

Graduate Studies in Space Science and Engineering (GSSSE)

A. Participants

Director: *R. Winglee* (Department of Earth and Space Sciences, ESS)

Earth & Space Sciences (ESS)

R. Holzworth – Atmospheric electricity
W. Harris, Thin Atmospheres
M. McCarthy, Space Instrumentation
G. Hernandez, Optical Aeronomy
T. Ziemba, Advanced Space Propulsion
E. Harnett, Planetary systems

Aeronautics&Astronautics (A&A)

J. Slough, Adv. Propulsion, Fusion
A. Bruckner, Space Systems
U. Shumlak, Advanced propulsion
T. Jarboe, Fusion

Assessment

UW Ed. Assessment

Electrical Engineering (EE)

B. Visions, Goals, and Thematic Basis

Vision for the Future: Exploration of space will be pushed by mankind’s curiosity of the hidden unknowns of our solar system, and beyond. The need for more efficient and extensive utilization of space will continue to increase as part of the nation’s broader goal of maintaining a competitive edge in a global economy. For this exploration to be successful, a myriad of new technologies will be needed to efficiently deliver payloads to their desired destinations, and to maximize the scientific return. Spin-offs from these technological developments will fuel the national economy across a variety of potential applications. By embedding our students in a host of emerging technologies, they will be well prepared to make new innovations and push forward irrespective of their career path. Students in the proposed GSSSE program will have a key role in advancing space exploration through the development and testing of breakthrough technologies, including advanced electric plasma propulsion that can enable new missions, and new instrumentation to better probe the earth, the planets and their space environments.

Goals: The objective of GSSSE is to implement a graduate program to foster scientific and engineering developments between academia and industry that would advance exploration of the solar system, from our atmosphere to the rim of the Kuiper belt.

Goals for the students within the program are

- To develop interdisciplinary knowledge of emerging technology and science issues to maximize developments in space exploration and utilization;

J. Sahr, Ionosphere, passive radar

B. Nelson, Plasma processing

T. Chinowsky, Space Instrumentation

Industrial Partners

R. Myers, Aerojet, Propulsion

C. Vaughan, Aerojet, Space Systems

R. Hoyt, Tethers Unlimited

N. Voronka, Tethers Unlimited

Educational Partners

J. DeCosmo, UW NASA Space Grant

L. Reinleitner, O’Dea High School

G. Vandoren, Heritage College

UW Nat. Society of Black Engineers

Advisory Board/Development

K. Reinleitner, Mindlin Foundation



Figure 1. Student testing output for a compact circuit to measure temperatures at high altitudes.

- Enhance their skill set across multiple disciplines to provide greater capacity for problem solving in any particular field;
- To develop communication and networking skills in problem solving, mentoring and public outreach.

Goals for faculty are

- To increase networking across disciplines and expand research activities;
- To develop interdisciplinary courses at the graduate (and undergraduate) level;
- Develop infrastructure to provide better educational opportunities both on and off campus.

Goals for GSSSE as a program will be to

- Develop leadership in space science and engineering;
- Establish diversity through recruitment of women and minorities;
- Establish outreach and contacts beyond UW to provide broader educational opportunities.

Thematic Basis: As noted in the National Academy of Sciences report on Reshaping the Graduate Education of Scientists and Engineers, graduate students have traditionally been trained within a specific discipline for permanent or tenure-track positions in which they conduct significant research in universities, industry, or government agencies. In the 1960's and 1970's, the majority of the graduate students on completing their studies could expect to find such a position in their field. This is no longer the case. Many more new science and engineering PhDs are only able to obtain part-time positions, short-term non-tenure-track positions, and postdoctoral positions. Many of the fields are now very mature and the new breakthroughs will not come from within a discipline but instead will come from interdisciplinary fields. One example of relevance to this proposal is the recent acknowledgement that plasma propulsion and not chemical propulsion will be the main means for advancing future space exploration and utilization over the next several decades. Advances will require a solid basis across several disciplines including plasma physics, space physics, astronautics, mechanical and electrical engineering, all of which are all key disciplines within NSF.

Science and engineering are taught by two very different schools with very different philosophies. This departmentalization can inhibit developments in both fields. The goal of the scientist is to maximize the scientific return of instrumentation. The goal of the engineer is to maximize the performance of a particular system and minimize risk to it. These efforts should be considered as complementary goals in an ideal world, but if there is a lack of communication/understanding between the different disciplines then both suffer from lost opportunities and non-optimal designs. GSSSE seeks to establish links between science and engineering disciplines, and between its academic and private sector partners, and to use the strengths of all the members to push the boundaries of exploration and utilization of space through comprehensive interdisciplinary studies using emerging technologies and ideas. Such studies will be facilitated by an augmentation of interdisciplinary courses already in place, including a joint ESS/AA/EE high altitude balloon experiment that includes the dropping of a high altitude glider carrying small scientific instrumentation. The proposed classes and research programs will mirror this set up where science and engineering graduate students will jointly be involved in building, testing and deploying ground-based/balloon/rocket hardware projects and in computer simulations of these systems and/or of the space/atmospheric environment in which the instrumentation will be deployed.

Planned Outcomes: GSSSE will be under the auspices of the Research Institute of Space Exploration (RISE) at the University of Washington. This institute, similar to this proposal, fosters interdisciplinary science and engineering studies and seeks to remove the inherent barriers produced by the different philosophies of the two different schools. We propose to use IGERT to provide 2-year funding of students of incoming students. We will impose the 2-yr restriction so that new and promising students can be recruited each year, rather than completely committing all the IGERT funds in the first few years. After this period the students will have their support

continued through other research grants. It is anticipated that GSSSE will support a total of 10 students per year out of a group of about 25 graduate students within RISE.

It is anticipated that about half of the group of students within RISE will be women and/or minorities, so that the student population within GSSSE truly reflects the US population. We anticipate an average degree completion time of 5-6 yrs so that about 4 to 5 graduate students per year are expected to be receiving their PhD by the end of the 5-yr IGERT cycle. The most important part of the program will be that the students be versed in laboratory and computations skills, have an understanding of relevant science and engineering issues, and be aware of emerging technology and science, and through required outreach and mentoring components be able to communicate and influence broader US developments in education, public awareness and technology. We anticipate that graduates from the program will be strongly recruited equally into the private and academic research sectors.



Figure 2. Students ready to launch a high-altitude (100,000 ft) balloon carrying the experiments developed by them to investigate the properties of our atmosphere at the edge of space.

Broader impacts of GSSSE: In addition, as outlined in Section D, GSSSE has a strong minority recruitment and outreach program, including tutoring, mentoring and recruitment at minority colleges, and outreach at local middle and high schools. Students within GSSSE will also have the chance to participate in the teaching of non-science major classes (taken by political science, history, English, and law majors) that reach hundreds of students who would otherwise not receive or participate in education or understanding of the excitement of space exploration. As such the number of people touched by the program will be very much larger than the number of students supported. Several of the technologies developed within GSSSE have other applications in other fields. One application is the continuing increase influence of plasma technology/science on the national economy. Examples include plasma applications in monitors, the production of semi-conductors, influence of space weather on commercial satellite performance and on the removal of errors in the global positioning systems (GPS).

C. Major Research Efforts

The students will work under the auspices of RISE, which has active participation from the Department of Earth and Space Sciences, Aeronautics and Astronautics, and Electrical

Engineering, and aerospace companies such as Aerojet and Tethers Unlimited. Graduates from the program are expected to be key contributors not only in space science and engineering but to be leaders supporting the broader national goals in technological developments for aerospace, communications, computer technology, and education. A strong industry component is incorporated in GSSSE to ensure that graduates have the necessary skill set to ensure leadership in either academic or private sectors.

The exploration of space is tied to instruments either carried on balloons, rockets, and satellites or linked to ground based observations. The detailed interpretation of data is often heavily dependent on numerical simulations. To gain cheap and better access to key regions of the solar system, advanced propulsion techniques need to be developed. The research programs listed below provide a comprehensive coverage of each of these areas, and often rely on an interplay between scientist and engineer for maximum return. The interdisciplinary nature in the proposed work is seen in that at each stage where state-of-the-art engineering is required for the successful development of the instrument package, with the science team working with the engineers from initial design, its deployment and the collection and analysis of the data. It is the interdisciplinary approach along with the comprehensive coverage of science and engineering issues that make GSSSE a fundamentally unique opportunity for graduate studies. The interdisciplinary nature of the work is demonstrated below where science and engineering faculty are working on closely related issues but from significantly different perspectives that brings synergism to the projects.

Theme I: New Ground-Based/Rocket Technologies for Viewing Thin Atmospheres
(G. Hernandez, W. Harris ESS; J. Sahr, EE)

Earth's atmosphere is highly structured. The region of interest within GSSSE is the upper atmosphere including (1) the mesosphere which is the coldest region sitting above the ozone layer at 50 to 80 km altitude, (2) the thermosphere which refers to the neutral gas at > 80 km which is heated by solar X-rays and ionized particles from space to several thousand degrees, and (3) the ionosphere which also lies above > 80 km but refers to the charged particle or plasma environment. The mesosphere is of importance as it is probably the region most sensitive to global change, and is also where meteors (and spacecraft) break up. The thermosphere/ionosphere provide critical information on the space weather conditions around the planet, which can significantly affect spacecraft performance through additional drag, and introduce errors into the Global Positioning System (GPS). Students within GSSSE will use newly developed Fabry-Perot spectrometers, medium frequency radars, and meteor radars, in New Zealand and Antarctica to study the mesosphere and thermosphere^{1,2}. New results are to show how dynamics in addition to chemistry play a role in the formation of the ozone hole. Students will also participate in the development of a new class of passive radar to study the ionosphere. These radars have no dedicated transmitter, observing serendipitous scatter of existing radio frequency sources such as commercial FM broadcasts³. Such radars have very high performance and cost far less than conventional radars. Students will participate in the design, development and deployment of these passive radar systems in different parts of the US and Canada.

Understanding the dynamics of neutral interactions with charged particle interactions is also critical to our understanding of the atmosphere at Mars, and of the Galilean moons of Jupiter, including Europa, Ganymede and Callisto, and in the extreme limit even provide information on the interplanetary medium. For orbiting spacecraft, multifunction radars are also being developed. To study these thin atmospheres/neutral populations remotely, emerging technology in the form of UV-Visible spatial heterodyne spectroscopy (SHS)⁴ will provide new opportunities to study the interplanetary medium (IPM), comets and the atmosphere of Jupiter using sub-orbital platforms (sounding rockets). UW is a leading institution in the development of this technology. Many graduate training experiences are possible including the development of SHS instruments

for various applications; design, construction, testing and flight of a rocket instruments; and theoretical modeling of the IPM, comets, and the Jovian atmosphere.

Theme II: New Balloon/Rocket Experiments (M. McCarthy, R. Holzworth, ESS; T. Chinowsky, EE).

Above a few hundred kilometers there is the magnetosphere which comprises the charged particle or plasma environment extending out to 10's to 100's of Earth radii into space. The most famous component of the magnetosphere is the Van Allen radiation belts where very energetic particles from solar flares, coronal mass ejections and cosmic rays become trapped by the terrestrial magnetic field. Although loss processes, such as diffusion, wave-particle interactions, and asymmetry in the magnetic field, have been identified and studied, we cannot yet say which are most important under various circumstances, or even if the known processes account for the actual losses^{5,6}. Understanding relativistic electron precipitation is a pre-requisite to understanding radiation belt dynamics and to comprehend the consequences of a radiation belt on a planetary atmosphere. Graduate students supported by GSSSE will participate in the development of high altitude balloon platforms and instrumentation, to study the characteristics of the waves in the region, hydrogen optical emissions, and precipitating electron spectra so that the importance of various precipitation mechanisms can be identified. Students will participate in a series of simultaneous balloon launches from Antarctica and northern Canada to generate new knowledge about the physics of radiation belt losses.

Graduate students within GSSSE will be involved in attaining a new understanding of the influence of lightning on global scales, using new 3-vector electric field measurements on rockets and balloons, as well as innovative computational tools to track the propagation of the electromagnetic energy from lightning. Students will utilize a pioneering global, real time lightning location system located at the University of Washington⁷. This new World Wide Lightning Location system (WWLL - see flash.ess.washington.edu), along with colleagues in New Zealand, provides the entire, real time data set on both lightning location, as well as very low frequency (VLF) broadband measurements. The WWLL data are already being used in conjunction with experimental balloon and satellite programs, and it is now time to conduct a system-wide global study of lightning as a driver to the global circuit.

Theme III: Advanced Plasma and Fusion Propulsion (R. Winglee, T. Ziemba, ESS; A. Bruckner, T. Jarboe, U. Shumlak, J. Slough, A&A)

The speed of a spacecraft and its ability to carry a payload is determined essentially by the speed of the propellant driving the spacecraft. The maximum exhaust velocity of chemical propellants is about 5 km/s. To gain increased efficiency with larger payloads and possibly longer lifetimes and mission capabilities, there is presently a major push in the aerospace industry for the development of advanced plasma propulsion systems. To date the primary contenders in this area utilize electrodes to produce accelerated plasma flows. The problem with these systems is that they tend to be very bulky due to limitations on the electrode current. GSSSE will support students in several innovative emerging technologies in relation to advanced plasma propulsion. These include (i) the first high power electrodeless system (called the high power helicon) that is able to produce propellant speeds of 40-60 km/s using intense radio waves to produce the acceleration of the plasma, and (ii) the development of a plasma magnet using rotating magnetic fields which can be extended in space without any significant mechanical structures and provide radiations shielding for the spacecraft, and by coupling to the ambient plasma provide enhanced propulsion for the spacecraft^{8,9}. These systems would be applicable to commercial spacecraft requiring a few kW of power available to the several 100 kW spacecraft being proposed for the Jupiter Icy Moon Orbiter that will be a precursor for human exploration in space. At even high power systems, fusion systems such as the flow Z-Pinch (ZaP)¹⁰ experiment become possible that would produce exhaust speeds at least another factor of ten faster than the above plasma systems.

Theme IV: Comprehensive Computer Modeling of Laboratory and Space Plasmas
(E. Harnett, R. Winglee, ESS; U. Shumlak, A&A)

To make progress in the understanding of any of the above laboratory or space applications, detailed computer modeling will be required. There is excellent synergism between the science and engineering computer modeling as many of the plasma physics issues are very similar, and it is only in the actual geometry, boundary conditions and numerical algorithms where the implementation differs. The most common tool to examine plasma is called magnetohydrodynamics (MHD) wherein the electrons and ions within the plasma are assumed to drift as one single fluid. Comparison with data, whether it be from laboratory or space experiments, show substantial deviations from this MHD treatment. In reality the electrons and ions orbit or gyrate about the magnetic field with opposite sense of rotation and with different gyro-radius so that a more comprehensive, non-idealized treatment is required.

At this time the engineering simulations focus on a two-fluid (electrons and ions) model for investigating the stability of ZaP. Instabilities lead to losses of confinement of energetic particles and inhibit the possibility of fusion. The simulations have demonstrated that a stability threshold exists if a flow is introduced into the device and this threshold has been verified in laboratory applications¹⁰. For space plasmas, graduate students will be involved in modeling the space environment around the planets, including the Earth¹¹ and Mars¹², and the Galilean moons of Jupiter¹³, including Europa, Ganymede and Callisto. A key problem is the loss of their atmospheres into space due to forcing from the solar wind in the case of the Earth and Mars, and by plasma winds within Jupiter's magnetosphere, including differential loss of hydrogen versus oxygen in the case of the Galilean moons. Students will work with state-of-the-art multi-fluid codes to quantify changes in the composition and loss of a planet's or moon's atmosphere from forcing by external plasma winds.

Theme V: Other Applications (A. Bruckner, AA; J. Sahr, EE; T. Ziemba, R. Winglee ESS)

Plasma systems have many applications beyond space science and engineering. High intensity plasma sources are critical for plasma processing in the semi-conductor industry for thin-film deposition, and as potential sources for high intensity lighting, also key NSF endeavors. As part of GSSSE we will be building up vacuum chamber facilities to provide testing facilities for the space science and engineering applications that would enable fast prototyping by any of its consortium members. This valuable resource could provide a much-needed resource at UW for the startup of plasma processing applications for GSSSE consortium members and colleagues that would have a broader impact beyond just space science and engineering. As GSSE matures we expect to include other astronomical applications with respect to building and launching of balloon, rocket and nano-satellite payloads.

D. Education and Training

Course Development: Each of the faculty members actively participate in very successful graduate teaching programs within their home departments. GSSSE seeks to development new interdisciplinary programs to provide a more comprehensive immersion in scientific instrumentation and engineering design and implementation. A seminar series will be jointly sponsored by the three departments so that all students can gain first-hand knowledge of recent developments across the different fields –e.g., ranging from recent developments for the Jupiter Icy Moon Orbiter, spacecraft power system, electric propulsion, remote sensing and in-situ instrumentation, to planetary dynamics and spacecraft orbital requirements. We have already established interdisciplinary plasma physics courses for graduate science and engineering students. These classes include *Space and Plasmas* (ESS415/ESS515/AA405) and *Space and Laboratory Plasmas* (ESS576/AA556) with EE students taking the class through the ESS designation. These courses, while servicing science and engineering students, only cater to the specialty field of plasma physics. With support of GSSSE, we will go much further by developing a comprehensive science/engineering instrumentation course sequence that will establish

networking and interdisciplinary studies to give the different perspectives from the science and engineering viewpoints. The sequence will involve the development and deployment of a scientific package associated with a possible funded research program (e.g., nano-satellite or sounding rocket) or a high-altitude (30 km) balloon experiment. The course sequence consists of:

- *Scientific Instrumentation and Systems Engineering*: The need for particle and spectral measurements; techniques for taking such measurements; Command and data handling, budgets, communications, ground station coverage, power systems.
- *Instrumentation development and payload construction*: Design and build instrumentation, payload delivery system, and ground station; test for design performance, and communication systems; model relevant environment;
- *Go fly it*: Integrate instruments with payload, test for interference under thermal/vacuum conditions; launch payload; analyze data; perform post-launch debriefing.

Dr Charles Vaughn from Aerojet, and Dr Nestor Voronka from Tethers Unlimited will be heavily involved in this endeavor, as both companies have active nano-satellite and satellite systems actively underdevelopment. The fact that a freshman graduate student would be able to build and fly a scientifically important and properly engineered payload within his/her first year would be a major advance. We will encourage our private sector partners to participate in the content and design of the courses and provide a resource for employees for possible additional education opportunities and to provide testing of emerging technologies in a relevant environment.

Recruitment & Mentoring: For on-campus activities, graduate students will participate in the teaching of undergraduate classes at the non-science major level (ESS102: Space and Space Travel, and ESS205: Access to Space, and to majors (AA420: Spacecraft and Space Systems Design) to demonstrate the excitement involved in space exploration. We will have representatives from the UW branch of the National Society of Black Engineers (NSBE) and UW's Graduate Opportunities & Minority Achievement Program (GO-MAP) on our advisory board to advertise the program and identify students that could be recruited into it. We will also instigate internships with our private sector members (Aerojet and Tethers Unlimited initially; additional companies will also be solicited to join). Students from GSSSE will also make presentations and mentor undergraduate students working with the Washington NASA Space Grant consortium to maximize outreach on campus.

Outreach and other Off-campus activities: As part of the recruitment process we will advertise nationally, including scientific meetings and through societies such as the National Society for Black Engineers. We will link our activities with GO-MAP and the Washington NASA Space Grant consortium to provide additional profile to our recruitment activities. We will also have our students participate in mentoring of minorities. Scholarship winners in addition to their standard teaching and research activities at UW will be required to work as a teaching assistant/mentor at Heritage College or similar college in the US for at least one week a year. Heritage College is a school serving students with diverse cultural and ethnic backgrounds, with about half the student population being Hispanic or Native American. In addition, the scholarship holders will be required to participate in outreach at a local middle/high school once a year to excite younger students about new developments in space science and engineering.

E. Management, Assessment and Institutional Commitment

The PI, Prof. Robert Winglee, will be the director of the program, and will have overall responsibility of the administration for the program and recruitment. He will be assisted by a 40% research professor acting as technical director who will be responsible for maintaining the technical components of the courses described above and working directly with students in their development of course project. By working directly with the student, the technical director will provide mentorship of the students in addition to the mentoring provide by the faculty participants to GSSSE. A 40% Associate Director will work with the students and middle/high schools and other educational institutions to facilitate outreach/mentoring and recruitment of students for

GSSSE. Dr L. Reinleitner will be our initial high school contact. The faculty from ESS and A&A in conjunction with Dr Vaughan from Aerojet will be responsible for the course development.

As part of the assessment component of this project, program evaluation staff at the UW's Office of Educational Assessment will evaluate both ongoing processes and project outcomes. As part of a formative evaluation, these researchers will work with students and faculty to determine how the education and training program can be improved, the extent to which the educational components (e.g., the comprehensive instrumentation course sequence) feed into existing research at RISE, and whether these elements remain consistent with the goals and thematic basis of the project. In addition, the evaluators will provide summative information about the goals and objectives of the grant. For example, researchers will follow up with students, their mentors, other faculty, and perhaps future employers to determine whether students' experience in the program has provided them with an enhanced set of skills, depth of knowledge in their discipline, and an interdisciplinary perspective in their research endeavors. In the formative and summative evaluations, both quantitative (e.g., surveys, existing enrollment/graduation data) and qualitative (e.g., focus groups, interviews) will be used.

We will also have an external advisory board headed by Dr. K. Reinleitner of the Mindlin Foundation which provides private donations for the fostering of science and technology. This advisory board will also include members from the private sector, as well as GO-MAP and UW ' chapter of NSBE to ensure the educational and recruitment goals are being met. The UW has recognized the importance of our efforts through the formation of RISE. The Provost, the School of Arts and Sciences and all the involved departments have contributed funding to the institute. We have also solicited private donations that will provide a small amount of graduate support.

F. Other Resources and Connections. Graduate students within RISE, under whose umbrella GSSSE will function, are typically funded through disciplinary studies supported by NSF, NASA and DoE. A Fusion Center with Dr T. Jarboe as PI and participation from ESS is presently under consideration by DoE. No other external support is available although we continue to solicit additional funding from our consortium members and beyond.

G. Recent Traineeship Experience and Prior NSF Support. The PI has been funded by NSF since 1998 under grants ATM-9731951 and ATM-0105032 for "Multi-fluid simulations of the magnetosphere, its boundary layers, and current systems." During this period, 5 students under his supervision have obtained their PhD's. Presently, he is supervising two graduate students, and 4 undergraduate students, about half of whom are women. He has participated in several outreach events at national conferences and societies including the Geological Society of America, National Space Society and the International Space Development Conference, and at elementary and middle schools in Seattle.