COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

A PROPOSAL TO THE
MICHIGAN RESEARCH EXCELLENCE FUND
TO ESTABLISH A
CENTER OF SCHOLARLY EXCELLENCE IN ADVANCED ELECTRONICS AND OPTICS TECHNOLOGY

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ABSTRACT

The University of Michigan College of Engineering seeks base funding at a level of $3,920,000 per year from the Michigan Research Excellence Fund to establish and sustain a center of scholarly excellence in advanced electronics and optics technology. Such technology will be the foundation on which the "factory of the future" will be built.

Sophisticated electronic devices will be the key to industrial automation, information processing and communication, sensors, management -- essentially all of the activities involved in complex manufacturing processes. Indeed, virtually every machine, instrument, or tool manufactured in the year 2,000 will be computer controlled. Already the automobile industry has become not only the largest consumer, but indeed, the largest manufacturing of electronic components.

Of similar importance is the closely related technology of applied optics: the use of lasers, electron beams, and ion beams in sensing, diagnostics, mechanical measurement, manufacturing (non-contact cutting and welding), and optoelectronics. Indeed, lasers and particle beams will almost certainly be the "machine tools" of the factory of the future, largely replacing traditional machining with non-contact sensing, diagnostics, cutting welding, and surface treatment. Furthermore, the exciting new field of integrated optoelectronics, "optics on a chip", has the potential of revolutionizing the electronics industry much in the same manner as the solid-state transistor in the 1960s.

The strong programs of the University of Michigan in these crtical areas provide the State of Michigan with an excellent opportunity to build a center of excellence in these critical technologies. Indeed, the ongoing construction of the State-funded Laboratory of Electrical Engineering and Computer Science provides a superb physical facility. However, it is important to recognize that this building is only the first step, since without additional funding for staff and equipment, the most critical component of this building, the Solid-State Electronics Laboratory, will remain a large, empty shell.

Hence there is not only an extraordinary opportunity, but as well a critical need, for the State of Michigan to make the investment necessary to achieve leadership in a center of excellence in advanced electronics and optics technology at the University of Michigan.

1. AN INVESTMENT IN ENGINEERING EXCELLENCE

There is strong evidence to suggest that a primary catalyst and necessary ingredient in technology-based industrial development is the presence of a world-class engineering school. Such institutions provide not only the outstanding engineering graduates necessary to sustain and strengthen the competitiveness of existing industry; in addition, they supply the technological innovation and entrepreneurs necessary for building new industry.

The presence in the State of Michigan of one of the nation's leading engineering schools, the University of Michigan College of Engineering, is of critical importance of its future economic prosperity. Michigan requires a massive infusion of new technology if it is to regain its traditional industrial and economic leadership and become the nation's source of emerging industrial technology, the world's leader in complex manufacturing processes. Our state must use technology to revitalize and diversify its present industrial base to protect existing jobs, even as it seeks to spawn and attract new industries over the longer term to create new jobs for Michigan citizens.

The dominant role played by world-class engineering schools in economic development has been identified in study after study. In California and New England, most of the signficant technological innovations behind industrial growth originated in key local engineering schools and their associated research laboratories (e.g., MIT, Stanford, UC-Berkeley, and Caltech). These innovations were typically exploited by new firms established by faculty, staff, and graduates of these schools. Companies with origins in these schools subsequently formed the basis of powerful agglomerations of new industries. Furthermore, these schools attracted the massive federal research contracts which played the key role of "risk capital" in building new industries such as electronics and aerospace.

In each case, the key engineering schools involved were top-flight institutions conducting research at the cutting edge of new technology. Furthermore, these schools were oriented to the commercial applications of their innovations, provided the entrepreneurial environment necessary for technology transfer, and attracted the federal funding necessary to stimulate such industrial development.

It is reasonable to expect that the role of a world-class engineering school will be even more critical in a future increasingly dominated by science, technology, and information. There seems little doubt that Michigan's ability to strengthen and diversify its industrial base, to compete for new industry and economic growth, and to create the jobs necessary for Michigan's long-term prosperity will depend on its success in building and sustaining such an institution.

The University of Michigan College of Engineering provides

Michigan with both a vehicle and an extraordinary opportunity for investing in the long-term economic health of the state. As one of the leading engineering schools in the nation today, the College is regarded as one of the few institutions in the world capable of achieving the degree of excellence in science and technology ncessary to have a major impact on economic development.

More specifically, the present status of the UM College of Engineering can be summarized as follows:

Reputation: 5th in the nation
Capacity: 6,000 students, 320 faculty (3rd in the nation)
Productivity: 1,250 BS, 550 MS, 100 PhD degrees annually
Research: $25 million per year (federal and industrial)
Student Quality: 98th percentile (1280 SATs, 3.8 GPAs)
Faculty Quality: Outstanding (energetic and innovative)
Physical Plant: Rapidly improving
Laboratory Equipment: Seriously deficient
Base Funding: Seriously deficient

Over the years, UM Engineering has had a major impact on Michigan's economic prosperity:

- Each year the College graduates over 1,800 engineers, of whom roughly 70% remain in the Great Lakes area.

- UM Engineering has been recognized as a national center of excellence in several areas of importance to Michigan, such as complex manufacturing technology, ergonomics, advanced electronics and optics, and computer engineering.

- The College has formed important research partnerships with Michigan companies across a broad range of technologies.

- Over the past three decades, the College and its affiliated research laboratories have spawned over 85 companies employing 40,000 Michigan citizens and generating over $2 billion per year in sales.

- UM Engineering faculty and staff are accelerating the rate at which they spin off new companeis (7 in 1984).

The UM College of Engineering today is in an excellent position to achieve national leadership in areas of major importance to Michigan's future including complex manufacturing technology, advanced electronics and optics technology, and machine intelligence and information technology. However, if the College is to have the capacity to respond to such needs and opportunities, it will require direct and immediate assistance from the State of Michigan to restore an adequate base level of support for its programs through initiatives such as the Research Excellence Fund.

2. THE IMPORTANCE OF ADVANCED ELECTRONICS AND OPTICS TECHNOLOGY TO MICHIGAN

Numerous studies have suggested that Michigan's economy will continue to be driven for the foreseeable future by durable goods manufacturing. However it is essential that this industry shift rapidly to complex manufacturing processes less vulnerable to low-wage competition. Michigan's future economic prosperity will depend on its becoming America's "factory of the future", its leading source of emerging industrial technology. In contrast to other regions of the country in which "high tech industries" are regarded as a separate industrial sector, in Michigan new technology will be at the heart of every industrial sector.

However, there is another equally important aspect of technology-based economic development for our state. Experience has shown that a primary source of new jobs is the creation of new companies and industries. And while durable goods manufacturing will continue to provide the basis of this state's economy in the near term, it is essential that Michigan stimulate and nurture the growth of new industries that will diversify and strength its economy for the long term. It is logical to expect that advanced technology and innovation will play the key role in bulding these new companies and creating new jobs.

In summary, then, Michigan faces two major challenges: First, our state must take actions to protect its present economic base by strengthening the competitiveness of existing industries such as the automobile and automotive supplier industry. Second, it must establish an environment capable of attracting or stimulating the growth of technology-based industries that can provide new jobs for Michigan citizens. Key in both efforts will be the availability of centers of excellence and innovation in key areas of technology.

Numerous State of Michigan studies have singled out the unique role of the UM College of Engineering in this effort. For example, one of the key recommendations of the Governor's Task Force for a Long-Term Economic Strategy for Michigan was:

> "To ensure the lead prosition in the development of manufacturing production processes, Michigan must invest heavily in centers of applied research in industrial technology, with special emphasis on developing the University of Michigan College of Engineering as a world leader in this field."

One of the key areas in which such investments must occur is advanced electronics and optics technology.

2.1. Electronics Technology

It is widely accepted that electronics is the foundation on which the "factory of the future" will be built. Sophisticated electronics device will be be the key to industrial automation, information processing, sensors, management -- essentially all of the activities involved in complex manufacturing processes. Fortunately, while the solid-state electronics industry has largely been external to Michigan, the State nonetheless has a base on which to build this necessary component of its manufacturing effort.

The field of solid-state electronics needs little introduction in terms of its importance and impact on society. From modest beginnings not quite twenty-five years ago, integrated circuits have allowed the cost of electronic functions to decrease by more than ten-thousand times as the timber of transistors which can be realized per chip has increased nearly a million-fold. Today, sophisticated microcomputers contained hundreds of thousands of devices and executiving instructions in millionths of seconds can be mplemented on single silicon chips less than a centimeter on a side and costing only a few dollars. In terms of any known fundamental limits, we are still several orders of mangitude from achievable levels of product performance and sophistication, and even without future advances it is clear that electronic instrumentation and control will revolutionize many aspects of society. As many have said, this is a pervasive technology and one in which every industrialized region of our nation will of necessity be involved. Once confined to localized areas near Boston and San Francisco ("Route 128" and "Silicon Valley"), the semiconductor industry is becoming sidely distributed geographically. As in other areas of industry, we are currently engaged in a struggle to maintain this nation's leadership in semiconductor electronics. This is a struggle we must not lose.

The State of Michigan has not been a leader in the "high tech" area of solid-state electronics in the past. It has no choice, however, but to become heavily involved in the future. Virtually every machine, instrument, or tool manufactured in the year 2000 will be computer-controlled, either to aid the human operator or as a replacement for him. The design of these electronic control systems will be a vital part of overall product development and is unlikely to be separated from it, geographically or otherwise. Already, the automobile industry has become not only the largest consumer, but indeed the largest manufacturer of electronic components.

The Solid-State Electronics Laboratory at the University of Michigan has been recognized as one of the top university programs in the nation for many years in this critical area. Research of the Laboratory has been internationally recognized, including awards at the 1979 International Solid-State Circuits Confrence and the 1980 International Electron Devices Meeting. The principal thrust areas of this Laboratory have been in the areas of high-speed, high-frequency devices for data processing and microwave power generation and in integrated solid-state sensors for use in industrial automation and health care.

Of particular importance to Michigan is the capacity and reputation of the Laboratory in the area of integrated solid-state sensors. Such devices combine transducers and signal-conditioning circuits on single chips which are capable of interfacing microcomputer-based control with the non-electronic world. This area represents a critical need in the application of elecronics to three areas of particular importance to the State of Michigan: automated manufacturing, transportation, and biotechnology. The Laboratory currently has one of the leading international programs in the sensor area and thus is in a position to provide an important leadership role. It should be noted that the automotive industry is currently the largest producer of integrated circuits and that it depends crititally on sensors for automotive control. Similarly, many other industries not formerly involved with electronics are becoming both users and producers of integrated circuits and sensors. Sensors are critically needed in the development of the complex manufacturing industry that must be Michigan's future path to prosperity.

The further development of the integrated electronics industry itself will depend critically on the development of very sophisticated manufacturing equipment for producing increasingly complex systems on a chip. Such equipment must be compatible with maintaining an ultraclean environment around the silicon wafer being processed. Very high levels of automation and equipment/product monitoring will be required at every state of the manufacturing process. Thus, the development of sophisticated production equipment for semiconductor processing is likely to be the most significant single factor pacing the development of the semiconductor electronics industry, which is expected to reach $50 billin in sales by 1988. Such equipment development will require skilled labor and is a possible area in which the State of Michigan could play an important leadership role.

Recognizing the need for increased university research in solid-state electronics, leading companies representing the United States semiconductor industry recently agreed to use a percentage of their sales to fund such research. The Semiconductor Research Corporation (SRC) was formed to administer the resulting research contracts and presently consists of nearly two dozen semiconductor companies (including Michigan companies such as Eaton and Burroughs). One of the SRC's three thrust areas is embodied in the Manufacturing Science Division. As the principal focus of this division, SRC has just announced the formation of a College Center of Excellence in Manufacturing Science and Advanced Automation. This Center consists of interacting programs at Stanford, the Microelectronics Center of North Carolina, and the University of Michigan.

Michigan will be responsible for the development of advanced automated sensing systems (including machine vision and expert systems) for the closed-loop control of future semiconductor process equipment and for the automated evaluation of advanced fabrication processes at the submicron level. It should be stressed that establishment of this Center at Michigan was not only in recognition of our combined strengths in both manufacturing and in solid-state electronics, but also recognition by the semiconductor industry that the State of Michigan can serve as a principal focus for the development of such equipment for semoconductor manufacturing. Indeed, this role represents a logical extension of efforts already underway in robotics.

There is considerable excitement about such activities in automated semiconductor manufacturing. However this is tempered by a recognition of the significant State investment that will be required to fulfill Michigan's role as a national center of excellence and catalyst for industry within the State. It should also not pass without comment that the American electronics made this commitment to UM Engineering in expectation of a similar commitment by the State of Michigan to assist in building these programs.

To calibrate the magnitude of this investment, it should be noted that Stanford is currently completing a $15 million facility for integrated systems as its component of the SRC program. The Microelectronics Center of North Carolina was formed by that State in a well-publicized effort to attract high-technology microelectronics industry. That Center is part of a $40 million effort by North Carolina and is currently funded at about $6.5 million per year, directly by the State.

At the University of Michigan, we are fortunate in having underway the construction of the State-funded Laboratory of Electrical Engineering and Computer Science which contains a Solid State Electronics Laboratory which has the potential of being the equal of any facility in the nation for research on solid-state devices, integrated sensors, and advanced automation. Unfortunately, only the basic construction of the laboratory area has been funded thus far by the State of Michigan. In order to complete the facility, an additional $8 million in laboratory equipment will be needed.

With this funding, the University of Michigan would have the capacity to be capable of fulfilling a leadership role for the semiconductor industry nationally and of acting as an important catalyst in the expansion of high technology in the State of Michigan. While the required investment is significant, the potential payoffs are enormous, and such investments are viewed as a necessary part in the renewal of the State as a major center for advanced manufacturing.

2.2. Applied Optics and Optoelectronics Technology

There is little doubt that the next major technological leap in both the manufacturing and electronics industry will involve the area of applied optics. By this term, we refer to the use of lasers, electron beams, and ion beams in sensing, diagnostics, mechanical measurement, manufacturing (non-contact cutting and welding), and optoelectronics and electro-optics. Laser, electron beams, and ion beams will be the "machine tools" of the factory of the future. Indeed, Michigan industry has led the way in the application of lasers to manufacturing processes. Over the next decade such "directed energy beam" devices will largely replce traditional machining with non-contact sensing, diagnostics, cutting, welding, and surface treatment.

The need for increases of several orders of magnitude in information storage capacity, transmission, and processing speeds will demand the transition of the microelectronics industry over the next 20 years to the use of optical methods for processing and storing information. Already there is significant work on "micro-optoelectronics" and "integrated optoelectronics" as the next stage of microelectronics and integrated circuits. Major progress in developing integrated circuit chips containing both optical and electronic microcomponents, e.g., microscopic lasers and optical channels, now threaten to revolutionize the electronics industry in much the same way that the introduction of the solid state transistor did in the 1960s. Without doubt we will again be engaged with other nations in a struggle for technological and industrial leadership.

The UM College of Engineering and the State of Michigan are ideally positioned to build the world's leading university laboratory for research and instruction in these critical areas. The College's world-class reputation in applied optics includes its early work on masers and lasers, its development of the technology of holography, its ongoing activities in manufacturing (through organizations such as the Center for Research on Integrated Manufacturing and the Industrial Technology) and microelectronics (through its Solid State Electronics Laboratory), its research on directed energy beams (its Laser-Plasma Interaction Laboratory), and the recent formation of an important new program in modern optics. Furthermore, there is no such applied optics programat any other university in the nation. (Indeed, the only two optics research institutes in this nation, those at the University of Rochester and the University of Arizona, focus largely on basic research in optics.) Over the next two decades, optics will change from what is largely an area of physics to being primarily an engineering discipline. We intend to lead the way in this evolutionary process.

The presence of several major research laboratories in the Ann Arbor area with strong reputations in applied optics, including the Environmental Research Institute of Michigan, KMS Fusion, and the Ford Scientific Laboratory, as well as development and production facilities such as Photon Sources, Ray-Con, and Perfect Optics, strengthen this effort. There is already a major industrial infrastructure in applied optics in Southeastern Michigan similar to that which first appeared in Silicon Valley in microelectronics technology. Since there is the strong possibility that optoelectronics will be the successor to microelectronics, the establishment of a Center of Excellence in Applied Optics at the University of Michigan could well be the catalyst for stimulating a "Gallium Arsenide Valley" along the Detroit-Ann Arbor corridor.

3. SPECIFIC PROPOSAL

The achievement of a national Center of Excellence in Advanced Electronics and Optics Technology at the University of Michigan will required a sustained base commitment from the State of Michigan of $3,920,000 per year. Of this amount, $1,920,000 will be necessary to attract and support the faculty necessary to staff and direct these research programs. In addition, a base commitment of $2,000,000 per year is necessary to leverage the massive industrial and federal contracts, contracts, and gifts necessary to equip such laboratory facilities.

Fortunately, several of the most critical components necessary for the establishment of the Center are already in place:

- The State-funded Laboratory of Electrical Engineering and Computer Science will provide a superb physical environment for research in electronics and optics -- provided it is equipped with the necessary equipment.

- American industry has already singled out the University's programs as a national center of excellence for semiconductor manufacturing through the SRC program -- although with the expectation that the State of Michigan will provide the necessary additional commitments to make this project a success.

- Many of the key faculty necessary for world-class programs in microelectronics and optics have already been recruited -- with the promise that the necessary State support would be forthcoming to sustain their activities.

Hence, Michigan is poised on the threshold of achieving world-class capabilities in these technologies so critical to its future -- if it can achieve the base level of sustained funding necessary to support such activities.

3.1. Laboratory Equipment

It is important to understand that electronics and optics technologies are equipment-intensive. Competitive research requires state-of-the-art equipment and facilities.

It is also important to understand that the State of Michigan has taken only the first step toward the establishment of a world-class program in these areas through its construction of the Laboratory for Electrical Engineering and Computer Science. Indeed, without the necessary equipment, the most critical component of this building, the Solid-State Electronics Laboratory, will be a large and embarrassingly empty concrete shell.

The total price tag necessary for equipping the Solid State

Electronics Laboratory with the equipment necessary to make it both a Center of Excellence and a major resource to State industry is $8 million in one-time capital outlay and $1 million in sustained operating costs. The Laboratory was originally designed with this further investment in mind.

Careful staging of this investment, coupled with major matching funds from federal agencies and industry, could reduce the initial first-year investment to $2,228,000 (although this is the minimum amount necessary to even open the doors of the new facilities). This investment is made all the more urgent by the fact that the clean room facilities of the Laboratory are scheduled for acceptance-testing in mid-fall, after which equipment installation will become extremely expensive.

More detailed equipment needs are listed in Table II.

3.2. Staffing

The detailed staffing needs for the Center are listed in Table III. The primary investment will be in the additional faculty necessary to build a critical mass for the research programs. Also included is the necessary expansionof technical support staff and research assistants.

TABLE I

BASE BUDGET NEEDS

CENTER FOR ADVANCED ELECTRONICS AND OPTICS TECHNOLOGY

Staffing	
Faculty participants: 15 FTEs	$1,350,000
Technical support staff: 4 FTEs	120,000
Graduate research assistants: 18 FTEs	450,000
Laboratory equipment (sustained needs)	2,000,000
Total Base Budget Needs	$3,920,000

TABLE II

LABORATORY EQUIPMENT NEEDS

SOLID-STATE ELECTRONICS LABORATORY

EQUIPMENT NEEDS ($K)

EQUIPMENT	BASIC	COMPETITIVE (Additional)	RESOURCE (Additional)
Diffusion Tubes (12)	400		
Mask Aligners (3)	200	125	
Mask Aligner (DSW)			400
Spinners (1 auto, 2 manual)	12	25	
Wafer Wash Station		20	
Microscopes	60		
Terminals, Computer	20		
Electron-beam writing station			1500
Microbonder, wedge			15
Microbonder, ball	3		
Optical Mask Making equipment	400	400	
MOCVD			350
Scanning Electron Microscope		90	
Vacuum Furnace		80	
Dektak	25		
Leak Detector	18		
Ion Implanter	100	500	
Residual Gas Analyzer			20
Plasma Etch Stations (4)	70		70

Reactive Ion Etcher (2)	100		115
Silicon Epitaxy			100
Ellipsometer		30	
C-V Profilometer			100
Sputter Evaporator			125
Molecular Beam Epitaxy			750
<u>TEACHING</u> <u>LABORATORY</u> ($385K)			
Diffusion Furnaces	180		
Evaporator	70		
Mask Aligner (1)		75	
Wafer Prober (2)	30		
Dicer	20		
Curve Tracer	10		
<u>GENERAL</u> <u>INSTRUMENTATION</u>			
Auger/Sims			250
Oscilloscopes (10)	100		
Pulse Generators	60		120
High Frequency Test Instrumentation	100	200	
CAD (4 stations)	250		
Miscellaneous Material Evaluation		200	
Microprocessor Instrumentation		100	
	$2,228K +	$1,845K +	$3,915K
TOTAL EQUIPMENT	=	$4,073K	$7,988K

MICHIGAN ELECTRON OPTICS AND SURFACE CHARACTERIZATION FACILITY

1. Electron Microscopy Equipment

JEOL Model JEM-4000EX High Resolution Electron Microscope

Equipped with electron energy loss spectrometer, image intensifier and computer system for instrument automation and image analysis.

$1,200,000

JEOL Model JEM-2000EX Analytical Scanning Transmission Electron Microscope

Equipped with energy dispersive x-ray analysis system, electron energy loss spectrometer, computer system for instrument automation and data analysis, and full complement of specimen stages.

$600,000

VG Model 501 Field Emission, High Resolution, Scanning Transmission Microscope

Equipped with energy dispersive x-ray analysis system and electron energy loss spectrometer.

$700,000

JEOL Model JSM-840 MK-II High Resolution Scanning Electron Microscope

Equipped with energy dispersive and wavelength dispersive x-ray spectrometers, full range of sample handling attachments and computer based automation and data analysis system.

$400,000

2. Surface Analysis Equipment

PHI Model 600 Scanning Auger Multiprobe

Equipped with full computer automation, high-pressure reaction system, and multiple sample handling and processing capabilities.

$650,000

JEOL Model JAMP-10SP Secondary Ion Mass Spectrometer

Equipped with fully automated data collection and processing system, energy dispersive x-ray spectrometer, and multiple sample-handling capabilities.

$400,000

KRATOS Model X5AM-800 X-Ray Photoelectron Spectrometer

Equipped with ultraviolet source, automated sample chamber, monochromator and multichannel detector, and microbeam etching.

$530,000

3. X-Ray Diffraction and Analysis Equipment

Philips Model APD 37-20 Computer Automated X-Ray Diffractometer

Equipped with automatic sample changer and accessory camera.

$250,000

Philips Model 1400 X-Ray Fluorescence Analyzer

Equipped with computer automation and automatic sample changer.

$225,000

4. Auxillary Equipment

Optical Metallograph with Image Analysis System

$150,000

Spark Machining and Ion Beam Thinning Units, Diamond Saws, etc. for Specimen Preparation

$100,000

Vacuum Evaporators, Leak Detectors, Residual Gas Analyzers, and Electronic Test Equipment

$100,000

Photographic Processing Equipment, Optical Benches, Optical Microscopes and Related Equipment

$250,000

5. Space Renovations

Renovation of 20,000 square feet of laboratory space to provide the necessary clean environment and special facilities needed to properly house the above equipment.

$1,700,000

TABLE III

STAFFING REQUESTS:

Faculty Participants		12 FTEs
Microelectronics		
Silicon devices	2	
Advanced devices	3	
Electronic materials	2	
Applied Optics		
Optoelectronics	3	
Quantum optics	2	
Quantum Engineering		
Condensed Matter Physics	2	
Atomic Processes	1	
Technical Support Staff		4 FTEs
Graduate Research Assistants		16 FTEs

4. CONCLUDING REMARKS

There is ample evidence across this nation to demonstrate the impact that world-class engineering schools have on economic development. A major investment by the State of Michigan in the UM College of Engineering through the Research Excellence Fund can be expected to have a similar impact on our State's long-term economic prosperity. Furthermore, since the most talented of Michigan's high school graduates now enroll in the College, such action would also represent an important investment in Michigan's most valuable resource, its youth. These extraordinarily talented students will become the leaders and bulders of Michigan industry. Not only will they sustain the competitiveness of existing Michigan companies, but they will found the new companies necessary to diversify Michigan's economic base.

The UM College of Engineering is unique in this State in its ability to attract outstanding facilty and students necessary to achieve national leaderhsip. Furthermore, it alone possesses the reputation to leverage this investment of State support several-fold through federal and industrial grants and contracts.

The requested investment of $3,920,000 in base support of a Center of Scholarly Excellence in Advanced Electronics and Optics Technology is modest compared to the almost certain economic impact of such activities. Furthermore, such an investment is necessary if the State of Michigan is to respond to the commitments made both by the American electronics industry and the federal government in the UM College of Engineering.

Roughly 70 years ago, the automobile industry originated in the inspired inventions of self-educated craftsmen skilled in building engines for boats and machinery. The industry took root in Michigan and triggered the economic growth which led to the impressive social institutions characterizing our State today. However, recent patterns of economic development such as Silicon Valley and Route 128 suggest that future industrial growth will be stimulated less by physical capital than by intellectual capital -- by technological nnovation, the talented engineers capable of understanding and applying this technology, and the entrepreneurs capable of stimulating industrial growth.

Leading engineering schools such as the UM College of Engineering are the key sources of these essential ingredients for technology-based economic development. it is from this perspective that the UM College of Engineering must be viewed as one of the most important investments Michigan can make for its long-term economic prosperity.

APPENDIX A

THE IMPORTANCE OF NECESSARY "INFRASTRUCTURE" SUPPORT

While the support of research "Centers of Scholarly Excellence" are of major importance to Michigan's future, it is essential to recognize that such Centers will only be successful if the State restores a adequate level of base funding to sustain the "infrastructure" of the parent academic unit. Perhaps nowhere is this more apparent that in the crisis presently faced the the University of Michigan College of Engineering.

The importance of world-class engineering programs to economic development has been recognized by state after state. One by ones, states such as Illinois, Ohio, Pennsylvania, Minnesota, Indiana, and New York have made massive commitments to build the MITs, the Berkeleys, and the Stanfords of tomorrow. They have recognized that only nationally competitive engineering schools are capable of a major impact on economic development, since only such world-class programs are able to attrct the outstanding faculty, the students, and the economic and technological resources necessary to stimulate the growth of new industry.

But, Michigan, unlike most of these other states, already has an institution with a competitive edge, the UM College of Engineering. Ironically, our state also stands apart from others in its failure thus far to restore an adequate level of support to its premier engineering school. During a decade in which enrollment int he College grew by over 45% to its present level of 6,000 students, the level of state funding for its programs has dropped dramatically. The College is currently understaffed by at least a factor of two relative to state formula funding models. This has led to a seriously overloaded faculty and limited opportunities for reserach and spinoff activities. Furthermore, technical support staff and equipment funds were cannibalized to offsset the deterioration in state support, and this has resulted in obsolete and inadequate laboratories and an equipment and computer inventory backlog now estimated at over $70 million.

Despite its importance to Michigan, the College's capacity to respond to the needs of Michigan and its citizens has been serously crippled by inadequate state support. More serous is the probably consequence that over the next several years the College will be forced to cut enrollments by as much as 50% and dismantle programs of critical importance to this state if this chronic underfunding cannot be reversed.

To calibrate the magnitude of this underfunding, it should be noted that the UM Engineering College receives an annual instructional budget of roughly $3,900 per student, compared to levels of $5,500 in most public peer institutions (Illinois, Purdue, Wisconsin,...) and an increasing number of emerging institutiosn (Texas, Arizona, Florida, Maryland,...). In sharp contrast, the leading engineering institutions such as UC-Berkeley, MIT, and Stanford receive roughly $7,000 per student for their instructional programs -- twice that provided to UM Engineering. It is evident that unless this serious funding gap is erased, the UM Engineering College will find it increasingly difficult to compete for the faculty and other resources necessary to achieve the national leadership required for maximum economic impact.

If the University of Michigan College of Engineering is to have the capacity to participate in positioning Michigan as the leader in merging industrial technology, it will require direct and immediate assistance from the State of Michigan to restore an adequate base level of support for its programs. University officials, working closely with leaders from State government, business, labor, and industry, have developed the following two-stage plan for special action:

State I (the "restoration" phase) of this plan would involve the rapid restoration of a level of State support for UM Engineering comparable to that presently received by other peer and emerging public institutions. Since UM Engineering's level of General FUnd support per student ($3,900) presently falls $1,600 behind these institutions, such action will require a base budget increase of $8.5 million (allocated both to staffing and sustained equipment support). Additional one-time support of $20 million will be required to support major initiatives in the critical areas of complex manufacturing technology, advanced electronics and optical devices, and advanced materials.

In Stage II (the "leadership" phase), a sequence of State investments would bring the support of UM Engineering to a level comparable to that of leading engineering schools (e.g., UC-Berkeley, MIT, Stanford, UCLA). This will require an additional increase in base appropriations of $9.5 million (bringing the General Fund support per student to $7,000) and one-time equipment support of an additional $20 million to restore the College's laboratory equipment inventory to competitive levels. In additiona, two new physical facilities would be required: a $20 million bulding to house laboratories for rapidly changing areas of technology, and a $20 million facility to serve as an incubation center for bringing together startup companies and satellite corporate R&D laboratories with College faculty, students, and staff.

It should be noted that the UM College of Engineering is unique in this State in its ability to attract the outstanding faculty and students necessary to achieve national leadership. Furthermore, it alone possesses the reputation to leverage this investment of State support several-fold through matching grants and contrcts from both the federal government and the private sector. More specifically, the proposed investment by the State would be matched by growth in College-generated revenues to a sustained level of over $70 million per year: $30 million per year from federal and industrial research contracts; $25 million per year from student tuition and fees; and $15 million per year from private and corporate gifts such a partnership involving State, federal, and private support is essential in achieving the level of resources necessary to compete with the nation's leading public and private institutions.

APPENDIX B

THE IMPACT OF THE UM COLLEGE OF ENGINEERING ON STATEWIDE ECONOMIC DEVELOPMENT

Background:

In recent months, several important new studies have been released which have clarified:

- The importance of technology to Michigan's future economic development.
- The investments that will be necessary if Michigan is to participate in this nation's long-term prosperity.
- The role that higher education will play in this effort.

These studies include:

1. Putting our Minds Together: New Directions for Michigan Higher Education, The Governor's Commission on the Future of Higher Education in Michigan (the "Ross Report")
2. The Path to Prosperity, Findings and Recommendations of the Task Force for a Long-Term Economic Strategy for Michigan
3. Preliminary Recommendations, Governor's Commission on Entrepreneurship and Small Business Development
4. Route 128 and Silicon Valley: A Comparison, Peter Eckstein, Executive Director, Governor's Commission on Jobs and Economic Development

In an attempt to respond to the recommendations of these reports, the UM College of Engineering has developed a strategy for assisting in statewide economic development activities. This strategy is reviewed in this Appendix.

Michigan's Path to Prosperity

As pointed out by the Ross Report, a state becomes prosperous in one way only: by increasing the value of the goods and services that industries in its economic base sell outside the state. While industries such as retail trade and medical services are among the fastest growing, they do not contribute to the economic base but rather simply shift resources internally from one economic sector to another. Rather, the vast majority (90%) of Michigan's economic base lies in durable goods manufacturing. In a sense, manufacturing industry is and will remain the real strength of Michigan's "economic engine".

By combining the state's largely unskilled and semi-skilled workforce with substantial amounts of capital and technology, Michigan has made its workers the most productive and best paid in the world. However today the facilities and technology employed by unskilled labor in high volume standardized production can be purchased by manufacturers anywhere.

Hence Michigan industry must replace the standardized, routine, low-skill, mass production of familiar products, in which we can no longer complete unless we dramatically lower wage rates, with competitive new products and processes that require skilled labor. We must shift our state's economic base toward products and processes that depend on the one part of the production system that cannot be readily transferred to competing regions: human skills. These skills include those of production workers, managers, technologists, and researchers. Production processes that rely on human skills must remain where the skilled people are.

Economic prosperity for Michigan lies not in tearing down the state's old industrial base for a different kind of economy, but in helping that base make the changes necessary to compete in a new economic environment. Indeed, because of its existing agglomeration of durable goods manufacturing firms, skills, and infrastructure, Michigan possesses an advantage in the competition to become a leading world center of durable goods complex manufacturing.

Michigan must become America's factory of the future. And it must become a world center for the export of the new industrial technologies and manufacturing machinery that will form the basis of the factory of the future. In Michigan's emergence as the center of complex manufacturing, new technology will not a separate industrial sector; it will be at the heart of every industrial sector.

Our ability to innovate -- to generate and to executive new economic ideas -- must become our principal economic advantage. Only in this way can we be competitive with other regions and nations and productive enough to earn the income required for a rising standard of living. In this sense, innovation will be the energy that drives change in our state's economy.

To position Michigan as the nation's source of emerging industrial technology, we must move rapidly along three fronts:

- To enhance the growth of research and development in Michigan.
- To accelerate the transfer of technology into Michigan industry.
- To develop a strong coalition within Michigan among government, industry, labor, and universities to create a "venture culture" in Michigan.

The Importance of the UM College of Engineering

Experience in other regions suggests that Michigan's success in achieving this rebirth in its industrial base and competing effectively with other states and nations will depend on its ability to build and sustain a world-class engineering school. Such schools play a vital role in economic development since they provide the intellectual creativity fundamental to technological innovation and the talented, broadly-educated engineers capable of understanding and implementing this technology.

Furthermore, when coupled with appropriate technology-transfer mechanisms, there is little doubt that world-class engineering schools at the cutting edge of research and development can have a major impact on both technological innovation and implementation in the private sector. They provide, through their faculty, students, and graduates, the mechanism for transferring research from the campus into the private sector for commercial exploitation. Finally, such schools are usually a key factor in attracting the "risk capital" represented by massive federal R&D contracts.

Experience has also shown that only those engineering schools capable of clearly ranking among the nation's leaders are able to have a major impact on economic development. Only such world-class programs are capable of attracting the outstanding faculty, the talented students, and the massive resources necessary to achieve the required level of excellence.

For this reason, each of the major studies has stressed the importance of the UM College of Engineering in determining the future economic prosperity of our state:

1. The Ross Report has called for special emphasis on the UM College of Engineering:

   "To ensure the lead position in the development of manufacturing production processes, Michigan must invest heavily in centers of applied research in industrial technology, with special emphasis on developing the University of Michigan College of Engineering as a world leader in this field."

2. The Governor's Commission on the Future of Higher Education has stressed:

   "The existence of high-quality engineering programs is critical to Michigan's economic future. The Commission recommends that state funds be focused on the few high-quality engineering programs consistent with institutional roles and missions."

3. The Governor's Commission on Entrepreneurship and Small Business Development has singled out UM Engineering as a key factor in enhancing the growth of R&D in Michigan, accelerating the transfer of this technology into Michigan industry, and developing a "venture culture" in our state.

4. _The Governor's Commission on Jobs and Economic Development_ has stressed the importance of leading engineering schools on the future of industry in our state.

There are several reasons for this focused attention on the UM College of Engineering as a major factor in Michigan's future: The College is a unique resource in this state. It alone among Michigan's institutions of higher education is within striking distance of achieving the degree of national leadership in engineering education and research necessary for major long term economic development.

The College is presently ranked 5th in reputation among the nation's leading engineering schools. It has been identified as a national center of excellence in technologies of critical importance to Michigan, including complex manufacturing technology, machine intelligence, microelectronics and optical devices, industrial engineering, computer engineering, and materials engineering. Furthermore, the 6,000 students enrolled by the College presently rank among the top 2% of Michigan's high school graduates and hence represent perhaps this state's most valuable source of "intellectual capital".

Coupled with this strong emphasis has been an increased recognition that prompt action is necessary to restore an adequate level of State support to allow the UM College of Engineering to play the role it must in establishing Michigan as the leader in emerging industrial technology. Each of these studies has called for increased commitments on the part of State government to provide the UM College of Engineering with the resources necessary to remain competitive with leading public and private engineering schools.

While such support will be a necessary prerequisite if the College is to play the critical role expected of it, there are also other steps which must be taken. The UM College of Engineering believes it has a major responsibility to respond to the needs of Michigan and its industry:

- Through the attraction of outstanding engineers and scientists and the establishment of national research centers of excellence capable of technological innovation.

- Through the transfer of this technology to Michigan industry through its graduates, continuing engineering education, research partnerships, and the formation of spinoff companies.

- Through direct participation in economic development by attracting companies and national R&D centers to Michigan and encouraging its faculty and graduates to spin off new companies.

A Strategy for Statewide Economic Development

The UM College of Engineering probably has its largest impact on statewide economic development through the over 1.800 engineers it graduates each year -- roughly 70% of whom accept positions in the Great Lakes area -- and the research achievements of its faculty and staff. However in recent years, UM Engineering has gone beyond these traditional mechanisms to initiate a number of new programs aimed at regional economic development. The College has developed its strategy in close cooperation with leaders of state government, industry, and business.

The basic strategy can be grouped into three areas:

Technological Innovation:

- o The attraction of outstanding engineers and scientists to Michigan
- o The establishment of national research "centers of excellence"

Technology Transfer:

- o Traditional mechanisms (graduates, consulting, publishing)
- o Research partnerships with industry
- o Continuing engineering education
- o Formation of spinoff companies
- o Industrial consortia

Job Creation:

- o Formation of spinoff companies
- o Attraction of new companies to Michigan
- o Attraction of major national R&D centers

We will consider each component of this strategy in turn.

Technological Innovation:

As noted by the Ross Report, "innovation is the energy that drives change in a state economy". It has also been noted that most of the significant technological innovations that stimulated industrial growth in other parts of the country originated in leading engineering schools. Hence, it is reasonable to expect that the UM College of Engineering will play (and has played) a similar role in stimulating technological innovation in Michigan.

To be a world leader in emerging industrial technology, Michigan must attract engineers and scientists of extraordinary ability and creativity. The UM College of engineering is one of the few institutions in the nation with the proven ability to attract such people.

For example, the 6,000 students presently enrolled in the College probably represents the largest concentration of students with exceptional abilities in science and mathematics of any institution in the United States. Furthermore, over the past three years the College has recruited 70 new engineering faculty from the finest institutions in this nation (Stanford, MIT, Caltech, ...).

In recent years the College has been able to build several programs which are now clearly identified as national research centers of excellence:

Center for Research on Integrated Manufacturing (CRIM)
Industrial Technology Institute (ITI)
Air Force Center of Excellence in Robotics
Computer-Aided Engineering Network
Center for Ergonomics
SRC Center of Excellence in Semiconductor Manufacturing

Additional major research centers under development include:

Center for Applied Optics
Materials Research Laboratory
Solid-State Electronics Laboratory
Center for Scientific Computation
Artificial Intelligence Institute
Machine Intelligence Center
Applied Physics Program

Technology Transfer:

Traditionally, leading engineering schools such as the UM College of Engineering have transferred technology to the private sector in the following ways:

- Placement of graduates in Michigan industry
- Co-operative engineering education
- Continuing engineering education for Michigan industry
- Publication of research results in the open literature
- Faculty/industry exchange programs
- Faculty and staff consultation with industry
- Special research projects conducted for industry

However, in recent years the College has gone beyond these traditional mechanisms to develop new ways to transfer technology. One of the most important mechanisms involves Industrial Affiliates Programs in which 10 to 20 companies will work with the College in areas of specific technological interest. Ongoing Industrial Affiliates Programs include:

- Solid-State Electronics
- Robotics
- Ergonomics
- Flow Reaction and Porous Media

- o Colloidal and Surface Phenomena
- o Machine-Tool Wear and Sensing
- o Information Systems Engineering
- o Computer-Aided Manufacturing
- o Construction Engineering and Management
- o Computer-Enhanced Productivity (EPIC)

The College has pioneered in the development of a more sophisticated and sustained type of relationship known as the Industrial Research Partnership. In these partnerships, the College works closely on common research problems with key companies. The College forms teams of PhD students led by faculty which then work side by side with industrial engineers and scientists (both in company facilities and on campus). Such partnerships have already yielded dramatic leaps forward in critical areas of technology. Existing research partnerships have been formed with the following companies:

- o General Motors: "factory of the future"
- o Ford: ergonomics, electronics, design
- o IBM: supercomputers and robotics
- o Intel: computer science
- o Semiconductor Research Corporation: automation
- o General Electric: computer-aided design
- o General Dynamics: computing networks

Other partnerships presently under negotiation include:

- o Chrysler: computer-integrated manufacturing
- o Dow: chemical process control
- o Bechtel: CAD in large-scale construction

Job Creation:

The UM College of Engineering is also involved in a number of activities aimed at direct job creation. One of the most important such mechanisms is through the formation of new "spinoff" companies by faculty, staff, and students. This has always been an active area, as evidenced by the 77 companies formed by the College and its affiliated research laboratories over the past two decades. However, strong steps are now being taken to encourage and facilitate this activity, and the rate of spinoffs is increasing rapidly.

There has also been considerable activity directed toward attracting industry to Michigan. Through close coordination with state and local government, the College has used its extensive industrial contacts to identify and interact with prospective companies. During the course of a typical academic year, faculty and staff of the College will conduct 50 to 60 day-long briefings both on campus and at industrial sites with the intent of stressing the desirability of locating new installations in Michigan. The College has also been an important partner in efforts to develop several research parks in the southeastern Michigan area.

Finally, the UM College of Engineering has frequently played a key role in attempts to attract major national R&D centers to Michigan. For example, the College provided the principal technical component of the State's proposal for siting the Microelectronics and Computer Corporation. It has taken the lead in efforts to attract the DOD Software Engineering Institute and the NSF National Supercomputer Center. Similar efforts are now underway to compete for the following centers:

- Air Force Artificial Intelligence Institute
- National Knowledge Engineering Center
- NSF Materials Research Laboratory
- DOD Strategic Defense Initiative
- National Laser Institute
- NSF Engineering Research Center

Conclusions

There seems little doubt that the UM College of Engineering represents a valuable resource to Michigan. Its role will become increasingly important as Michigan strives to diversify and strengthen its economic base with technology-based industry. In this sense, the UM College of Engineering provides state government with both a vehicle and an extraordinary opportunity for investing in the long-term economic health of our state.

APPENDIX C

EXAMPLES OF ACTIVITIES OF THE UM COLLEGE OF ENGINEERING RELATED TO ECONOMIC DEVELOPMENT

1. In 1981 the College established the Center for Research on Integrated Manufacturing to conduct research and instruction in areas concerned with the computer-based automation of the functions of industrial production, ranging from product design to manufacturing to management, sales, service, and upgrading -- all of the activities of the so-called "factory of the future". As the Ross Report has noted, it is just such complex manufacturing that will be the key to Michigan's long-term economic prosperity. The Center currently involves the efforts of 45 faculty and 100 graduate students from 6 academic departments. In less than three years, the Center has received international recognition as one of the leading manufacturing research programs in the nation. It has built a sustained level of funding from industrial and federal sources of roughly $6 million per year.

2. The College played a key role in the development of the Industrial Technology Institute of Michigan. This Institute will be come a world-class center for research and development in a variety of areas related to manufacturing, ranging from automation and manufacturing processes to technology transfer and the social implications of industrial technology. The Institute is currently housed in College facilities and building its initial programs with the assistance of College staff. Within a short time the Institute expects to employ roughly 200 staff and be engaged in a broad spectrum of basic and applied research and development in manufacturing.

3. In parallel with these major thrusts into industrial technology and manufacturing engineering, UM Engineering has begun an exciting new program in "white collar" or "professional" productivity, the EPIC Project (Enhanced Productivity through Integrated Computer Workstations). In collaboration with several Michigan companies, the College is working to apply modern computer and communications technology to develop a prototype computer network of tomorrow, the Computer Aided Engineering Network, that will support industry and business. Major computer companies such as IBM, Apollo, Apple, AT&T, EDS, and General Electric are active participants in assisting in the development of this system.

4. The College of Engineering conducts the leading program in the nation in occupational health and safety through its Center for Ergonomics. Recently, the Center has played a key role in analyzing and restructuring the workplace environment of the factories of one of Michigan's leading companies, in order to address the concerns both of labor and management. Of particular concern has been the development of an effective "man-machine interface" between workers and automated machines.

5. In 1984 the College began construction of the Laboratory of Electrical Engineering and Computer Science. Concurrent with this project, the College has consolidated its programs in electrical engineering, systems engineering, and computer science and engineering into one of the largest and most comprehensive Departments of Electrical Engineering and Computer Science in the nation, with almost 100 faculty and 1,800 students. Moreover, during the past two years the College has developed what is now regarded as the nation's most sophisticated university computing environment. These factors have provided Michigan with world-wide recognition for its programs in electrical engineering, computer science, and telecommunications techology -- areas of critical importance to Michigan industry.

6. In recognition of its combined strengths is solid-state electronics and industrial automation, the American electronics industry recently selected the UM College of Engineering (along with Stanford and the North Carolina Research Triangle) as the cornerstone of a major new research effort concerned with developing the technology of the microelectronics factory of the future. Since the automobile industry will be both the largest consumer and manufacturer of electronic components, this research project has an extraordinary importance for future industrial growth in the state.

7. The College has recently attracted several of the leading materials scientists in the nation to build a world-class research laboratory in advanced materials research. Eight new faculty will be added in this important area. The College is now seeking a $6 million grant from the National Science Foundation to establish a major Materials Research Laboratory in Michigan.

8. The College has been the driving force behind the University's efforts to attract a major federally-sponsored supercomputer center to Michigan. Associated with the center will be a Center for Scientific Computation which will attract many of the leading scientists and engineers in the world to our State.

9. The College is building on its traditional strength in applied optics to establish a new Center for Applied Optics. Research areas for the Center include optical diagnostics, high-powered lasers, opthmological measurements, laser spectroscopy, holography, optical data processing, guided optics, coherent optical measurement techniques, and nonlinear optics. Of particular interest will be a major new program in optoelectronics -- optics on a chip. Since many believe that this technology will eventually replace microelectronics, the development of one of this nation's leading programs in this area could well trigger a Silicon Valley (more precisely, a "Gallium Arsenide" Valley) phenomenon in the southeastern Michigan area.

10. Research and instruction in artificial intelligence has been a part of many departments at Michigan. The recent creation of the Department of Electrical Engineering and Computer Science has brought together the majority of researchers in this area. The College is committed to

building a strong applied research program in artificial intelligence with special emphasis on industrial applications. Working closely with major companies such as Electronic Data Systems (recently acquired by General Motors), the College intends to build a national Institute in Knowledge Engineering, the application of artificial intelligence to manufacturing processes.

11. For many years the College has conducted Industrial Affiliates programs in which companies collaborate in a variety of technical areas of mutual interest. At present there are ten such programs in areas such as Robotics, Solid State Electronics, Machine Tool Wear, CAD/CAM, Catalysis and Surface Science. However, UM Engineering has recently negotiated several more extensive interactions, Industrial Research Partnerships, with key companies such as General Motors, IBM, and General Dynamics in which the College places faculty-graduate student teams into their facilities to identify and develop joint research projects, and then these teams return to campus, along with their industrial colleagues, to continue the research.

12. The College has taken very seriously its obligations to transfer the fruits of its research activities into the private sector to stimulate economic growth and job creation. Through a major restructuring of internal prolicies, the College has sought to encourage faculty and students to spin off research developments into the private sector. During the past year along, 7 new companies have been started by faculty of the College bringing the total number started by College faculty, staff, and affiliated laboratories to 85 (see Appendix C).

13. Furthermore, the College has worked with the University to found the Michigan Research Corporation, an independent corporation, with the mission of identifying intellectual properties developed on campus and providing the guidance and resources necessary to bring these to commercial application. The College also works quite closely with a number of leading venture capital firms.

14. The College has taken steps to expand its delivery of instruction in engineering to industry through a variety of mechanisms, including its Instructional Television Network, tutored-videotape instruction, and engineering short courses and conferences held both oncampus and at widely-scattered industrial sites. It is also participating with industry through co-operative education programs in a variety of fields.

15. The College has cooperated closely with state and local government in a variety of economic development activities. For example, the College was a founding member of the Michigan Technology Council. Furthermore, it has participated with the Governor's Office in efforts to attract new companies and national R&D Centers to Michigan.

APPENDIX D

SPINOFF COMPANIES ESTABLISHED BY
UM ENGINEERING FACULTY AND STAFF

Applied Dynamics, Inc.	(Howe)
Applied Theory, Inc.	(Cole)
Arktronics	(students)
Automated Analysis Corp.	(Anderson)
CFR Inc.	(Hilliard)
Coastal Dynamics Inc.	(Meadows)
Conductron	(Siegel)
Electrocon International	(Enns)
Environmental Dynamics Inc.	(Cole, Weber)
ESZ Associates Inc.	(Edlund, Shure, Zweifel)
Explosion Research Corp.	(Kauffman)
ISDOS Inc.	(Teichroew)
Limno-Tech Inc.	(Canale)
Jodon Inc.	(Gillespie)
Michigan Automotive Research Corp.	(Cole)
Machine Vision International	(Sternberg)
Materials Technology Corp.	(Felbeck, Jones, Bolt)
Mechanical Dynamics Inc.	(Chace)
Medicus Inc.	(Jelinek)
Project Management Assoc.	(Ponce De Leon)
QED Environmental Systems	(Weber)
Raycon, Inc.	(Check, Rupert)
Solarcon, Inc.	(Clark)
Starpak Energy Systems, Inc.	(Clark)
Stoll, Evans, Woods, Consultants	(Woods)
TDR Inc.	(Felbeck)
Transidyne General	(Diamond)
Traverse Group	(Armstrong)
VAI	(Vorus)
Vector Research	(Bonder)

SPINOFF COMPANIES ESTABLISHED BY
UM ENGINEERING AFFILIATED LABORATORIES

(Willow Run, ERIM, Space Physics Research Labs, Radiation Lab...)

Argo Science, Inc.	1976
Ann Arbor Computer Corp.	1972
Applied Intelligent Systems	1982
Arono Pemex	1969
Bendix Aerospace Division	1961
CFC, Inc.	1971
Conductron	1960
Control Data Corp.	1958
Crystal Optics Research, Inc.	1963
Cytosystems Corp.	1982
Daedalus Enterprises	1969
Data Max	1967
Data Products	1960
Data Systems, Inc.	1961
DeKalb, Inc., Sensors Div.	1974
First Ann Arbor Corp.	1967
Geospectra Corp.	1974
Harris Electro-Optics Center	1969
Hearing & Noise Assoc.	1979
Hewlett-Packard, Data Systems Div.	1964
Holly Carburetor-Rochester Div.	1957
Intelldata, Inc.	1959
Irwin Industries International	1979
Jervis Webb, Inc., AA Comp. Div.	1973
KMS Corporation	1969
KMS Fusion	1971
Kaiser Optical Systems, Inc.	1980
Laser Systems, Inc.	1967
Lear Siegler, Laser Systems Div.	1965
Machine Vision International	1983
Manufacturing Data Systems, Inc.	1962
McDonnell Douglas, Conductron Div.	1967
Michigan Computers and Instru.	1983
Nichols Research Corp.	1978
Northern Telecom, Sycor Div.	1978
Olivetti, Inc. - Irwin	1982
OptiMetrics, Inc.	1979
Photon Equipment	1957
Radiation, Inc., Adv. Optics Center	1968
Ritt Labs	1962
Sarns, Inc.	1962
Science Applications Inc. (AA Div.)	1972
Sensor Dynamics	1964
Sensors, Inc.	1969

Sonovision	1971
Strand Consultant	1965
Strand Engineering, Inc.	1960
Sycor, Inc.	1967
Synthetic Vision Systems, Inc.	1983
Trion Institute	1960
Union Carbide, Data Systems Div.	1962
Veda Corporation (Ann Arbor)	1964

UM COLLEGE OF ENGINEERING

FACT SUMMARY

REPUTATION:

- o Generally ranked 5th nationally in overall quality.
- o 18 of its degree programs are ranked in the top ten.
- o UM's programs in industrial engineering, aerospace engineering, nuclear engineering, and naval architecture are generally regarded as national leaders.

TRADITION:

- o UM has 7th oldest engineering college.
- o Ranks 3rd in total number of degrees awarded (50,000).
- o Pioneered in introduction of programs: metallurgical engineering (1854), naval architecture (1881), chemical engineering (1901), aeronautical engineering (1916), nuclear engineering (1953), and computer engineering (1965).

CAPACITY:

o Enrollment (1984):	Undergraduates	4,512
	Masters	1,041
	Doctorates	539
	Total	6,092
o Degrees (1984):	B.S.	1,210
	M.S.	584
	Ph.D.	93
	Total	1,887

- o Ranks 4th nationally both in enrollment and degrees.

STUDENT QUALITY:

- o 3,400 applications for 750 positions.
- o Average entering freshman ranked in 98th percentile.
- o SATs: 580 verbal, 680 math (1260)
- o Entering high school grade point average: 3.8
- o 27% of entering freshmen are straight A (4.0) students.

FACULTY CHARACTERISTICS:

- o 320 faculty members.
- o Over 100 new faculty will have been hired in period 198085.
- o 650 research staff.

RESEARCH ACTIVITY:

- $25 million per year in federallysponsored research (plus an additional $12 million in affiliated institutes).
- Research in all areas of science and technology.
- Major new interdisciplinary research efforts: integrated manufacturing, microelectronics, materials processing, biotechnology, ergonomics, space systems instrumentation, applied optics, computer systems and networks, gas dynamics and combustion, supercomputers

RESOURCES:

- Physical Plant: 1,000,000 nsf (15 buildings)
- Equipment Inventory: $30 million
- Computer Network Inventory: $20 million
- Operating Budget:

Tuition Revenue	$25 million
Sponsored R&D	$25 million
Gifts	$10 million
State appropriation	$10 million
Total	$70 million

NARRATIVE DESCRIPTION

The College of Engineering of the University of Michigan has consistently ranked among the leading engineering schools in the nation and the world, whether measured by the quality of its instructional programs, its research accomplishments, or the impact of its graduates. The College's combination of disciplinary breadth and depth of quality across the full spectrum of instruction and reserach make it unusual among the nation's engineering schools. Most surveys rank each of the College's undergraduate and graduate degree programs high among the leading programs in the nation.

The College is one of the few leading engineering schools imbedded in a great univeristy with strengths across all academic and professional disciplines. This has provided it with a unique opportunity to develop new academic programs and applications involving those related fields. It has also provided students of the College with an unparalleled breadth of educational opprotunities and experiences. Graduates of the College are widely known for their strong background in fundamental science and their ability to apply this knowledge in engineering practice. They move easily and rapidly into positions of leadership in industry, government, and academe.

The primary objective of the College for the decade ahead is to continue and to strengthen its position of leadership in engineering education by achieving excellence in education, research, and the pofessional activities of faculty, students, and graduates.

Today over 6,000 students are enrolled in the College's 20 degree programs. Each year it graduates more than 1,800 engineers at the BS, MS, and PhD levels. Ranking third among engineering schools in the total number of degrees awarded, it has more than 50,000 alumni spread throughout the world.

In recent years the College has seen an unprecedented interest on the part of the most outstanding high school graduates to enroll in its programs. For example, in 1984 the average entering freshman ranked in the 98th percentive of his or her high school graduating class. Over 25% of these students had perfect 4.0 grade point averages in high school. The College has seen a similar increase in the demand for admission to its graduate programs (particularly at the PhD level).

The College has long been a leader in the development of new academic programs at the very forefront of technology. It pioneered in the introduction of programs in metallurgical engineering (1854), naval architecture (1881), chemical engineering (1901), aeronautical engineering (1916), nuclear engineering (1953), and computer engineering (1965). This tradition of leadership continues today, as evidenced by the College's thrusts into such new areas as robotics and computer-integrated manufacturing, microelectronics, biotechnology, and advanced materials.

The College has adopted a matrix management structure to coordinate its array of research activities. As such research efforts have demanded a broader, interdisciplinary approach involving the strong interaction of a number of traditional academic disciplines, the College has created numerous research Laboratories, Centers, and Institutes to coordinate these activities. Of particular note are major research organizations such as the Center for Research on Integrated Manufacturing, the Space Physics Research Laboratory, the Center for Ergonomics, the Solid State Electronics Laboratory, the Phoenix Memorial Laboratory, the Computing Research Laboratory, and the Ship Hydrodynamics Laboratory.

In addition, the College has developed numerous mechanisms for interacting more closely with industry. These range from a variety of Industrial Affiliates programs in which a number of companies will sponsor and participate in research in particular areas, to Research Partnerships in which the College will work closely with a particular company to develop a major research relationships involving facultyled teams of PhD students along with scientists and engineers from industry. In addition the College has spawned several research organizations separate from the University such as the Industrial Technology Institute and the Environmental Research Institute of Michigan to better facilitate industrial research. And, of course, the College continues to provide assistance to industry through cooperative engineering education programs, continuing engineering education, and its Instructional Television System.

Finally, the College of Engineering has strongly encouraged its faculty, students, and staff to become involved in the transfer of intellectual properties from the campus into the private sector. Working closely with the University, it has streamlined conflict of interest regulations to facilitate the establishment of spinoff companies. (By way of example, in 1983, faculty and staff of the College started 7 new companies.) It has also worked closely with venture capital groups, financial institutions, and the UM School of Business Administration to stimulate this important activity.

UM COLLEGE OF ENGINEERING

A TRADITION OF EXCELLENCE

SOME PARAMETERS:

- UM has 7th oldest engineering college.
- It ranks 3rd in total number of degrees awarded (50,000).
- Pioneered in introduction of programs: metallurgical engineering (1854), naval architecture (1881), chemical engineering (1901), aeronautical engineering (1916), nuclear engineering (1953), and computer engineering (1965).

SOME FIRSTS OF UM ENGINEERING:

o Metallurgical Engineering	1854
o Naval Architecture	1881
o Chemical Engineering	1901
o Aeronautical Engineering	1916
o Nuclear Engineering	1953
o Computer Engineering	1965

UM COLLEGE OF ENGINEERING

CAPACITY

ENROLLMENTS (1984):

Undergraduates	4,512
Masters	1,041
Doctorates	539
Total	6,092

DEGREE PRODUCTION (1984):

B.S.	1,210
M.S.	584
Ph.D.	93
Total	1,887

ENROLLMENT PATTERNS:

Electrical and Computer Engineering	1,427
Mechanical Engineering	912
Chemical Engineering	445
Aerospace Engineering	443
Civil Engineering	391
Industrial Engineering	382
Computer Science	340

UM COLLEGE OF ENGINEERING

STUDENT CHARACTERISTICS

STUDENT QUALITY:

Selectivity:	3,400 applicants for 750 positions
Percentile Ranking:	98th percentile
SAT Scores:	580 verbal 680 math 1,260 total
High School GPA:	4.0 (27% of class) 3.8 (average) 3.5 (cutoff)
Attrition rate to graduation:	10%

OTHER STUDENT CHARACTERISTICS:

- 23% women
- 7% minority (3% black)
- 74% of undergraduates from Michigan
- 11% foreigh nationals

UM COLLEGE OF ENGINEERING

NATIONAL RANKINGS

CAPACITY:

o	Enrollment:	Undergraduate:	4th
		Graduate:	4th
o	Degree Production:	B.S.	4th
		M.S.	4th
		Ph.D.	6th
o	Alumni:		3rd
o	Sponsored Research Volume:		7th

QUALITY:

o Overall Quality: 5th or 6th

o Program Rankings:

	UG	Grad
Atmospheric & Oceanic Sciences		
Aerospace Engineering	2nd	3rd
Chemical Engineering	9th	9th
Civil Engineering	7th	8th
Computer Science & Engineering		
Electrical Engineering	5th	5th
Engineering Science	3rd	
Industrial Engineering	1st	1st
Materials Engineering	3rd	
Mechanical Engineering	4th	5th
Metallurgical Engineering	9th	9th
Naval Architecture	1st	2nd
Nuclear Engineering	1st	2nd

UM COLLEGE OF ENGINEERING

ACADEMIC PROGRAMS

DEPARTMENTS:

Atmospheric and Oceanic Sciences
Aerospace Engineering
Chemical Engineering
Civil Engineering
Electrical Engineering and Computer Science
Industrial and Operations Engineering
Materials and Metallurgical Engineering
Mechanical Engineering and Applied Mechanics
Naval Architecture and Marine Engineering
Nuclear Engineering

DEGREE PROGRAMS:

Aerospace Engineering (BS, MS, PhD)
Applied Mechanics (BS, MS, PhD)
Applied Physics (MS, PhD)
Atmospheric Sciences (BS, MS, PhD)
Bioengineering (MS, PhD)
Chemical Engineering (BS, MS, PhD)
Civil Engineering (BS, MS, PhD)
Construction Engineering (MS, PhD)
Computer Engineering (BS, MS, PhD)
Computer Science (BS, MS, PhD)
Electrical Engineering (BS, MS, PhD)
Engineering Physics (BS)
Industrial and Operations Engineering (BS, MS, PhD)
Manufacturing Engineering (MS)
Marine Engineering (BS, MS, PhD)
Materials Science and Engineering (BS, MS, PhD)
Mechanical Engineering (BS, MS, PhD)
Metallurgical Engineering (BS, MS, PhD)
Naval Architecture (BS, MS)
Nuclear Engineering (BS, MS, PhD)
Oceanic Sciences (BS, MS, PhD)

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RESEARCH LABORATORIES, CENTERS, AND INSTITUTES

MAJOR RESEARCH UNITS:

- Automotive Laboratory
- Center for Catalysis and Surface Science*
- Center for Ergonomics
- Center for Research on Integrated Manufacturing
  - Robotics Systems Division
  - Integrated Design and Manufacturing Division
  - Manufacturing Systems Division
- Computer-Aided Engineering Network
- Computing Research Laboratory
- Gas Dynamics Laboratory
- Great Lakes Research and Marine Waters Institute*
- Laser-Plasma Interaction Laboratory
- Macromolecular Research Center*
- Rehabilitation Engineering Center
- Phoenix Memorial Laboratory (Ford Nuclear Reactor)*
- Solid State Electronics Laboratory
- Space Physics Research Laboratory
- Ship Hydrodynamics Laboratory
- Transportation Research Institute*
- Water Resources Laboratory

RESEARCH UNITS UNDER DEVELOPMENT:

- Center for Applied Optics
- Center for Scientific Computation*
- Materials Processing Research Institute*

*Intercollege activity

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RESEARCH AREAS OF MAJOR THRUST

<u>TRADITION</u> OF NATIONAL LEADERSHIP:

- Aerospace Engineering
- Applied Optics
- Atmospheric Sciences
- Gas Dynamics
- Image Processing
- Industrial Engineering (ergonomics, operations research)
- Naval Architecture
- Nuclear Engineering
- Remote Sensing
- Thermal and Fluid Sciences
- Solid State Electronics (sensors, microwaves)

<u>MISSION</u> FOR NATIONAL LEADERSHIP:

- Integrated Manufacturing
- Materials Processing Technology
- Biotechnology
- Computer Science and Engineering

<u>POTENTIAL</u> FOR NATIONAL LEADERSHIP:

- Applied Mechanics (micromechanics)
- Advanced Scientific Computation (supercomputers)
- Construction Engineering
- Electronic Materials
- Modern Optics (optoelectronics, nonlinear optics)
- Polymer Process Engineering

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KEY INTERDISCIPLINARY THRUST AREAS

Engineering and LSA:

Computer Science and Engineering (CCS + ECE --> EECS)
Applied Physics (Physics, Nuclear, ECE, MME)
Materials Research (Physics, Chemistry, MME, ChE)
Numerical Analysis and Scientific Computation (Eng, Math)
Earth and Planetary Sciences (A&OS, Geo Sci)
Biotechnology (Bio Sci, Chem, ChE, ECE)

Engineering and Medicine:

Biotechnology (Med, ChE, ECE)
Image Processing (Med, ECE, Nuclear, MEAM)
Biomechanics (Med, MEAM)

Other Interactions:

Ergonomics (Eng, Pub Health, Med)
Biochemistry (Eng, Phar, Med)
Computer Networks (Eng, LSA, Bus Ad, Med)
Transportation (Eng, Pub Health, UMTRI)
Water Sciences (Eng, LSA, Pub Health, Nat Res, GRMLK)