

## **A Shared Vision for Space and Atmospheric Sciences and Engineering**

College of Engineering  
University of Michigan

### **OUR VISION**

It is the combined vision of the faculty of the AOSS department to reinvigorate our department through initiation of new educational opportunities in atmospheric and space science and engineering. It is also our intention to establish a vigorous earth systems science research program to meet national and global needs, while maintaining present strengths in space and atmospheric sciences and engineering. This vision embraces our department's unique position within the College of Engineering emphasizing the design and use of new instruments and models to explore our complex space and Earth systems. While this plan requires investment from the College of Engineering it will be initiated by existing faculty through restructuring of our curriculum and a shared commitment to identification of shared opportunities.

### **EXECUTIVE SUMMARY**

The Atmospheric, Oceanic and Space Sciences (AOSS) department has long prided itself on its capacity to design and develop instrumentation for the exploration of the atmosphere of earth, the planets and the space environment. However, over the past decades our research interests have partitioned significantly creating an environment that has often been more competitive than collaborative. At the same time our undergraduate and graduate enrollments have remained relatively low compared to many other College of Engineering departments.

While the space<sup>1</sup> and atmospheric<sup>2</sup> sciences have each achieved recognition for their scholarly contributions to their fields, the space science division has been extremely productive in its research volume driven by its capacity to build space hardware and create high-performance numerical simulation models. Its contribution to formal classroom teaching has been modest but the availability of research opportunities has provided excellent learning opportunities for both graduate and undergraduate students. The atmospheric science faculty on the other hand have a research volume that mirrors faculty at peer atmospheric sciences departments across the nation but pales in comparison to the space science volume. Its contribution to undergraduate education, has been, by and large, focused on providing high-quality cross-university survey courses, with a modest enrollment of College of Engineering (CoE) undergraduate and graduate majors.

Despite this history of polarity, the AOSS department is now at a place that is more open to mutual opportunities and goals than at any other time in the past. New faculty members have brought new

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<sup>2</sup> Atmospheric science here includes Earth-centered atmospheric dynamics and chemistry.

insights that welcome broadening and inclusion, and new opportunities exist for research that spans across discipline boundaries.

It is our vision that the AOSS department should now build on its excellence in atmospheric and space sciences research to grow excellence in earth systems science and engineering, while preserving its clear strengths in space science and engineering. We have unique capacities to design, build and maintain space-borne instruments for the study of the sun, the magnetosphere, the upper atmosphere and other planets. We have unique capacity to measure atmospheric constituents on Earth and on other planets. We possess recognized excellence in modeling space and atmospheric systems. The synthesis we envision maintains and preserves these strengths, and integrates them toward the study of Earth systems. This synthesis will provide new opportunities not only for research but also for CoE education through laboratory (virtual and real) and field research at the undergraduate and graduate level.

It is also our vision that the AOSS department shall make a major contribution towards addressing the workforce shortage in space industry that is now confronting the nation and the world. The ideal training for the workforce in space industry is an undergraduate degree in a core engineering discipline (electrical, mechanical, aerospace, computer science), followed by a Masters degree in space engineering. AOSS will introduce a new SGUS/MENG degree program that will address this key national need.

AOSS should also play an expanded role in the educational mission of the college and university. AOSS faculty can and should play a leadership role in delivering "the broad education necessary to understand the impact of engineering solutions in a global and societal context" expected as an outcome for engineering programs by the Accreditation Board for Engineering and Technology. Participation in courses and curricula in other CoE departments, notably the Aerospace Department and Civil and Environmental Engineering will be pursued for our mutual benefit. Additionally we envision playing a significant role in education and public outreach, including K-12 education outreach.

The goals of this AOSS department realignment are:

1. Significantly streamline AOSS course offerings to focus the department's educational missions to space science and engineering and to atmospheric aspects of global climate change.
2. Modify the degree programs in AOSS. We will maintain (with modifications) the following degrees:
  - a. B.S. Degree in Atmospheric Science — But streamline the existing program, and establish a B.S. program with LS&A to increase enrollment of majors.
  - b. MS/PhD program in Atmospheric Science — Redesign to reduce total AOSS course offerings by allowing greater flexibility in curriculum design.
  - c. MS/PhD program in Space Science — Redesign to reduce total AOSS course offerings by allowing greater flexibility in curriculum design.

MS/PhD program in Space and Planetary Physics — Existing joint degree program with the Physics Department.

- d. MS/PhD program in Geoscience and Remote Sensing — Existing joint degree program with EECS and CEE.
3. Create the following new degree programs:
    - a. SGUS/MENG program in Earth Systems Science and Engineering — This new program will be offered as SGUS to AOSS majors and majors from CEE and EECS at a minimum.
    - b. SGUS/MENG program in Space Engineering — This new program will be offered as SGUS to AOSS majors and majors from Aerospace Engineering, Mechanical Engineering, and Electrical Engineering and Computer Science at a minimum.
    - c. USGUS program in Earth System Science and Engineering — This new program to be created together with the Program in the Environment, LS&A, SNRE and School of Education.
    - d. MS/PhD program in Earth Systems Science — New joint program with the Geology Department.
  4. Collaborate with other department towards mutually beneficial academic programs.
    - a. Examine the value of dry appointments of selected AOSS faculty in CEE and selected CEE faculty in AOSS in support of the Environmental Engineering program and/or the cross-listing of courses.
    - b. Examine the value of dry appointments of selected AOSS faculty in Aero and selected Aero faculty in AOSS in support of the Aerospace Engineering program in Aero and the Space Engineering program in AOSS and/or the cross-listing of courses.
  5. Expand a limited number of service courses in LS&A. These courses generate considerable interest among students and can serve as a natural recruiting tool for some of the new initiatives (especially our proposed USGUS program).
  6. Establish an Education and Public Outreach program in collaboration with other programs across campus to facilitate coordination of efforts and to establish related curriculum.
  7. Initiate a Center/Program in Earth Systems Science and Engineering that encompasses the research interests of, at a minimum, AOSS atmospheric science faculty and Geologic Science faculty.
  8. While it will be possible for items (1) to (6) to be offered with the existing AOSS instructional faculty, in order to establish a nationally competitive program in earth systems science and engineering we need strategic investment in instructional faculty positions. Replacing recently retired instructional faculty members can start this process. Reassigning Prof. Tony England and Prof. Gerald Keeler full-time to AOSS will aid our capacity to reach critical mass in atmospheric science.

Additional instructional faculty hires should be based on demonstrable progress towards the

educational and research goals described in this document. New instructional faculty needs to be recruited in the following critical areas over the next five years:

- a. Optical remote sensing experimentalist, particularly with expertise in radiative transfer. This would give us broad, synergistic capabilities in earth observations and planetary exploration.
- b. Mission Principal Investigator class scientist (either Earth or Space Systems with preference to Earth System). This would ensure long-term continuity in our large instrument building capability. These kinds of efforts are essential to maintain and enhance our engineering capabilities.
- c. Planetary scale GCM modeler with emphasis on subgrid scale processes in climate models.
- d. Space physicist<sup>3</sup>.
- e. Space modeler to replace retiring faculty.
- f. In addition, we would support joint hires with other CoE departments, or other departments in the University, in the following areas:
  - o Modeler and/or experimentalist in carbon cycle or ecosystems,
  - o Modeler and/or experimentalist in hydrology,
  - o Modeler in ocean modeling,
  - o Integrated "assessment" modeler for risk analysis and decision-making, and
  - o Data assimilation specialist.

The first three new hires are needed to replace retiring faculty in atmospheric science (Profs. Jacobs, Drayson, and eventually Prof. Kuhn). The additional hires are needed to maintain viability over the long run while taking advantage of national career advancement opportunities.

9. To reflect our new vision we recommend that the name of the department be changed to "Department of Space and Atmospheric Science and Engineering" (SASE).

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<sup>3</sup> We would like to take advantage of a new NSF initiative offering five-year startup and career advancement support for tenure track faculty in solar-terrestrial physics.

# A Shared Vision for Space and Atmospheric Sciences and Engineering

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## VISION

The Atmospheric, Oceanic and Space Sciences (AOSS) department stands at a cusp in its history. While the space and atmospheric sciences have each achieved recognition for their scholarly contributions to their fields; the department has suffered from a history of polarity in its divisions and ineffectiveness in attracting undergraduate and graduate students to its programs.

This report details a new vision, where the faculty are collectively more open to mutual opportunities and goals than at any other time in the past decade. This new enthusiasm for synthesis comes, in part, from new faculty who have brought new insights that welcome broadening and inclusion and, in part, from the recognition of new opportunities that exist for research that requires competence in science and technology. But it is also grounded in an appreciation by all faculty that restructuring is an opportunity to integrate more with other College of Engineering (CoE) and University of Michigan (UoM) programs to create stronger academic and research programs for the future.

Specifically, our role for the future lies in building upon current strengths to 1) participate in a critical examination of the future of the Earth system through acquisition and interpretation of new data sets, 2) maintain our strong research program in space and planetary science, and, 3) provide new educational opportunities that will help produce the workforce in space and atmospheric science and engineering the nation will require in the future.

## The Future of the Planet

We live on a planet of extraordinary complexity; the presence of an atmosphere and oceans with the right chemical composition on a solid planet has supported the development of an abundant diversity of life. Throughout geologic history the atmosphere, oceans and biosphere have responded to the forces of the Earth's solar environment to produce global environmental change to which life has contributed and adapted. The environmental fabric of the Earth is now facing unprecedented challenges as the climate of the Earth changes in response to the increasing concentrations of radiatively important gases<sup>3</sup>. These changes will have societal, economic and political implications that may influence virtually every aspect of our future.

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<sup>3</sup> A thorough and independent description of the scientific basis for global climate change is available from the Intergovernmental Panel on Climate Change, <http://www.ipcc.ch/>.

We have embarked on a global experiment with unknown consequences. Model predictions suggest that the Earth should be warming in response to increasing carbon dioxide and other greenhouse gases in the atmosphere, and observations, albeit sparse, seem to support this expectation. But our ability to forecast spatial details of those changes and how they affect hydrology and weather patterns, and ultimately economy, politics and society is still in its infancy. Likewise our understanding of how solar perturbations may directly or indirectly affect change and our capacity to make inferences based on the processes affecting other planets is incomplete.

On the other hand, the science tells us that change is inevitable in climate so it behooves us to address responses to these changing conditions. All of society will require guidance on how to respond to a changing global climate. Our capacity to engineer changes in energy sources and efficiencies gives hope that we can influence, if not manage, changes in important components of the cycles that govern radiatively important trace gases. We can and should take a national leadership role in the science and engineering response to this global issue. Current, highly visible activities in climate dynamics, biogeochemical cycles, atmospheric chemistry and air pollution provide a solid foundation for growth. We believe that existing efforts, coupled with CoE interests in energy sources and efficiencies, form the basis for a unique capacity to address national and global concerns.

### **The Workforce in Space**

The nation faces a major workforce shortage in the space industry in the near future. In a speech at the University of Michigan on February 14, 2003, US Representative Joe Knollenberg, a senior member of the House Appropriation Committee, spelled out the challenge: "To succeed in the future, we are going to need a workforce that is capable of supporting the space program. Unfortunately, that workforce may not be available in the very near future. NASA's own statistics tell the story. The average age of its workforce is over 45, and the agency is finding it particularly difficult to hire people with engineering, science, and information technology skills – fields critical to NASA missions. Within the science and engineering workforce, the over-60 population outnumbers the under-30 population nearly three to one. Further, 15 percent of NASA's science and engineering employees are eligible to retire now. Within five years, approximately 25 percent will be eligible to retire. Of course, this wouldn't be a problem if a steady supply of people with science and engineering skills were entering the workforce. That is not the case, however. There is a growing national concern over the availability of an educated workforce to accomplish our space program's goals. Simply put, the pioneers who developed the Nation's capabilities in space are nearing retirement, and there is a need for an infusion of young, new talent."

Congressman Knollenberg continued: "We inserted language into the bill that funds NASA that we believe will begin to address this issue. This provision directed NASA, in cooperation with the Nation's leading research universities, including the University of Michigan, to develop a comprehensive plan and implementation strategy that will result in an increase in the number of students pursuing advanced degrees in the presence of vibrant university research efforts. We asked that the plan include the means to increase the number of university research and educational groups. We asked that the plan increase the number of new, young faculty and to build cooperative relationships between universities and NASA centers. The plan should also develop the means for attracting and supporting students. .... There are two important ingredients in the education of engineers and scientists for careers in space. The faculty performing the education must themselves be active

participants in the space program. And the students must be given opportunity for hands-on experience in the development of space hardware. The best education is to learn by doing. The College of Engineering is to be commended for its commitment to provide the educated workforce to pursue the nation's space program, and to do so by having faculty and students who actually build space hardware."

The space industry considers its aging workforce to be a primary challenge, and we are in need of becoming an important solution to this problem. Even the most pessimistic forecast with a declining total workforce would require around 15,000 new professionals a year. Space industry draws its workforce from a broad range of engineering disciplines. The complex electrical engineering requirements of space vehicles, or the challenging structures issues, require the broad range of skill sets of electrical, mechanical, aerospace, software, and systems engineering. For more details on this need see Appendix A.

## **Our Role**

The national workforce shortage challenge in space and the global environmental threats to society demand a strategic response in the research and teaching agenda of the University of Michigan. The faculty of the Department of Atmospheric, Oceanic and Space Sciences (AOSS), challenged to rethink their place in the College of Engineering (CoE) of the University of Michigan, embrace this as an opportunity to play a new, expanded role within the college, the university and the nation. The name of the department is expected to change to better represent its new identity. However for the purpose of this report the department is referred herein as AOSS.

Our vision is to build upon the unique capabilities already existent in AOSS to create new opportunities in research and teaching focused on the gathering of new earth and space systems data, developing new enabling technologies, interpretation of existing data, and modeling future conditions. Our challenge is to reinvigorate our department, maximizing use of existing resources, with the expectation of CoE investment in our faculty depth based first on a shared vision of growth in space research and earth systems science and engineering and then on progress towards measurable goals. Our plan is to redesign our academic programs, embrace new relationships within and beyond the CoE for academic and research opportunities, and work with the CoE to develop a plan for excellence in earth systems science and engineering, while maintaining our premiere position in space science and engineering.

This vision is contingent upon significant but necessary change in the structure of our program. For the faculty of AOSS this requires of us a new effort to work to establish dialogs with other departments that promote integration of our mutual educational pursuits. It requires that the faculty be dedicated to providing new and expanded opportunities for CoE student involvement in courses and research. It requires that we embrace our unique position in the space and atmospheric sciences by taking full advantage of the engineering capabilities available within the department.

For the college this vision requires investment in strategic faculty positions that replace the current and expected list of faculty retirements and offer opportunity for additional instructional faculty hires based on demonstrable progress towards goals. It also requires the cooperation of the college and other colleges and schools of the University of Michigan to help facilitate the organization of a cross-department initiative on global environmental and energy science and engineering and to facilitate a

cross-university initiative for earth system science. Its success would be aided by a college commitment to more flexibility in CoE department curricula to allow, or better, encourage shared responsibility for student coursework. It asks the college's support in our exploration and application for accreditation of its programs from the Accreditation Board for Engineering and Technology (ABET) to promote our unique stature in the atmospheric and space sciences and to formally align our educational goals with the rest of the college.

## **THE CONTEXT FOR CHANGE**

### **Background**

AOSS has an outstanding research program in space science and engineering, with an accompanying MS/PhD program that is a major contributor to the education of the next generation of space scientists. However, despite all the ongoing projects in space science and engineering, there is relatively little involvement in education programs that serve the needs of undergraduate engineering students in CoE. The atmospheric science component of AOSS faces different dilemmas. It has a substantially smaller research effort, and a strong undergraduate education program with relatively large enrollments in LS&A survey courses but weak enrollments from within the CoE and a modest number of CoE undergraduate majors. While new courses have been formed with the goal of addressing global issues that directly address ABET goals (e.g. AOSS 300, Global Environmental Impact of Technological Change) our ability to attract CoE students is limited to date by limitations on student flexibility throughout CoE programs, our limited 'marketing' to COE students and advisors, and a general lack of environmental curriculum coordination. Moreover, many COE departments specifically limit if, or which courses in AOSS their students can take, further limiting the pool of potential students within CoE.

### **Change**

Despite a history of polarity the AOSS department is at a place that is more open to mutual opportunities and goals than at any other time in the past decade. New faculty members have brought new insights that welcome broadening and inclusion and new opportunities exist for research that spans across disciplinary boundaries.

The important national and international issues to which AOSS is capable of contributing, and indeed has an obligation to the college, the university and the nation to do so, are clear:

All of society will require guidance on how to respond to a changing global climate. We are in need of establishing the faculty and facilities to take a national leadership role in the science and engineering response to this global issue. We believe that this effort, coupled with CoE interests in energy sources and efficiencies, form the basis for a unique capacity to address national and global concerns.

The space industry considers its aging workforce to be a primary challenge, and we are in need of becoming an important solution to this problem. Much of space industry was staffed near the beginning of the space program in the 1960's and certainly by the early 1970's, with relatively young employees, who then had productive careers for the next 30-40 years. Hiring was limited over this time period, but now this aging workforce needs to be replaced. The typical age distribution of the technical staff of a space industry is bi-modal, with about half the workforce with a mean age in

excess of 60. Industry estimates that at least 20,000 new hires are required annually simply to maintain the current workforce, let alone allow for growth. Even the most pessimistic forecast with a declining total workforce would require around 15,000 new professionals a year. Space industry draws its workforce from a broad range of engineering disciplines. The complex electrical engineering requirements of space vehicles, or the challenging structures issues, require the broad range of skill sets of electrical, mechanical, aerospace, software, and systems engineering. For more details on this need see Appendix A.

Virtually all industry has or will require guidance on how to respond to a changing global climate. We encourage establishing the faculty and facilities to take a national leadership role in science and engineering response to this global issue. We believe that this effort, coupled with CoE interests in energy sources and efficiencies, form the basis for a unique capacity to address national and global concerns.

## **Challenge**

During the fall of 2002, the AOSS department was challenged to consider its position in the College of Engineering. That examination began with two committees, one charged with exploring commonalities between the atmospheric scientists in AOSS and the Department of Civil and Environmental Engineering, co-chaired by Mary Anne Carroll, Professor of Atmospheric Science. The second was given the same charge between the space scientists in AOSS and the Aerospace Department, co-chaired by Hunter Waite, Professor of Space Science. In addition an *ad hoc* committee formed to discuss opportunities between the atmospheric scientists in AOSS and the Geological Sciences Department in the College of Literature, Science and the Arts (LS&A), and another to explore opportunities for redesigning the AOSS department. This report is an outgrowth of the last effort, initiated by John Barker and Tony England, and continued through participation of virtually all tenure-track faculty and Senior Research Scientists on both the atmospheric and space science sides of the department, and coordinated by Perry Samson and Tamas Gombosi.

## **BASIS FOR GROWTH**

### **Faculty**

The AOSS department has a long and storied history of excellence in research. Many of the faculty (with its cadre of world class Senior Research Scientists) are responsible for the design and execution of space missions. Hunter Waite, Chris Ruf, Tony England, Brian Gilchrist, Nilton Renno and Thomas Zurbuchen (England and Gilchrist have their primary appointment in EECS) all design and build space hardware, fly instruments in space and analyze the resulting data, design and manage entire space missions and lead large industrial and scientific teams for the execution of complex space missions. Bob Clauer, Paul Drake, Len Fisk, Tamas Gombosi, Janet Kozyra and Andy Nagy define the space environment in geospace, the heliosphere, and other plasma environments in the solar system and beyond. Sushil Atreya, Steve Bougher, Mike Combi and Bill Kuhn define the environment in planetary atmospheres and on their surfaces. Joyce Penner is an internationally recognized modeler of the influence of aerosols on global climate change. Jerry Keeler, Mary Anne Carroll, and John Barker have established strong programs in the measurement and modeling, and the underlying chemistry of atmospheric constituents. John Boyd is a highly respected geophysical fluid dynamicist, and Perry

Samson is a leading expert in scientific visualization and in public outreach. In addition to the AOSS Instructional and Senior Research Faculty in space science and engineering there is also a large number of outstanding research faculty who cover a broad range of disciplines in space science and engineering from ionospheric and magnetospheric research to space environment simulation tools, space hardware, and planetary and cometary environments. In atmospheric science there are also distinguished research scientists studying such environmental issues as air quality and global climate modeling.

## **Facilities**

The Space Physics Research Laboratory (SPRL) of AOSS is one of only a handful of university based research laboratories that is still capable of designing, fabricating, testing and operating instruments for spaceflight on some of NASA's most challenging missions. SPRL includes a cadre of dedicated, and well-trained engineers and technicians, who cover the complete skill sets necessary to build space instrumentation, such as mechanical and thermal design, state-of-the-art electronics, sensor development, data system development, and in-flight operations. In addition SPRL has available clean rooms and thermal-vacuum chambers, and computer controlled manufacturing facilities.

SPRL is capable of developing a wide range of instrumentation, for observation of the sun, the heliosphere and the geospace environment, for exploration of the planets, for observation of the Earth from space, and many different types of ground-based instrumentation for studying the environment. SPRL can support all the experimental research thrusts envisioned in the new Vision for AOSS.

AOSS has a variety of field studies under way including the PROPHET at the University of Michigan Biological Station with a 31-meter scaffolding tower. With its attached Pyrex sampling manifold that extends above the canopy to 34 m above the surface UMBS provides access to research and educational facilities that facilitate opportunities for effective collaboration between atmospheric and biological researchers. Likewise extensive field capabilities exist for the measurement of toxic aerosols in the atmosphere. The adaptation of SPRL capabilities and facilities to support the educational thrusts of the new vision holds some challenges. New facilities will be required to provide the growth in students envisioned with hands-on experience. Also, should the senior engineers of SPRL become involved directly in the educational process, a funding mechanism for their support will need to be developed.

## **OPPORTUNITIES**

### **Education**

The AOSS department has long been successful at producing some of the best scientists in its many fields. Today, many forces are pressing AOSS to change traditional priorities so as to emphasize education, broadly interpreted, as well as research. Some of these pressures stem from the wider world of policy and politics, such as the need for a scientifically literate general population. Other forces stem from the demographic realities of the science community itself, such as the national desire to encourage a larger number of U.S. citizens to have a high degree of scientific understanding. Thus, strengthening our educational program is an investment in the future of the university, the nation and indeed the world.

***K-12 and Public Outreach***

Science education itself is in the midst of a wide-ranging reform movement in the United States. The geosciences are well suited to lead in this reform, beginning in the pre-college phase, because the geosciences provide a natural window on the world of science. Children display an innate curiosity about the physical world, and everyday events, such as weather forecasts, can be powerful examples of science in action. To be effective, education in science must begin early and take advantage of this curiosity before it is lost. Many young people emerge from the K-12 educational experience largely ignorant of science and frightened by technology. We know that many K-12 teachers lack an adequate background in science in general, and in geosciences in particular. The AOSS department has an essential role to play in helping to train teachers, in supporting outreach by geoscientists to teachers, and in providing educational training for geoscientists themselves. A strong pre-college component provides a crucial foundation for geosciences education at all subsequent levels: undergraduate, graduate, and postdoctoral, as well as for the general public.

***Undergraduate and Graduate Education in the Geosciences***

Education in the geosciences is multifaceted and includes a broad spectrum of activities. Geosciences education for undergraduates is far more complex than simply training relatively few students in the traditional geosciences major fields. It includes exposing a wide range of undergraduates to scientific principles and practices through discovery- and inquiry-based learning. Geosciences education at the graduate and postdoctoral levels is more than supporting research assistants who will be molded in the practices of their advisors. It includes providing a strong foundation in the geosciences for professionals destined for diverse careers including law, business, public policy, and education.

***New Graduate Education Opportunities******SGUS/MENG in Space Engineering***

The ideal training for students in the College of Engineering who wish to pursue careers in space industry would be an undergraduate degree in a basic engineering discipline, such as electrical, aerospace or mechanical engineering, and a Master's degree in the particular issues of designing, fabricating and launching space vehicles, and their many subsystems, from avionics to instruments, and even such issues as spacecraft communications and operations, or the handling of large data sets. The Master's degree should also provide training on such issues as project management for the complex projects encountered by space industry, on the environment of space which can be very challenging for the design of space missions, on the scientific and remote sensing requirements for space missions, and even on the political environment for the successful execution of the global space program.

Thus, a degree program that should be pursued for training the workforce for the space industry is the Sequential Graduate/Undergraduate Studies (SGUS) program, in which a Master in Space Engineering is offered in combination with basic undergraduate engineering degrees in electrical, mechanical, or aerospace engineering. It would also be possible to have an SGUS program jointly with bio-medical engineering for the students who wish to pursue life sciences applications in space.

The SGUS in Space Engineering can be the natural extension of the two MENG programs that AOSS has developed: an MENG program in Space Systems (joint with AERO) and an MENG in Applied

Remote Sensing and Geoinformation Systems. These programs are quite unique both nationally and internationally. The academic elements for these programs were excellent, and can readily be extended and improved to be a successful SGUS program. The enrollment in the two MENG programs has been stable but somewhat low (about 10 students at any given time). While the programs have not been particularly well advertised, and they were introduced prior to the developing industry demand for engineers well trained in space engineering, we will want to monitor industry's ability to attract a larger enrollment. We are committed to developing an SGUS program in Space Engineering that will target CoE students who want the training in space necessary to obtain an interesting position in space industry, and pursue successful careers in space science and engineering. Coursework will, to the extent possible, overlap with the SGUS program being established for Earth Systems Science and Engineering (below) to maximize the effectiveness of our courses.

It will be helpful if astronautics faculty in AERO will participate with the space science and engineering faculty of AOSS in a SGUS Master program in Space Engineering, as was done in the MENG program in Space Systems. There are subjects such as orbital dynamics and aspects of controls and space propulsion that are better covered in AERO than in AOSS.

There are also subjects that will be important to an SGUS program in Space Engineering that are not covered anywhere in CoE. For example, individuals who have managed some of the space program's most complex projects may be best qualified to teach project management at the professional level.

Early in 2002, AOSS - on behalf of the College - entered into a partnership with JPL to jointly pursue both research and education. JPL has selected only a small number of universities for such arrangements and AOSS, through its extensive involvement with JPL planetary missions and also its service on JPL senior advisory committees (L. Fisk was responsible for JPL during his NASA career), was a natural choice. JPL is committed to assisting AOSS with its educational program, and has offered to provide instructional personnel, where appropriate, to assist in an SGUS program. It is noteworthy that in order to make this commitment, JPL needed to and did modify its contract with NASA to allow it to spend its own resources for education.

#### *SGUS/MENG in Earth Systems Science and Engineering*

The nature of education in the geosciences, including the atmospheric sciences is rapidly changing. In the past a four-year degree was adequate for employment as a weather forecaster or consultant. Today the applicants desired by industry have higher level of preparation with greater breadth. According to the National Science Foundation<sup>8</sup>: "It is now widely recognized that a new system of graduate education is needed to prepare students for broad competence and flexibility in the workplace. A solid geosciences education can be excellent preparation for 'non-traditional' career paths in fields such as law, business, and education." The SGUS program for students currently enrolled as undergraduates in AOSS has recently been enacted with a majority of eligible candidates

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<sup>8</sup> *Geoscience Education: A Recommended Strategy*, National Science Foundation, [http://www.nsf.gov/geo/adqeo/geoedu/97\\_171.htm](http://www.nsf.gov/geo/adqeo/geoedu/97_171.htm)

expressing interest. The program focuses on a depth of study that overlaps with the SGUS to be offered in space science to maximize the effectiveness of our courses.

We will expand this program to other CoE departments including, at a minimum, CEE and EECS. Eventually we will offer this program university-wide to attract students from a wider range of fields in recognition of the multidisciplinary nature of these topics.

## Research

### ***Earth and Energy System Science and Engineering***

In December 2002, the Agencies that support the US Climate Change Program unveiled their "Strategic Plan". While the plan is still being finalized, it outlines areas for enhanced research that were called for by the President in June 2001 in his announcement of the "Climate Change Research Initiative" and it aims to balance near-term research needs to decrease key uncertainties with the longer term research needed to advance knowledge of the physical, biological and chemical processes that influence the Earth system.

The questions that are highlighted for increased near term funding include research to examine (1) the relative role of aerosols to climate change; (2) North American carbon sources and sinks and the processes controlling the dynamics of these sources and sinks; and (3) the consequences of feedback processes to expected climate change. In addition, further effort is needed to improve the record of past observations in defining the role of anthropogenic changes to climate, to help initialize models to predict future climate, and to improve observations of biological and ecological systems. Finally, decision support services for policy-makers need to be improved. Therefore it behooves AOSS to provide the leadership for the CoE and the UoM to organize a research agenda appropriate for the need. The National Research Council<sup>9</sup> expressed the imperatives that the nation should:

- a. Optimize and integrate atmospheric and other Earth observation, analysis and modeling systems.
- b. Develop new observational capabilities for resolving critical variables on time and space scales relevant to forecasts of significant atmospheric phenomena.

We believe that the University of Michigan is in a unique position to address these priorities because of the unique capabilities and experience of the AOSS faculty. The research budget for 2003 expresses the opportunities as:

1. Develop more reliable representations of the global and regional climatic forcing resulting from atmospheric aerosols (\$4 million).

Aerosols and tropospheric ozone play unique, but poorly quantified, roles in the atmospheric radiation budget. FY 2003 CCRI investments (NOAA: \$2M, NASA: \$1M, and NSF: \$1M) will be used to begin implementation of plans to define and evaluate the role of aerosols that absorb solar radiation such as black carbon and mineral dust.

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<sup>9</sup> National Research Council, 1998, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academies Press.

2. Inventory carbon and model sources and sinks (\$15 million).

This program will have an intensive focus on North American land and adjacent ocean basin carbon sources and sinks to improve monitoring techniques, reconcile approaches for quantifying carbon storage, and elucidate key controlling processes and land management practices regulating carbon fluxes between the atmosphere and the land and ocean. The NACP calls for expansion of the AmeriFlux sites, the development of automated carbon dioxide and methane sensors, improvements in ground based measurements and inventories of forest and agricultural lands, and empirical and process modeling.

3. Climate Modeling Center (\$5 million).

The continued development and refinement of computational models that can simulate the past and potential future conditions of the Earth system is crucial for developing capabilities to provide more accurate projections of future global change.

4. Tools for Risk Management under Uncertainty (\$6 million).

It is uncertain how potential climate change could affect natural resources and the economy at local and regional geographic scales. Given these uncertainties, it is necessary to develop tools and approaches to manage risks associated with climate change at the regional level.

5. Atmospheric Observations (\$4 million).

NOAA to work with other developed countries to reestablish the benchmark upper-air network, emphasizing data-sparse areas, and place new Global Atmosphere Watch stations in priority sites to measure pollutant emissions, aerosols, and ozone, in specific regions, will use these FY 2003 CCRI funds.

6. Ocean Observations (\$4 million).

In FY 2003, NOAA will use these CCRI funds to work toward the establishment of an ocean observing system that can accurately document climate-scale changes in ocean heat content, carbon uptake, and sea-level changes.

7. Satellite Observations (\$2 million).

In FY 2003, NASA will begin a significant long-term effort working with NOAA and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) toward the development of high-fidelity climate data records from satellite observing systems.

### ***Space Science and Engineering***

There are many exciting programs in space science and engineering, in which the faculty of AOSS can and should be active participants. Indeed, there has been a major increase in funding for the space science program of NASA, which in FY03 has a budget of \$3.6 billion, and in FY04 is proposed to

increase by an additional \$500 million. These funds support a broad range of space disciplines, including the study of the sun, the heliosphere, and the geospace environment, and the exploration of the planets.

Of particular interest to the faculty of AOSS is NASA's Living with a Star (LWS) program, which will undertake a systematic, end-to-end study of the sun and how it impacts the space environment of Earth. AOSS can contribute to every aspect of LWS, from the development and flight of instruments to measure the sun, the heliosphere, and geospace, to the interpretation of the resulting data, to the development of state-of-the-art numerical models that simulate and reproduce all aspects of the plasma environment of this interlocking system. Indeed, we are unique among university programs in our ability to cover all aspects of the LWS program, and we are in need of coordinating our own activities, marketing our capabilities to NASA, and become the lead university program for LWS.

The LWS program also provides natural linkages to the earth science activities of AOSS. The sun and its variations, and resulting variations in outputs of radiation and particles, needs to be fully taken into account as we begin to understand the human impact on global climate change. NASA recognizes this linkage, and thus AOSS can play an even more important role in LWS, through both the study of sun and its impact on the space environment of Earth, but also on the impact of these variations on the climate.

Another space science area of particular interest to the faculty of AOSS is the exploration of the planets. Instruments developed and operated by AOSS have explored every planet in the solar system, except Pluto. There are currently instruments en route to Saturn and Titan and one will be launched shortly to Mercury. The planet Mars will continue to be important in planetary exploration, and while we are already involved in two projects we believe we can have an expanded role. Through our partnership with JPL we will actively pursue the detection of life on the surface of Mars; this activity is being pursued jointly with several other departments in the University and represents an excellent example of the broad capabilities that exist at Michigan and need to be harnessed in the interest of the nation's space program. Other joint efforts to explore Mars are being pursued in collaboration with the NASA Goddard Space Flight Center. We also have an opportunity to develop a meteorological package for deployment at Mars through NASA's Mars Scout program.

As with Living with a Star, the exploration of the planets provides opportunities for linkages between the space and Earth science activities of AOSS. Important information on the atmosphere of the Earth can be obtained through comparative planetology, in which the widely different atmospheres of the planets, driven by different solar inputs, are compared and contrasted.

The decreasing role of universities in the space program is a growing national concern, and we should benefit from the solution. In the recent Congressional Appropriations Bill for NASA and the NSF, in which Congress expressed its serious concerns that "too few students are pursuing advanced degrees in aerospace science and engineering", they also noted "for advanced education to be effective, it must be pursued at colleges and universities with active research programs." Thus, Congress recommends that the strategy that is developed should "include means to increase the number of university research and educational groups, to increase the number of new, young faculty; to build cooperative relationships between universities and the various Federal agencies; and means for attracting and supporting undergraduate and graduate students. "In a separate effort, the NSF is actively pursuing a program to increase the number of young faculty at universities who can educate

and undertake research in space science. It is expected that they will provide funding for salary support and startup for young, untenured faculty, to facilitate their recruitment and development. The NSF considers that the absence of young faculty in space science at universities, particularly such fields as solar-terrestrial research is the single most serious impediment to the development of a sufficient workforce in space science, and space in general.

## **PLAN FOR CHANGE**

### **Redesign of Academic Programs**

#### ***Undergraduate Program***

The AOSS Department has attracted only a modest number of majors over the past two decades. This contrasts with our peer institutions (University of Wisconsin, Penn State, University of Illinois), which maintain high undergraduate enrollments. While the quality of our education programs is generally considered to be high, our unique position in the College of Engineering makes our program less accessible than at other institutions. Students who are admitted to the College of Engineering have a wide range of options for majors, many of which offer more and better employment opportunities. Only those dedicated to the study of weather persevere through our undergraduate program, focusing on a career in weather forecasting.

Likewise, while we are able to fill large classes within LS&A we have been far less successful in attracting College of Engineering students to our courses. The reasons for this are 1) our failure to promote our offerings within the College, 2) the general limitation on elective hours in other College programs, and 3) a general lack of discussion between departments to create courses of mutual value and interest. Table 1 illustrates the number of technical elective hours available to COE students in each department and the constraints placed on these hours. Not only are there only a limited number of technical electives available to COE students, in some cases AOSS courses are specifically excluded from consideration.

This lack of opportunity leaves AOSS to compete for free electives among COE students and severely limits our potential enrollment numbers. Given the quantity of courses and departments across the university this model is unlikely to produce significant enrollment. In fact, until specific courses in AOSS are encouraged in other COE departments as part of the COE's interest in global and societal issues the likelihood of increasing COE student enrollment in AOSS courses is poor.

Table 1. The list of eligible technical electives for which AOSS courses can compete is limited.

	Free Electives	Eligible Technical Electives	Notes
Aerospace Engineering	12	8	Courses subject to approval of faculty advisor
Biomedical Engineering	12	0	
Chemical Engineering	10	4	"Courses in AOSS are not considered engineering courses for technical electives."
Civil and Environmental Engineering	12	0	
Electrical Engineering and Computer Science	16	3	
Industrial and Operations Engineering	12	8	
Materials Science and Engineering	12	0	"AOSS courses will not be accepted."
Mechanical Engineering	10	0	Tech electives outside M.E. only if on approved non-M.E. course list. No AOSS courses are currently on that list. Students are allowed ONE course outside department in a 300 level course with a 300-level prerequisite.
Naval Architecture and Marine Engineering	12	0	
Nuclear Engineering and Radiological Sciences	9	3	

Based on these realities, it is our proposal to invigorate the undergraduate program through the following steps:

#### *Obtain ABET Accreditation*

No atmospheric sciences department in the nation has ever attempted to become ABET accredited. But as a symbol of our uniqueness and place in the College of Engineering we will, in concert with the College of Engineering, pursue accreditation through ABET. The American Geophysical Union has agreed to explore the possibility of serving as the Lead Society for Applied Science Accreditation.

#### *Promote College-Wide Global Impacts Curriculum*

The College of Engineering is obligated by Accreditation Board for Engineering and Technology<sup>10</sup> (ABET) requirements to promote "the broad education necessary to understand the impact of engineering solutions in a global and societal context." The AOSS department offers courses (e.g. AOSS 300, Global Environmental Implications of Technological Change; AOSS 467, Biogeochemical Cycles; AOSS 475, Earth-Ocean-Atmosphere Interactions") that deal with these issues. The College of Engineering should require or at least encourage COE departments to add these AOSS courses to their list of recommended technical electives.

<sup>10</sup> The Accreditation Board for Engineering and Technology (ABET, <http://www.abet.org/>) is a federation of 31 professional engineering and technical societies. ABET accredits more than 2500 engineering, engineering technology, computing and applied science programs at over 550 colleges and universities nationally.

*Build and Promote an Environmental Strand w/CEE and Others*

There is excellent opportunity to embrace educational synergies with the Civil and Environmental Engineering department (CEE) and Chemical Engineering (ChemE). Currently the Environmental and Water Resources Engineering (EWRE) division of CEE, while highly respected internationally, lacks accreditation by ABET as environmental engineering. The addition of coursework in atmospheric science would help make that option possible. Additionally, it may be desirable to offer joint positions to a few AOSS faculty to formally participate in the design and execution of a CEE environmental strand.

*Introduce Cross-University B.S. Degree Programs*

While we have debated the value of terminating the undergraduate program in atmospheric science the reality is that "if we destroy it they will STILL come," as there are students who are dedicated to careers in weather forecasting. Moreover we should embrace our undergraduate program and expand upon it by opening options for LS&A majors in atmospheric science. The field of atmospheric science, available both as a major and minor in LS&A would provide a broader range of students with interests beyond forecast meteorology who can use the program to pursue interests in the atmospheric environment and earth systems.

Moreover, there is expected to be a dramatic growth in need for geosciences educators at the K-12 level in the future<sup>11</sup> and the AOSS department has experience in leading K-12 and informal education programs. It behooves us to take a leadership role in preparing geosciences educators through creative collaboration with LS&A and, possibly, the School of Education.

*Promote LS&A Service Courses*

At a minimum we can significantly increase enrollment through more active promotion of existing courses throughout other schools and colleges. This effort requires a clear statement from the College of Engineering that survey courses taught outside the CoE will reward department student credit hour counts as we would receive for courses specifically designed for College of Engineering students. On the other hand, we must be selective in the courses we offer in LS&A to insure these offerings are not at the expense of other departmental goals.

*Promote Education through Research*

The College of Engineering requires its seniors to participate in capstone courses. AOSS should expand its promotion of opportunities for COE seniors to participate in research activities within AOSS. Opportunities in design and testing of remote and in-situ sensing instrumentation and data analysis systems exist that would provide excellent design experience for seniors.

This approach, like others involving COE student participation, will require an active promotion to faculty advisors and student groups as well as availability of on-line resources.

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<sup>11</sup> Geoscience Education: [http://www.geo.nsf.gov/adgeo/geoedu/97\\_171.htm](http://www.geo.nsf.gov/adgeo/geoedu/97_171.htm)

*Improve our Facilities for Offering Design Courses*

Offering design courses to both undergraduate and graduate students, and providing hands-on experience will require improvements in our classrooms and laboratories. We consider that funding is available for these improvements from the industry that will be served by our graduating students, particularly the space industry. We accept the challenge to seek and obtain this funding. Since many space industries depend on the ability of our faculty to propose for and win major space missions, we have access to the highest levels of these corporations, which we can exploit.

**Graduate Program**

The graduate program in AOSS has traditionally focused on producing Ph.D. students. This emphasis must be expanded to embrace the value of a Master's program to future students. The department can improve its enrollments and provide a valuable product to students through a series of Master's level programs including the Sequential Graduate/Undergraduate Studies (SGUS) programs both within the College of Engineering and between COE and LS&A.

*Introduce SGUS/MENG in Space Engineering*

As part of our redesign an SGUS program has been instituted in the winter semester, 2003, for AOSS students wishing to continue to a Master's degree<sup>12</sup>. We expect to expand this over the next year to include an SGUS program for Aero, EECS and ME students wishing to obtain a Masters in Space Engineering. Details of this program are contained in Appendix B.

It is our hope that the astronautics faculty in AERO will participate with the space science and engineering faculty of AOSS in the SGUS Master program in Space Engineering, as was done in the MENG program in Space Systems. There are subjects such as orbital dynamics and aspects of controls and space propulsion that are better covered in AERO than in AOSS.

There are also subjects that will be important to an SGUS program in Space Engineering that are not covered anywhere in CoE. For example, individuals who have managed some of the space program's most complex projects may be best qualified to teach project management at the professional level.

Early in 2002, AOSS, on behalf of the College, entered into a partnership with JPL to jointly pursue both research and education. JPL has selected only a small number of universities for such arrangements and AOSS, through its extensive involvement with JPL planetary missions and also its service on JPL senior advisory committees (L. Fisk was responsible for JPL during his NASA career), was a natural choice. JPL is committed to assisting AOSS with its educational program, and has offered to provide instructional personnel, where appropriate, to assist in an SGUS program. It is noteworthy that in order to make this commitment, JPL needed to and did modify its contract with NASA to allow it to spend its own resources for education.

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<sup>12</sup> A survey of AOSS undergraduates conducted in the fall, 2002, indicated that over 90% would seriously consider an SGUS option if they qualified.

*Introduce SGUS/MENG for Global Climate Change*

As part of our redesign an SGUS program has been instituted in the winter semester, 2003, for AOSS students wishing to continue to a Master's degree<sup>13</sup>. We expect to expand this over the next year to include an SGUS program for CEE students wishing to obtain a Masters in Atmospheric Science and for Aerospace Engineering students wishing to continue to a Master's degree in Space Science. Details of these programs are contained in Appendix B.

*Introduce USGUS for Earth Systems Science and Engineering*

At the same time, it is our expectation that a university-wide SGUS-like program (USGUS) will be attractive to students in Physics and Chemistry and possible SNRE and School of Education. AOSS will work with the COE to create a pilot USGUS program.

*Joint M.S./Ph.D. Earth Systems Science w/Geology*

To promote interdisciplinary opportunities for students in Earth Systems Science AOSS should embrace the parallel efforts underway in Geological Sciences to build depth in Earth Systems Science. The creation of a joint M.S./Ph.D. program with Geological Sciences could help promote interdisciplinary through shared students. It is our expectation that such a program would be attractive to candidate graduate students.

*Maintain MS/PhD Program in Atmospheric Science*

We will streamline and maintain our program in atmospheric science. For course details see Appendix B.

*Maintain MS/PhD Program in Space Science*

We will streamline and maintain our program in space science. For course details see Appendix B.

*Maintain MS/PhD Program in Space and Planetary Physics w/Physics Department*

We will maintain our joint degree program with the Department of Physics. In the last decade this program was highly successful and we are not planning any major changes.

*Maintain MS/PhD Program in Geoscience and Remote Sensing w/EECS and CEE*

We will maintain our joint degree program with the Department of Electrical Engineering and Computer Science and with the Department of Civil and Environmental Engineering. In the last decade this program was highly successful and we are not planning any major changes.

**Courses**

The revised course offerings and their relation to the new degree programs are listed in Appendix B. It is important to emphasize that the total number of courses to be taught in an academic year is 34

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<sup>13</sup> A survey of AOSS undergraduates conducted in the fall, 2002, indicated that over 90% would seriously consider an SGUS option if they qualified.

plus two seminar courses. This course load per FTE is close to the CoE average, and these courses can be taught by the present instructional faculty members.

In revising the curriculum we tried to eliminate overlaps and maximize synergism between the various degree programs. The new set of courses will serve a variety of programs in both atmospheric and space sciences and related engineering disciplines.

### **Research Agenda**

While the growth in enrollments is a key component of our future planning, the foundation for our future lies in the strength of our research programs. Strong and viable research attracts the best graduate students and provides the best mechanism for national and international impact. Research in space and planetary science is of very high quality and it is very successful. It is our goal to maintain this excellence and build on this foundation. The research volume in the earth systems science and engineering must be expanded with an eye toward coordinated growth that takes advantage of our unique strengths in engineering capability.

To this end we must identify opportunities for research collaboration within AOSS and, at the same time, identify new leadership for improving research volume in earth systems science.

### ***Collaboration***

Opportunities for intradepartmental collaborations need to be embraced. There are well-documented opportunities in remote sensing and educational outreach, at a minimum. Such collaborations pull together the talents and engineering capabilities of the department and produce new opportunities to strengthen our intellectual commonalities. The AOSS department must commit itself to facilitate the exploration of commonalities through support of informal planning sessions, proposal preparation, seminar series and other creative means.

Hand-in-hand with this planning it will be advantageous to strengthen the collaboration with Profs. Anthony England, Brian Gilchrist and Jerry Keeler who have their primary appointments in other departments. They bring synergistic experience of using technology that would reinforce the research goals of the department. In particular reassigning Prof. Tony England and Prof. Gerald Keeler full-time to AOSS will aid our capacity to reach critical mass in earth systems science. They would also be able to provide significant input to the academic programs of the department.

### ***Investment in Earth Systems Science Faculty***

Excellence in Atmospheric Science will not be achieved without sustained investment by the College of Engineering in the atmospheric science faculty. Current and pending retirements (Drayson, Jacobs, Kuhn) will significantly reduce the breadth of core courses the department can offer below the level recognized as normal by our peer institutions. While the new academic program can be maintained without these replacements, no progress can be made on the research side without additional faculty hires. To be successful, the College of Engineering must embrace this vision for growth in AOSS with strategic faculty hires. These future hires should embrace the strengths of the department and our unique position in the College of Engineering. These positions should focus on use of technology (remote sensing, computational) in areas that compliment the present faculty in both atmospheric and space sciences. In particular, the new instructional faculty required are:

- Optical Remote Sensing experimentalist with expertise in radiative transfer. This would give us broad, synergistic capabilities in earth observations and planetary exploration.
- Mission Principal Investigator class scientist (either Earth or Space Systems). This would ensure long-term continuity in our large instrument building capability. These kinds of efforts are essential to maintain and enhance our engineering capabilities.
- Planetary scale general circulation modeler.

It is also important to develop creative cross-university collaborations to cover the essential disciplines required for studying global climate change, not currently available in AOSS. These could involve joint appointments with other departments in CoE or in other units of the university. In particular, faculty will be needed to address carbon cycle and/or ecosystems issues. We have no one who specializes in understanding the historical record associated with climate change in the last 100 years. Likewise we believe the value of the earth systems science and engineering initiative within CoE would be enhanced with a faculty member in AOSS or elsewhere whose interests include an integrated “assessment” capability for risk analysis and decision-making, as well as a specialist in data assimilation.

Excellence in Atmospheric Science will not be achieved without sustained investment by the College of Engineering in the atmospheric science faculty. Current and pending retirements (Drayson, Jacobs, Kuhn) will significantly reduce the breadth of core courses the department can offer below the level recognized as normal by our peer institutions. While the new academic program can be maintained without these replacements, progress will be restricted on the research side without additional faculty hires. For this plan to be successful, the College of Engineering must eventually support this vision for growth in AOSS with strategic faculty hires. These hires need to replace those faculty retiring, and should offer hope for additional performance-based hires in the future.

### ***Maintaining Excellence in Space Science and Engineering***

AOSS is among the small number of top universities that can build and fly space instruments, analyze their data, and interpret the results with the most sophisticated high-performance computer simulation models. As a result of this excellence in research, we are also well positioned to educate the next generation of space professionals from engineers to scientists. These strengths in space engineering and computational technologies should be used as a leverage to create a world-class program in earth systems science and engineering. It is, however, essential to maintain the vitality of the space science and engineering faculty.

There are anticipated retirements and opportunities in space science and engineering. Prof. Andrew Nagy is past his 70<sup>th</sup> birthday and he will retire in the next five years or so. We will need to use his retirement to hire a space modeler to maintain competitiveness and viability in this area.

The NSF is actively pursuing a program to increase the number of young faculty at universities who can educate and undertake research in space science. It is expected that they will provide funding for salary support and startup for young, untenured faculty, to facilitate their recruitment and development. The NSF considers that the absence of young faculty in space science at universities, particularly such fields as solar-terrestrial research is the single most serious impediment to the

development of a sufficient workforce in space science, and space in general. We need to take advantage of this program, when it becomes available, and hire a promising, young space physicist.

## **Structural and Administrative Issues**

### ***Departmental Finances***

The General Fund budget of AOSS has been severely strained over the last decade. The changes in Federal regulations, the OMB Circular A21 rules, which require basic administrative services to be charged to the General Fund as opposed to direct charges to grants and contracts, has had a larger impact on AOSS than any other CoE Department. In the current budget approximately \$400,000 of basic administrative costs, which were previously charged directly to grants/contracts, now have to be absorbed on the General Fund, and yet no additional General Funds have been provided. AOSS has been forced to cover this shortfall by applying all of its RIPIII allocation and 40% of its RIPI allocation. This application has severely limited the intended use of the RIPIII funds to support first year graduate students, and of the RIPI funds to seed new research.

There is a clear need to correct the funding of AOSS, and to return to it the flexibility that a correct allocation of RIP funding can provide. These funds will be necessary if AOSS is to achieve the fundamental changes called for in this document. In the current, limited budget environment of the College it is unlikely that a major infusion of additional General Fund support will be forthcoming. At the very least, a plan should be put into place, and phased in over several years, to correct this problem.

There is no reimbursement for the technical infrastructure related expenses. Large hardware projects have significant infrastructure requirements, but there is no reinvestment coming from anywhere. The situation became particularly difficult in the last decade, when the College and the University did not provide any equipment funds for SPRL engineering. This long hiatus had a particularly negative impact on our engineering capabilities and it seriously endangers our long-term competitiveness. We recommend that every effort be made to provide Infrastructure funding. In particular, we recommend restoring the annual equipment fund. This is absolutely essential for the survival of our engineering capabilities.

### ***Marketing***

#### *Course Promotion*

Little effort has been made in the past to promote AOSS courses outside the department. This effort must be supported with strategic goals of 1) lobbying the COE to encourage or require courses aligned with ABET goals that AOSS can provide, 2) lobbying other COE departments to add AOSS courses to their lists of allowed technical electives, and 3) promoting existing courses offered in LS&A.

#### *Undergraduate Student Recruitment*

As we develop new opportunities for undergraduate and graduate students we must promote these opportunities across campus. The means must be found to improve communication through improved web presence, targeted promotion to students, and presentations in other courses.

### *Graduate Student Recruitment*

Attracting excellent graduate students requires having an attractive graduate program with a vibrant research agenda. Nonetheless, steps must be taken to make the program more visible to potential candidates through creation of professional-quality marketing tools and through an aggressive campaign by faculty to identify and attract candidates.

## **SUMMARY**

### **The Changes**

The space industry considers its aging workforce to be a primary challenge. Industry estimates that at least 20,000 new hires are required annually simply to maintain the current workforce, let alone allow for growth. Even the most pessimistic forecast with a declining total workforce would require around 15,000 new professionals a year. To educate this workforce and maintain excellence in space science and engineering research is a major challenge and opportunity for the AOSS department and the College of Engineering.

There can be little debate that the future of the Earth's environment is uncertain. The atmospheric sciences in the College of Engineering is fortunate to have a faculty whose expertise in modeling, measurement and education cover key components necessary for leading national debate on these issues. We are committed to building this expertise to national prominence but realize that we cannot achieve that goal without the commitment of the entirety of the Department of Atmospheric, Oceanic and Space Science, the College of Engineering and the University.

- The **Department** must commit to restructuring its teaching loads and evaluating its course offerings to maximize the value of its programs within and beyond the College of Engineering. We believe there is significant opportunity for addressing the space industry workforce problem and for atmospheric sciences within a restructured AOSS department in the College of Engineering. Moreover, we believe that the reinvigoration of the atmospheric sciences is an opportunity for the entirety of the AOSS department.
- The **College** must commit to 1) enforcing current ABET requirements for the broad education necessary to understand the impact of engineering solutions in a global and societal context and insuring that AOSS courses are listed as an integral part of that effort, and 2) investing in faculty positions in areas that maintain excellence in space science while improve research volume in the study of the earth system and take advantage of the unique space science and engineering capabilities already existent in the department. We feel strongly that we need to replace our retiring faculty positions, with the option for additional positions based on improved performance.
- The **University** must commit to removing barriers to inter-college degree programs. Atmospheric science enrollments are limited because we do not have a degree program outside of the College of Engineering even though there are logical relationships with students in LS&A and, possibly, SNRE and the School of Education. The growth of atmospheric programs in Geological Sciences should be coordinated with plans in AOSS to maximize value to the university. **Rackham** must commit to helping us define a university-wide SGUS program so students majoring in other science and math can obtain a M.S. in AOSS.

This roadmap builds on our combined strengths, and seizes the opportunity to take a leadership role in earth system and space/planetary science and engineering. It promises leadership in global systems and space engineering education and an improved research environment but requires significant commitment to change from all involved. Moreover, it warns that short of this the atmospheric sciences may well suffer further erosion or splintering of its core competencies beyond the current attrition issue.

## Milestones

### Research

Goal	Timescale
Identify models for collaboration between AOSS and Geology.	One year
Prepare proposal for new COE center focused on global environment and energy science and engineering.	One year
Develop a coordinated response to NASA's Living with a Star program.	One year
Implement partnership with JPL	One year
Add faculty in remote sensing of components of earth system that compliment existing capabilities.	Two years
Add faculty with expertise in climate modeling, particularly with emphasis on sub-grid scale processes that compliment existing capabilities.	Three years
Add a young space physicist (provide NSF new faculty program in solar-terrestrial physics is approved, and Michigan is awarded funding)	Three years
Encourage joint appointments with other departments for faculty who are modelers or experimentalists in the carbon cycle, ecosystems, hydrology and energy systems.	On-going
Add a faculty member who can be Mission Principal Investigator for an Earth system or space mission.	Three years
Add a faculty member who is a planetary scale GCM modeler	Four years
Add a faculty member with expertise in new observational techniques for the atmospheric sciences.	Four years
Add a faculty member who is space modeler (depending on additional retirements)	Five years

**Education**

<b>Goal</b>	<b>Timescale</b>
Add SGUS program for existing AOSS undergraduates	Done
Add SGUS program for selected COE departments	One Year
Explore joint Ph.D. program in Earth System Science with Geological Sciences	One year
Add SGUS program available to LS&A students	Two years
Open B.S. opportunities for LS&A students	Two years
Explore joint Ph.D. program in Earth System Science with School of Natural Resources and the Environment (SNRE)	Two years
Increase enrollment in Space Science MENG/SGUS programs to 30/year	Three years
Increase enrollment in Atmospheric Science MENG/SGUS programs to 30/year	Three years
Increase undergraduate survey course enrollment by 50% in AOSS 105 and AOSS 202	Three years
Achieve course enrollment goal of an average of at least 250 student hours/FTE/year	Three years

## APPENDIX A

### WORKFORCE CHALLENGES IN SPACE INDUSTRY

We start with discussing the workforce needs of the space industry, defined in the broadest sense: commercial, military and scientific. These workforce needs serve as the basis for an educational mission for the space science and engineering faculty of AOSS.

#### The Global Space Industry

The space industries of the world have a combined annual revenue of ~\$96 billion, divided into the following business sectors: infrastructure (e.g., launch vehicles and satellites), \$53 billion; telecom, \$29 billion; use of space data and assets \$10 billion; support services, \$4 billion [Source: International Space Business Council]. For infrastructure, the largest customer is the government at about \$34 billion, with the military purchasing \$15 billion and the civilian sector \$19 billion. The Infrastructure sector breaks down further as \$11 billion in satellite manufacturing, \$12 billion in ground hardware, \$6 billion in launch vehicles, and \$23 billion in R&D such as space station, shuttle operations, etc. The U.S. share of this market is by far the largest: 0.3% of the Gross National Product of the U.S. is spent on space, whereas other nations spend smaller percentages of smaller GNPs. For example, the top eight companies in space are U.S., with only Alcatel, the European consortium, in the top ten, and then only at 10% of the revenue of the leading company, Boeing.

The prospects for space industry are mixed in the short term and very promising in the long term. The NASA budget, almost all of which supports the exploration and utilization of space, is \$15.2 billion in FY03, and is scheduled in the President's out-year plan to grow to \$16.75 billion by FY07 [Source: OMB]. Almost all of this growth is in space science, and the satellites and launch vehicles necessary to conduct it, which is scheduled to grow by over \$1 billion during this same time period. Earth Sciences from space, in contrast, and other aspects of the NASA program, are relatively level-funded.

Military space also expects considerable growth, particularly in classified reconnaissance satellites, although difficulties with several ongoing programs may delay new starts. The DARPA budget has increased 40% in the last two years, with a renewed emphasis on space. The rate of growth in military space, although very promising in the long term, will be captive to near-term operational needs, such as the war on terrorism, or a war with Iraq.

The space telecommunication sector is presently at a low point. Telecommunication satellites were being purchased at a rate of ~30 per year during the boom years of Internet-based, communication companies. With the implosion of this industry, an over-capacity of space assets now exists, with the result that telecommunication satellites are expected to be purchased at a rate of ~15 per year from 2002-04. Telecommunication satellites of course have a finite lifetime (96 on-orbit telecommunication satellites will reach their end-of-life in 2002-08), and with no further decline in the communications industry, or better yet a return to growth, industry expects telecommunication satellites to return to a purchase rate in excess of 24 per year by FY05 [Source: Orbital Sciences Corporation].

## **Workforce Issues in Space Industry**

Space industry considers its aging workforce to be a primary challenge. The total worldwide workforce in space is approximately 400,000, distributed roughly by business sector and by countries in proportion to the above discussed revenue distribution. In a steady state, with a normal 35 year career, the workforce will need to be replaced at a rate of ~10,000 per year. The problem, however, is much more serious. Much of space industry was staffed near the beginning of the space program in the 1960's and certainly by the early 1970's, with relatively young employees, who then had productive careers for the next 30-40 years. Hiring was limited over this time period, but now this aging workforce needs to be replaced.

The typical age distribution of the technical staff of a space industry is bi-modal, with about half the workforce with a mean age in excess of 60. Industry estimates that at least 20,000 new hires are required annually simply to maintain the current workforce, let alone allow for growth [Source: International Astronautics Federation Symposium on Workforce Issues, Houston, 2002]. Even the most pessimistic forecast with a declining total workforce would require around 15,000 new professionals a year.

## **Workforce Issues in Space Science**

The aging workforce issue is equally pronounced in space science, particularly for experimental space scientists that build and fly space instruments. The reason is the same as in space industry: young experimental space scientists entered the field in the 1960's, have had productive careers since, but are about to retire without replacements available. In an analysis for the Sun-Earth Connections Advisory Committee of NASA, Len Fisk determined that to execute the Living with a Star program, a more than \$1 billion new initiative, NASA would need to find ~1,000 new PhD scientists in this field alone in the next 15 years, just to compensate for the upcoming retirements and accommodate the expected growth. For example, one third of the scientific staff of the Solar Physics Branch at NASA/Goddard Space Flight Center is now over 70 years old, with the youngest scientist 45.

The Europeans, who still have mandatory retirement ages, are particularly concerned about the pending loss of experimental capability. Within five years there will be no capability to build instruments in Germany in the general field of geospace science (the study of the space environment) [Source: H. Volk, Director Max Planck Institute, Heidelberg]. A similar situation exists in France [Source: R. Bonnett, past Science Director of the European Space Agency and current Science Director, CNES].

## **Space Science and Space Industry**

It is important to note the interrelation between space science and space industry. NASA, with its \$15 billion annual budget, purchases infrastructure – satellites, launch vehicles, etc. – from space industry, primarily for the purpose of doing space science. Congress regularly considers the scientific justification of major space missions as the most important consideration for funding. Indeed, the normal selection process of NASA for a ~\$150M space science mission requires a scientific Principal Investigator (PI), such as the faculty of AOSS, to propose an entire mission, including the industrial partners who will provide the satellite and launch vehicle. The selection depends on the scientific team and the instruments that the PI proposes to fly. It will also depend on the system design and

trade-offs, and cost control, for which the PI is ultimately responsible. The full funding rarely flows through the PI's institution, but rather through a NASA center, but the scientific PI is responsible for justifying the mission, and for its execution. It follows that the absence of qualified space experimentalists will make it impossible for NASA to execute its science program, or for space industry to benefit from it.

The space science faculty of AOSS includes several individuals who have the experience and scientific credibility to be NASA mission PIs. These faculty members will play a critical role in designing and executing the new educational mission aimed at meeting the workforce needs of both the space industry and space science.

### **Required Education for the Workforce in Space Industry.**

The Orbital Sciences Corporation is an interesting case study of the education required for students who wish to enter space industry. Orbital is a medium-sized space company, with annual revenue of about \$750 million and a workforce of ~2,000. Orbital is a pure space company, deriving its revenue almost entirely from space infrastructure, launch vehicles, missile defense, and satellites. Moreover, Orbital is a relatively young company, formed in the mid-1980s, and thus was able to hire the workforce it needed, as opposed to being saddled with a workforce from the past. The average age of the technical workforce of Orbital is 41, as compared to typical competitors whose average age is over 50, and with a bi-modal age distribution, with half of the technical staff having an average age of 60.

Of the technical staff of Orbital, 55% are engineers and scientists, with the balance of 32% management and business support specialists, and 23% manufacturing, test and QA. Of the engineers and scientists, 24% are Mechanical Engineers, 22% are Electrical Engineers, 19% are software engineers, 18% are systems engineers, 5% are designers, and the balance of 12% are Aerospace Engineers, RF/Optical Engineers, etc. [Source: L. A. Fisk, Member of the Board of Directors of Orbital Science Corporation].

The obvious conclusion is that space industry draws its workforce from a broad range of engineering disciplines. An undergraduate degree in Aerospace Engineering is a possible route into space industry, but certainly not the most likely. The complex electrical engineering requirements of space vehicles, or the challenging structures issues, require the broad range of skill sets of electrical, mechanical, software, and systems engineering.

Another interesting case study is TRW, which recently won two major new contracts: NPOESS, the multi-billion dollar contract to develop the next-generation polar weather satellites, and the Next Generation Space Telescope (NGST), also valued at more than a billion dollars. These projects are necessitating many new hires for TRW. TRW has approached AOSS for some assistance in their recruitment, since their ideal new hire is someone with a firm foundation in a basic engineering discipline, but with knowledge of the science that is to be accomplished by their new missions, in particular, knowledge of meteorology to work on NPOESS.

Both of these case studies argue that the ideal training for students in the College of Engineering who wish to pursue careers in space industry would be an undergraduate degree in a basic engineering discipline, such as electrical, aerospace or mechanical engineering, and a Master's degree in the particular issues of designing, fabricating and launching space vehicles, and their many subsystems,

from avionics to instruments, and even such issues as spacecraft communications and operations, or the handling of large data sets. The Master's degree should also provide training on such issues as project management for the complex projects encountered by space industry, on the environment of space which can be very challenging for the design of space missions, on the scientific and remote sensing requirements for space missions, and even on the political environment for the successful execution of the global space program.

Thus, a degree program that should be considered for training the workforce for the space industry is the Sequential Graduate/Undergraduate Studies (SGUS) program, in which a Master in Space Engineering is offered in combination with basic undergraduate engineering degrees in electrical, mechanical, or aerospace engineering. It would also be possible to have an SGUS program jointly with bio-medical engineering for the students who wish to pursue life sciences applications in space.

### **Required Education in Space Science**

The basic degree to pursue a career in space science is an MS/PhD. This program of course includes original research in a broad range of possible scientific areas, from the study of geospace, to planetary science, to solar and heliospheric physics. The required skill sets include basic theory, data analysis, computer simulations and/or the ability to develop space hardware. The normal application of this degree program is a career in research in academia, national research laboratories, or industry.

## APPENDIX B NEW AOSS CLASS OFFERINGS

AOSS	Title	CH	Serv.	UG	Atm. SGUS MENG	Atm. MS PhD	Space SGUS MENG	Space MS PhD	Comments
105	Changing Atm.	3	LS&A						Fall & Wint.
202	Severe Weather	3	LS&A	Core					New name; Fall & Wint.
204	The Planets	3	LS&A						
300	Global Env. Impact Technol. Change	3	LS&A	Core					
313	Map Analysis	3		Core					310 & 311
399	Atm. Sci. Design	6		Team project					Could be a summer course
402	Dynamics	4		Core					401 & 451
404	Atm. & Oceanic Env.	4		Core	Senior Core				Replaces 304
412	Dynamics of Climate	3		Core					
415	Atmospheric Physics I	4		Core	Senior Core	Pre-Req			415 & 416 merge 411, 430 & 432
416	Atmospheric Physics II	4		Core	Core	Pre-Req			415 & 416 merge 411, 430 & 432
426	Mesoscale Meteorology	4		Core					Combines 424 & 454
456	Bound. Layer Met.	3		Core					
463	Air Quality	3		Core					
464	Space Environment	4					Senior Core	Core	Incl planet. phys.
467	Biogeochemical Cycles	3		Core		Elective			
475	Earth-Ocean-Atm. Int.	4		Core					
479	Atmospheric Chemistry	4		Core	Core	Core		Elective	Revised and extended
495	Aeronomy	4				Elective		Core	Combines 495 and 564
4xx	Visualization & Public Outreach	4			Core	Elective	Senior Core	Elective	New CoE capstone
532	Radiative Transfer	4				Core		Elective	Modify to include Sun
565	Planetary Atmospheres	3				Elective	Elective	Core	
581	Space Policy & Manag.	3				Elective	Core	Elective	Modified course
582	Spacecraft Technology	4				Elective	Core	Elective	Credits from 3 to 4
583	Space System Design	4					Team project		Team proj. 2 faculty
585	Remote Sensing	3			Core	Elective	Core	Elective	
592	Masters Project	4			Project		Project		Individual project
595	Space Weather	3						Core	Modified course
596	Gaskinetic Theory	3				Elective		Elective	Modified course
5xx	Data Systems & Analysis	4			Core	Oblig.	Core	Oblig.	New course
597	Space Plasma Physics	3						Elective	
5xx	Space & Atmospheric Instrumentation	4				Oblig.		Oblig.	New course
749	Space Science Seminar	1					Elective	Oblig.	
7xx	Atm. Science Seminar	1			Elective	Oblig.			