, et al, "Subacromial Contact on the Rotator Cuff in the Shoulder," *38th Ann Meet Orthop Res Soc*, Washington, D.C.

Soslowsky LJ, et al, "Excursion of the Rotator Cuff under the Acromion: Patterns of Subcromial Contact," *11th Annual Closed Meeting, American Shoulder and Elbow Surgeons.*

Soslowsky LJ, et al, "Kinematic Analysis of the Glenohumeral Joint," *11th Annual Closed Meeting, American Shoulder and Elbow Surgeons.*

Soslowsky LJ, et al, "A Stereophoto-grammetric Method to Determine the Kinematics of the Glenohumeral Joint," *Advances in Bioengineering*, ASME 22:143-146.

Ateshian GA, Kwak SD, Soslowsky LJ, and Mow VC, "A Stereophoto-grammetric Method for Determining In Situ Contact Areas in Diarthrodial Joints: A Comparison Study," *Advances in Bioengineering*, ASME 22:35-38.

Professor John Taylor

Pedersen P and Taylor JE, "Optimal Design Based on Power Law Nonlinear Elasticity," *IUTAM Symp: Optimal Design with Advanced Materials*, Aug 18-20, (P Pedersen, ed).

Taylor JE, "Truss Topology Design for Elastic/Softening Materials," *NATO Adv Res Workshop: Topology Design of Structures*, June 20-26 (M Bendsøe and CA Mota Soares, eds).

Taylor JE and Logo J, "Analysis and Design of Elastic/Softening Truss Structures Based on a Mixed-Form Extremum Principle," *NATO/FRG Conf Optimization of Large Structural Systems*, Sept 23-Oct 4 (G Rozvany, ed).

Associate Professor Grétar Tryggvason

Song M and Tryggvason G, "Numerical Investigation of an Oblique Collision of a Vortex Ring with a Clean Free Surface," *19th Symp Naval Hydrodynamics*, National Academy Press, Wash. D.C.

Tryggvason G, Jan Y-J, Esmaeeli A, and Unverdi SO, "Full Simulations of Multi-Bubble Flows," *2nd Intl Symp Propeller and Cavitation*, Hangzhou, China.

Professor Galip Ulsoy

Beikmann R, Perkins NC, and Ulsoy AG, "Free Vibration Analysis of Automotive Serpentine Belt Accessary Drive Systems," *CSME Transport 1992+ Conf*, Montreal, Canada.

Brusher GA, Kabamba PT, and Ulsoy AG, "Quantification of the Coupling Between the Modeling and Control-Design Problems," *Symp Automated Modeling, ASME WAM*, Anaheim, CA.

Brusher GA, Kabamba PT, and Ulsoy AG, "The Coupled Modeling and Robust Control Design Problem," *IEEE Conf Decision and Control.*

Chen SG, Ulsoy AG, and Koren Y, "Modeling, Simulation, and Analysis of Regenerative Chatter in Turning Using the ß Domain Formation," *IFAC Workshop Intelligent Manufacturing Systems*, Dearborn, MI.

Furness RJ, Wu CL, and Ulsoy AG, "Statistical Analysis of the Effects of Feed, Speed, and Wear on Hole Quality in Drilling," *ASME WAM*, Anaheim, CA.

Furness RJ, Wu CL, and Ulsoy AG, "Dynamic Modeling of the Thrust Force and Torque for Drilling," *Amer Control Conf*, Chicago, ILL.

Professor Alan Wineman

Wineman A and Hulway JA, "A Model for the Crush of Polymer Matrix Composite Tubes," *Advanced Composites: Design, Materials, and Processing Technologies*, 8th Ann ASM/ESD Advanced Composites Conf, Chicago, ILL.

Books or Book Chapters:

Associate Research Scientist
James Ashton-Miller

Stohler CS, Zhang X, and Ashton-Miller JA, "Experimental Model of Jaw Muscle Pain in Man," in *The Biological Mechanisms of Tooth Movement and Craniofacial Adaptation*, (Z Davidovitch, ed) pp 503-11.

Professor James Barber

Barber JR, *"Elasticity,"* Kluwer Academic Publishers, Dordrecht, Netherlands, p 293.

Assistant Professor Giles Brereton

Hwang JL and Brereton GJ, "Turbulence in High-Frequency Periodic Fully Developed Pipe Flow," in *Turbulent Shear Flows Eight* (BL Launder, U Schumann, and R Friedrich, eds), Springer-Verlag, pp 51-65.

Associate Professor John Holmes

Holmes JW, "Fatigue of Fiber Reinforced Ceramics," in *Ceramics and Ceramic Matrix Composites*, (SR Levine, ed), ASME, New York.

Assistant Professor Gregory Hulbert

Gallagher R and Hulbert GM (eds), *Computer Technology and Applications - 1992*, ASME, New York, PVP 234.

Smolinski P, Liu WK, Hulbert GM, and Tamma K (eds), *New Methods in Transient Analysis*, ASME, New York, AMD 143.

Professor Noboru Kikuchi

Guedes JM and Kikuchi N, "Premat/Postmat: A Computer Software for Computational Mechanics of Composite Materials" in *Computer Aided Innovation of New Materials* (M Doyama, et al, eds), North-Hollan, pp 925-934.

Kikuchi N, "Recent Development of Design Optimization of Elastic Structures," in *Computer Applications in Civil and Building Engineering* (M Fujimoto, ed), Japan Society of Civil Engineers and American Architectural Institute of Japan, pp 143-150 .

Kikuchi N and Suzuki K, "Structural Optimization of Linearly Elastic Structures Using the Homogenization Method," in *Shape and Layout Optimization of Structural Systems and Optimality Criteria Methods* (G Rozvany, ed), Springer-Verlag, Wien, pp 199-1242.

Lin GJ, Kikuchi N and Takahashi S, "Adaptive Remeshing Methods for Finite Element Simulation of Composite Material Processing," in *Numerical Methods for Simulation of Industrial Metal Forming Processes* (MJ Saran, AB Pifko, N Kikuchi, and KK Tamma, eds), ASME, New York, CED 5/AMD 156:37-45.

Suzuki K and Kikuchi N, "Generalized Layout Optimization of Three-Dimensional Shell Structures," in *Geometric Aspects of Industrial Design* (DA Field and V Komokov, eds), Philadelphia, pp 62-88.

Associate Professor Sridhar Kota

Kota S, "Computational Models for Conceptual Design," *Concurrent Design* (A Kusiak, ed), John Wiley.

Kota S, "Computational Models for Routine Design," *Concurrent Design* (A Kusiak, ed), John Wiley.

Kota S, Erdman AG, and Riley DR, "MINN-DWELL - Computer Aided Design" and Kota S, "Type Synthesis and Creative Design of Mechanisms," *Modern Kinematics* (A Erdman, ed), John Wiley.

Professor Wen-Jei Yang

Yang WJ, "Heat and Fluid Flows in Manufacturing Process," *Advances in Transport Processes, Vol. VIII* (AS Mujumdar and RA Mashelklar, eds), Elsevier, Amsterdam, pp 59-104.

Yang WJ and Danks TL, "Analytical Models for the Mechanism of Heat Shock," *1992 Advances in Bioengineering* (MW Bidez, ed), BED-Vol. 22, ASME, New York, pp 455-456.

Yang WJ and Inada S, "Evaporation and Boiling in Sessile Drops on a Heated Surface," in *Experiments in Heat Transfer and Thermodynamics* (R Granger, ed).

Yang WJ, Kawashima G, and Ohue H, "Visualization of Unsteady Flow in Rotating Drums," *Flow Visualization VI* (Y Tanida and H Miyashiro, ed), Springer-Verlag, Berlin, pp 62-66.

Yang WJ, Kawashima G, Ohue H, and Yang PP-T, "Flow Behavior in Human Intracranial Saccuar Aneurysyms," *1992 Advances in Bioengineering* (MW Bidez, ed), ASME, New York, BED 22:525-527.

Yang WJ, Lee JS, and Kim MH, "Performance Evaluation of Heat Transfer Surfaces by Single-Blow Method with Laplace Transform Correlation," *Transport Phenomena Science and Technology 1992* (B-X Wang, ed), Higher Education Press, Beijing, pp 899-903.

Yang WJ and Liu J, "Transport Phenomena in Sessile Drops of Protein (Lysozyme) Solutions with Internal Solidification," *Transport Phenomena Science and Technology 1992* (B-X Wang, ed), Higher Education Press, Beijing, p 547-552.

Yang WJ, Ohue H, and Kawashima G, "Visualization and Image Processing of Thermal Fields in a Drum with Inner Surface Heating," *Transport Phenomena Science and Technology 1992* (B-X Wang, ed), Higher Education Press, Beijing, pp 1049-1054.

Yang WJ, Taniguchi H, and Kudo K, "Radiative Heat Transfer by the Monte Carlo Method" *Research Trends* (J Menon, ed), Council of Scientific Research Integration, India.

Yang WJ and Torii S, "Bubble and Particle Behavior in Air-Solid Injection," *Transport Phenomena Science and Technology 1992* (B-X Wang, ed), Higher Education Press, Beijing, pp 341-346.

Yang WJ and Torii S, "Speckle Velocimetry in Gas-Liquid-Solid Mixing Flows", in Optical *Methods and Data Processing in Heat and Fluid Flow, Institute of Mechanical Engineers*, London, pp 207-210.

Yang WJ and Umeda S, "Traceability of Surface-Floating Particles in Fluid Flow," in *Computational Methods and Experimental Measurements V* (A Sousa, CA Brebbia and GM Carlomagno, eds), Computational Mechanics Publications, Southampton Boston, pp 201-212.

Yang WJ and Zhang N, "Research Trends toward Micro-and Nano-Scale Heat Transfer Phenomena," Keynote Paper, *Transport Phenomena Science and Technology 1992* (BX Wang, ed), Higher Education Press, Beijing, pp 1-15.

Yang WJ, Zhang N, and Lee CP, "Local Convective Heat Transfer in Flow Networks," *Transport Phenomena Science and Technology 1992*, (B-X Wang, ed), Higher Education Press, Beijing, pp 296-301.

Research Expenditures

July 1, 1992 - June 30, 1993

Sponsor	Researchers (Dir. listed first)	Project Title	$ Funded	$ Expended
Air Force	Akhavan	Intermittent Fine Scale Structure of Vorticity and Dissipation Fields in Turbulent Shear Flows	82,010	59,849
USAF-OSR	Dutta	Next Generation Solid Modelers for Electronic Prototyping		74,869
	Dutta, Woo	Next Generation Solid Modelers for Electronic Prototyping	74,705	2,445
	Dutta	N.C. Machining of Cyclide Surfaces	130,143	0
USA Research Office	Pierre, Shaw	Modal Analysis Techniques for Nonlinear Large-Scale Structural Systems	80,558	6,868
Batelle Labs	Pan	Effects of Pipe Geometries on Crack Opening Angles Surface Cracks with Residual Stress	5,000	7,895
Battelle Labs	Ward	Electronic Evaluation Guide Development		12,324
EPA	Brereton, Borgnakke, Patterson	Small Engine Test Facility	139,100	84,826
Lawrence Livermore	Kaviany	Hydrodynamic Interactions Among Fibers in High Efficiency Filters	16,000	40,499
	Kaviany	Hydrodynamic Interactions Among Fibers in High Efficiency Filters	49,995	12,815
NASA	Merte	Grad. Student Res. Prog. - Bouyancy Effects on the Forced Convection Critical Heat Flux	22,000	16,896
	Tryygvason	Computational Studies of Drop Collision and Coalescence	67,680	105,363
NASA-Langley	Felbeck	High-Toughness Graphite/Epoxy Composite Material Experiment		230
NASA-Lewis	Arpaci	Droplet Evaporation under Microgravity	40,000	44,047
	Atreya	An Experimental and Theoretical Study of Radiative Extinction of Diffusion Flames	65,000	10,574
	Holmes, Mansfield	Elevated Temperature Creep/Fatigue of Fiber-Reinforced Ceramics		6,005
	Holmes	Microstrc. Design, Elevated Temp. Creep and Recovery Behavior of SiC-Fiber RBSN Composites	115,498	101,734
	Merte, Keller	Pool Boiling Experiment	149,999	137,475
	Merte, Keller, Platt	A Study of Forced Convection Nucleate Boiling in Microgravity — additional funding	51,480	28,778
	Pierre	Effects of Mistuning on the Forced Response of Turbomachinery Rotors	35,782	42,877
NCMS	Ni	Post Process for the Gen. of Probing Cycles & Anal. for Preventive Maint. on a Cambell Grinder	169,001	59,314
	Ni	Real Time Error Compensation (RTEC) Project	190,000	2,383
Nat Inst Dental Res	Ashton-Miller	Regeneration and Transplantation of Skeletal Muscle	16,900	52,762
NIH	Ashton-Miller	Control of Trunk Equilibrium in Sitting Individuals		37,116
	Schultz, A., Alexander, Shepard	Biomechanics of Falls and Balance in Old Adults		88,971
	Schultz, A., Alexander, Cornell, & Shepard	Biomechanics of Falls and Balance in Old Adults	546,715	165,507
	Schultz, A, Ashton-Miller, Alexander, & Cornell	Fundamental Aspects of Mobility in Old Adults (Program Project)	600,000	146,903
NIST	Atreya	Basic Research on Fire Suppression	58,982	0
Nat Inst on Aging	Schultz, A, Ashton-Miller	Biomechanics Core		92,988
NSF	Atreya	NSF - PYI (Transferred from Michigan State University)CTS-9396128	85,300	3,262
	Barber	Thermoelastic Effects in the Solidification of Castings	57,308	44,741
	Borenstein	Design and Control of Multi-Degree-of-Freedom Vehicles for Industrial Applications	75,783	51,432
	Chen	IPA Agreement for Dr. Michael Chen	133,392	121,825
	Dutta	Toward Automation of Design and Manufacture of Dies		4,701
	Dutta	Travel Supplement for Towards Natural Quartics in Solid Modeling	10,615	34,567
	Holmes	Young Investigator Award	25,000	34,904
	Kannatey-Asibu	Laser Beam-Splitting and Materials Processing	93,253	90,496
	Kannatey-Asibu	Laser Materials Processing	90,000	0
	Kaviany	Desorption of Soil Contaminants During Steam Cleaning	86,798	82,331
	Kikuchi, Holmes	Study of Ceramic Matrix Composites Using Computational and Experimental Techniques		124,028
	Koren	Sensor-based Control of a Mechanical Snake		81,032
	Koren	Fundamental Research for National Competitiveness		9,843

Sponsor	Researchers (Dir. listed first)	Project Title	$ Funded	$ Expended
NSF	Koren	Two-Axis Rotary Table		746
	Koren	A New Architecture of CNC Servo-Controllers	75,473	61,550
	Kota	REU Supplement - Synthesis and Simulation of Machine Systems Using Motion Control Blocks	10,000	83,371
	Pan	Stress Resultant Constitutive Laws for Sheet Metal Forming		49,529
	Papalambros, Kikuchi	Engineering Research Equipment Grant: Generalized Layout in Mechanical Design		3,015
	Papalambros, Kikuchi	Generalized Layout Problems in Structural Optimization		15,445
	Pierre	Localization Phenomena in Structural Dynamics		39,709
	Shaw, Pierre	An Invariant Manifold Approach to Modal Analysis of Nonlinear Structural Systems	91,947	35,938
	Shaw	Nonlinear Dynamics in Mechanical Systems	67,464	77,473
	Stein	Design and Control of Servo Systems		14,194
	Stein	Well-Conditioned Observers for High-Performance Low-Cost Sensing Systems	57,491	0
	Tryggvason	Numerical Studies of Multi-Fluid Systems	71,568	78,277
	Ulsoy	Variation Reduction for Stamping and Body Assembly Operations	5,000	38,425
	Ward	REU Suppl. Foundations of Quantitative Inference About Sets of Design Possibilities		18,556
	Wu, Ni, Schunk, Woo	Development of a Science Base for Drills and Drill Grinding Processes	599,296	189,408
	Wu	Acquisition of a Coordinate Measuring Machine		442
	Yang, W.J.	NSF Workshop on Particulate Two-Phase Flow Visualization		199
NIAMSD	Kikuchi, Goldstein			34,761
ONR	Ceccio	Large Scale Experiments on Cavitation Bubble Dynamics and Acoustics		26,026
	Ceccio	Large Scale Experiments on Cavitation Bubble Dynamics and Acoustics	227,401	154,368
	Ceccio, Bernal	HPIV Measurements in Cavitating Flows	79,028	4,058
	Ludema	Form. of Surface Protective Films vs Progression Toward Scuffing Failure in Sliding.		126,180
	Perkins	Nonlinear Mechanisms Controlling The Dynamics and Elastic Stability of Suspended Cables	79,225	13,136
	Perkins	The Dynamics of Slack Cable-Mass Systems	33,300	3,815
	Perkins	New Generation Cable Model for Local Mechanics	44,544	53,947
	Perkins	Vibration Analysis of Cable/Mass Suspensions Under Low Tension	65,000	336
	Tryggvason	Studies of Bubbly Flows	67,504	90,868
	Ward	Generalized Quantitative Inferences on Sets of Possibilities in Design and Planning	75,000	41,152
US DOC	Ni	Modular Thermal Error Sensing and Compensation System on a 3-Axis Machining Center	755,568	253,564
Carnegie Mellon	Pierre, MacBain	Design Tools for Predicting the Forced Response of Mistuned Bladed Disks	83,900	26,004
UM COE	Koren	In Support of ERC Research Proposal Preparation	15,750	15,667
	Papalambros	Design Lab - MEAM		1,054
	Ulsoy	Manufacturing Initiatives	100,000	13,402
GLCTTR	Kota	Differential for N-Wheel Independent Drive	18,800	12,933
	Ulsoy	Characterization and Modeling of On-Board Lane Sensing Systems	18,800	19,020
MI Sea Grant	Shaw	A Nonlinear Probabilistic Approach to Fishing Vessel Capsizing		24,401
Michigan, State of	Wu	NSF-I/UCRC on Mechanical and Optical Coordinate Measuring Machines		54,545
UM	Dutta	On Symmetry and Skeletons		4,958
	Yang, W.H.	Manufacturing Initiative		4
Rackham	Arruda	FRR	14,950	2,512
	Ceccio	FRR	12,000	1,964
	Dowling	FRR	14,928	1,409
2mm Program, Inc.	Hu	Controlling Dimensional Variation in Automobile Body Manufacturing	3,302,628	847,361
Applicon	Dutta	Computer Aided Generative Process Planning for Parallel Machine Tools Mill	20,849	18,073

Sponsor	Researchers (Dir. listed first)	Project Title	$ Funded	$ Expended
API	Wu	Unrestricted Gift	5,800	790
Chevron Field Res.	Kaviany	Penetration of Two-Phase Region Around Buried Heat Pipes		16,040
Chrysler	Hu	Controlling Dimensional Variation in Automobile Body Manufacturing	132,000	64,765
	Ni	Gift Administration for Ni & Hu Discretionary Fund	170,000	
Cummins Engine	Dutta	Computer Aided Generative Process Planning for Parallel Machine Tools (Mill Turns)	34,747	26,957
Detroit Diesel	Borgnakke	Performance of Methanol Blend in a Diesel	28,005	42,808
	Patterson	General Research		13,121
Eastman Kodak	Fassois	Identification of Stochastic Multivariable System Subject to Cross-Correlated Excitations	30,000	32,408
Egyptian C&EB	Borgnakke	Collaboration on Thermal Sciences		8,225
	Dutta	Collaboration on Thermal Sciences		8,740
Ford Motor Co.	Arpaci	Prediction of Flame Initiation and Growth in SI Engines		20,080
	Arpaci	Unrestricted Research Grant in Modeling Turbulent Combustion Using Microscale Approaches	50,000	31,102
	Clark	Unrestricted Grant	25,000	2,429
	Fassois	Modeling/Est. and Power Demand Strategies for Automobile Hydraulic Active Suspension		3,803
	Johnson	Unrestricted Grant for ME350 Course Support	80,000	1,488
	Kaviany	Effective Interstitial and Surface Convective Cooling of Alternators	54,290	44,269
	Kaviany	Pressure Drop and Local Heat Transfer, Including Dryout in a Plate Evaporator	27,000	52,102
	Kikuchi	Evaluating the Topological Optimization Approach	14,180	10,832
	Kikuchi, Papalambros	General Research	50,000	53,300
	Ludema	Phase One: Study of Rack & Pinion Steering Gear Seal Friction Dynamics	37,925	0
	Pan	Plastic Anisotrophy and Failure Criteria	40,000	42,109
	Papalambros	Design Management Strategies: An Application to Powertrain Design	50,000	51,910
	Papalambros, Pan, Arruda, Haghi, Kikuchi, Hulbert,Wineman	Center for Automotive Structural Durability Simulation	1,200,000	0
	Selamet	Research on Manifold Dynamics		4,229
	Selamet	MANDY Engine Flow Dynamics Model Improvements		44,660
	Selamet	Study of Exhaust System Elements for Engine Performance and Noise Prediction		301,934
	Selamet	Research on Dynamic Pressures in Induction Systems	25,000	23,289
	Selamet	Ford/Alpha 1.9L Escort, 2.0L Zeta and 3.0L Vulcan Project	284,033	82,118
	Selamet	Unrestricted Grant for Research in Engine Performance Modeling	75,000	17,410
	Ulsoy, Perkins	Accessory Drive Belt Dynamics Design Program	50,000	25,600
	Yang W J	Visualization of Flows in Torque Converters	68,500	110,233
Gas Research Inst	Atreya	Formation and Oxidation of Soot in Diffusion Flames	12,009	0
General Electric	Ward	Application of a Set-Based Language for Concurrent Engineering to Cooled Turbine Blade Design		37,771
GE Aircraft	Holmes	Manufacturing Testing		4,569
	Yang, W.J	Flow and Heat Transfer Characteristics Inside Crossed Tubes	27,500	42,533
General Motors	Dutta	Toward Automation of Design and Manufacture of Dies		14,407
	Hu	Controlling Dimensional Variation in Automobile Body Manufacturing	150,000	0
	Ni	Electronic Report and Data Transfer System Phase III: Modification and Enhancement		104,116
	Ni	Comparison of Body Framing Tooling Systems	24,000	0
	Papalambros	Doctor of Philosophy in Mechanical Engineering	8,066	
	Ulsoy	Coupled Drill Force and Vibration Modeling including Breakthrough		17,120
	Wu, Ni	Statistical Evaluation of Sheet Metal Conformance to GD&T		7,029
	Wu	Variation Reduction		52,085

Sponsor	Researchers (Dir. listed first)	Project Title	$ Funded	$ Expended
General Motors	Wu	Variation Reduction - Hamtramck (3)		50,969
Hatch Stamping	Wu	Unrestricted Gift For The Area of Die Maintenance and Stamping	12,500	655
Horiba Instrument	Geister	Computerized Control and Measurement of I.C. Engine Performance		1,703
Hyundai America	Borgnakke	Engine Performance and Emissions	11,468	61,420
ITI	Kota	Adjustable Robotic Mechanism - Proof of Concept Software	9,119	11,225
	Ward,Stein	A Novel Milling Machine Structure	69,288	76,793
Jujo Paper Co	Yang, W.J.	Gift	19,195	
Kimberly-Clark	Schultz, W., Perkins	Fluid Mechanics of Paper Forming	31,816	
Nissan Motor Co.	Kikuchi	Optimization Theory Using the Homogenization Method for Dynamic Response Problems	83,956	
	Kikuchi	Unrestricted Research Gift	28,000	18,972
Parke-Davis	Fijan	Integration of Multi-Robot System for Automated Chemical Processes	135,541	0
Perceptron	Wu	Unrestricted Grant	25,000	32,279
Rand Corp (NSF - Prime)	Ulsoy	Machine Tool Technology State-of-the-Art Assessment	50,000	5,797
Rhl. & Frac.	Felbeck	Mechanical Engineering, Rheology and Fracture Laboratory	563	673
Saginaw Machine	Wu, Ni	Advanced Compensation Techniques for Enhancing Machine Tool Accuracy		132,254
	Wu	General Research		117
SNEC	Pierre	Case Studies of the Dynamics of Mistuned Turbomachinery Rotors	24,026	26,230
	Pierre	Studies of the Dynamics of Blade Assemblies	11,279	60
SONY	Kikuchi	Development of a Meshless Analysis Capability for Mechanical Design Optimization	47,670	20,486
Suzuki Motor Corp.	Kikuchi	Development of an Integrated Optimal Structural Design System for Vehicle Bodies		142,146
Tarus	Ni	Tarus Research - S M Wu		5,803
Tecumseh Prod.	Patterson	Combustion Research in I.C. Engines	10,800	13,222
Toyota	Kikuchi	Seminar Series in Finite Elements		1,108
Toyota GTC	Kikuchi	Computational Mechanics Lab	19,600	2,339
Toyota TC, USA., Inc.	Hulbert	Toyota Seminar Series	10,000	1
TRC	Borenstein	Innovative Kinematic Design for a Four-Degree-of-Freedom Vehicle	16,650	18,064
Various	Ludema	Surface Phenomena	100	2,830
	Ulsoy	NSF-I/UCRC Mechanical and Optical Coordinate Measuring Machines	550,000	294,626
	Ulsoy	Manufacturing Research	3,150	3,395
	Ward	ME 450 Project Support	15,200	8,415
Whirlpool Corp.	Brereton	Experimental Determination of Air Flow in Refrigeration Devices		18,147
	Dutta	Whirlpool Research		2,913
	Fassois	Whirlpool Research		12,559
	Keller	Cooperative Research in Appliance Engineering		2,261
	Keller	Cooperative Research in Appliance Engineering (Fellowship)	35,311	39,059
Alcoa Foundation	Hulbert	Computational Mechanics for Time Dependant Processes		2,926
Chirp. Ed. & Res.	Schultz, A.	Biomechanical Studies of Chiropractic Manipulation		53,056
John Deere	Kota	Machine Anatomy Laboratory Development	5,000	0
	Kota	Synthesis, Simulation and Rapid Prototyping Using Motion Building Blocks	20,000	3,943
		Total	**$13,226,665**	**$7,303,130**

Honors and Awards to Faculty and Staff - 1992-1993

National Honors

Albert B. Schultz, Vennema Professor of Mechanical Engineering and Applied Mechanics, was elected to membership in the National Academy of Engineering, one of the highest professional distinctions accorded an engineer. He is one of only seventy-three members elected from across the country in 1993 bringing total membership in the Academy to 1,684. Professor Schultz was cited for his contributions to the biomechanics of the spine, treatment of lower back pain, and understanding of falls in the elderly.

Panos Papalambros and **A. Galip Ulsoy** were named Fellows of the American Society of Mechanical Engineering.

University of Michigan
Faculty Awards

Distinguished Faculty Achievement Award
The late S.M. (Sam) Wu

Faculty Recognition Award
Noel Perkins

AMOCO Teaching Award
Bruce Karnopp

College of Engineering
Awards and Honors

Paul G. Goebel Endowed Professorship 1993-1998
Yoram Koren

Excellence in Service
Bruce Karnopp

Excellence in Teaching
Walter Debler

MEAM Faculty Awards

Excellence in Research
Noboru Kikuchi
Christophe Pierre

Excellence in Service
Joseph Datsko
Galip Ulsoy

Excellence in Teaching
Glen Johnson
Alan Wineman

Other Awards and Honors

Pi Tau Sigma, Professor of the Term, ASME Travel Award
Giles Brereton

UMEC
Special Recognition Award for Service
Walter Debler

Society of Manufacturing Engineers, Outstanding Young Manufacturing Engineer
Member of the North American Manufacturing Research Institution (NAMRI) of SME
Jack Hu

Technion University, Lady Davis Professor (while on sabbatical in Israel in 1992)
Yoram Koren

ASME/Kodak Best Paper in Design Automation (Co-author)
Panos Papalambros

Pi Tau Sigma, Professor of the Term
Noel Perkins

ASM/ESD Advanced Composites Conference, Best Industrial Paper Award, (Co-recipient)
Alan Wineman

Japan Society of Mechanical Engineering, Thermal Engineering Memorial Award
Visualization Society of Japan, Best Paper Award
Wen-Jei Yang

Papers Selected for Publication in the 50th Anniversary Issue of Journal of Dynamic Systems Measurement and Control
Yoram Koren
Jeffrey Stein
Galip Ulsoy

Staff and Alumni

MEAM Staff Excellence Awards
Ruth Howard
Cynthia Quann-White
Beverly Pyle

MEAM Alumni Society Merit Award
Roger Heimbuch

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MEAM Publications

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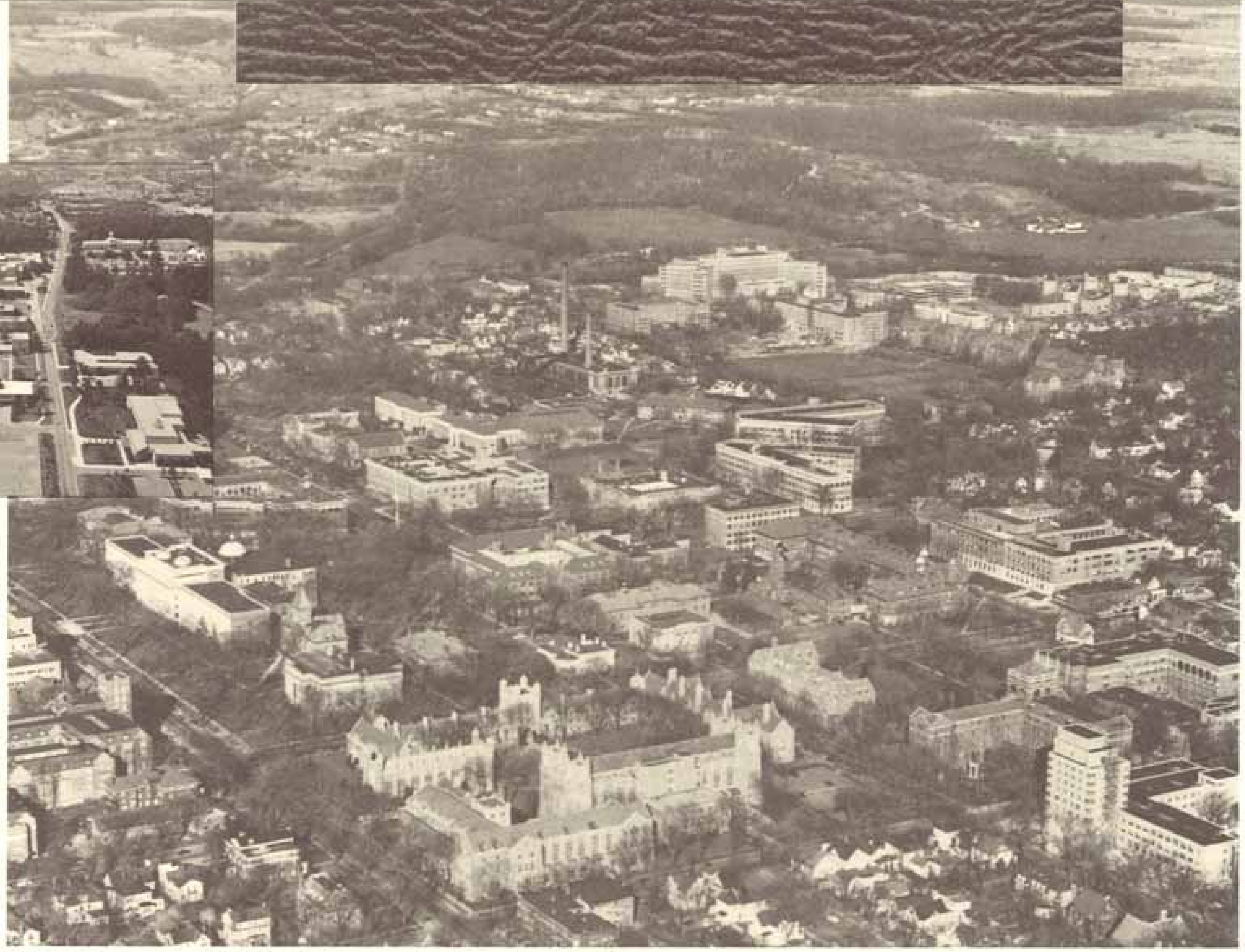

125 Years of Mechanical Engineering

Mechanical Engineering and Applied Mechanics

1992-93 Annual Report

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