**Steven R. Woodruff**

## Personal, Relevant Background, and Future Goals Statement

***Exposure to Structural Analysis:*** Structural analysis first became clear to me via a plastic ruler. Prior to this, I would confuse the meaning of internal bending moments of a beam and the sign convention for support reactions. Clamping one end of the straightedge with my fist while pushing down on the other demonstrated how analysis and structural behavior fit together – how the differential equations lead to deflections with the shear and moment in between. I experienced a sort of pride in this personal discovery because I understood what the numbers and diagrams I had been calculating in strength of materials meant. With the help of my ruler, my understanding of structural analysis and what it is meant to show flourished.

With a foundational understanding of structural analysis, my view of the world shifted. This was especially apparent during my study abroad experience at the University of Hong Kong. In a city as densely populated and highly developed as Hong Kong, innovation in structural design is paramount. The skyscrapers, bridges, and tunnels which permeate through the city show how far civil engineering has come, but the glamour of these monuments cannot hide the problems which stymie and even harm the people who live in this world city. Housing in Hong Kong is prohibitively expensive. Some families live in flats with a bunk bed and a few square meters to spare. In a city with such amazing infrastructure, the problem of housing and living conditions have not been solved. I believe that structural engineering can enter a new era where infrastructure can address problems beyond strength, serviceability, and reliability.

***Professional Experiences:*** My optimism for the future of structural engineering was further cultivated by my experiences in the design and analysis industries. Last year, I was a member of a team at Infrasense, Inc. in Woburn, Massachusetts in charge of incorporating non-destructive testing data of pavement and bridge structures into a comprehensive and usable geographic information system database using ArcGIS for the Idaho Transportation Department. As the resident expert in ArcGIS, I was in charge of independently processing data and choosing how to best display the hundreds of thousands of rows of data. I collaborated with other members on the team and the client about big-picture decisions like how to organize the data in a manner that will allow for the expansion of the project across the entire state in an efficient and effective way.

The experience I have gained on this project has proven to me that I enjoy the autonomy and collaboration of large projects. Through this project, I have researched the ASTM methods used to analyze pavement remaining life and the jargon associated with bridge deck deterioration. I even had an opportunity to conduct field data collection on twenty bridges outside of Chicago, operating a ground penetrating radar rig attached to a Ford Expedition at 3am. Currently, the data our team collected and processed is on display online in the Idaho IPLAN database for use by contractors and politicians in charge of maintaining eastern Idaho's roadways. Our accomplishments continue to make roadway management simpler and more cost-effective – saving tax money which could be diverted to social improvement efforts.

***Research Experiences:*** This past summer, I joined the newly established Deployable and Reconfigurable Structures Lab at the University of Michigan. My first goal was to investigate the static behavior of curved crease origami structures, flat sheets when folded along curved creases can support loads exceeding their own weight. I pursued this goal by writing a script in MATLAB which would create finite element models and display the results on plots of the deformed structure. I found that improving my coding skills by examining the disadvantages of my earlier code led to new methods that would make my script more robust and general – saving me hours of work in the future. Our investigation compared the different ways a sheet can be folded in a numerical model. This culminated into a paper submitted to the ASCE Earth and Space conference in August. My work this past summer has fortified my conviction that research in this field can offer tremendous opportunities to solve pressing infrastructural problems like reducing the impact of natural disasters with deployable structures.

My second goal for this project was to develop myself as a researcher and mentor. With help from my advisor, I exposed myself to the fundamental literature in our field as well as other papers concerned with topics beyond origami inspired structures including heat transfer modeling and differential geometry. I was fortunate enough to attend the ASME IDETC/CIE conference in Cleveland in August and see how other researchers are exploring origami-inspired structures. I was able to take these experiences and use them to offer advice to the undergraduate students working in our lab. For instance, a technique for 3D printing foldable rigid models that I saw at the conference proved useful for one of our members. Because I am the first student in my lab, I already have substituted for my advisor when coordinating with undergraduate researchers. For one of the visiting undergraduates, I assisted in guiding his poster presentation and provided feedback when my advisor was out of town.

***Current Research & Academic Projects:*** Since the end of the summer, my focus has been on developing skills pertinent to my research goals. I decided to attend the University of Michigan because of its willingness to explore original ideas. The university's investment in origami-inspired structures, structural fire engineering, and intelligent systems show a forward thinking approach to civil engineering that aligns with my interests and offers ample opportunity to collaborate with experts in their respective fields.

In order to continue cultivating my goals, I am taking a class on structural fire engineering which has exposed me to concepts in heat transfer and fire safety and continues to strengthen my skills in finite element analysis. The topics discussed in this course have led me to think about how heat energy from the sun or mechanical equipment can be used to modify structural behavior, especially in the context of deployable, origami structures. My class in structural dynamics has exposed me to modal analysis which would be essential for a parametric study of stiffness for curved crease origami structures. I have also taken the initiative to attend workshops on supercomputing and high-level coding languages like C++, which I believe can be used to expedite my research and improve productivity. These learning experiences feed into my thoughts about research on curved crease origami structures and have provided a litany of ideas for the direction of my PhD thesis.

***Future Goals:*** I want to use my doctorate degree to become an expert in the field of structures and to work at the forefront of structural innovation. My goal is to explore the possibility of civil infrastructure solving societal problems by reducing costs with efficient designs and utilizing structures that can adapt for non-structural purposes. By creating a more holistic structural paradigm, resources used to solve problems in heat transfer and acoustics could be diverted to address social issues. Conserving resources will become more important as populations grow and urbanization continues to rise. The problems I saw in Hong Kong could become more widespread if they are not addressed from perspectives as niche as structural engineering. I believe that my research in curved crease structures could contribute to broader and more efficient applications of structures.

I am also interested in using my expertise to educate future engineers and non-engineers. My passion for structural analysis comes from years of excellent teaching from professors who not only taught the mathematics of structural behavior, but also gave it context through hands-on lessons and big picture seminars. Coupled with the liberal arts courses I took at Tufts University, I believe that a well-rounded education includes exploration of issues beyond a single field. I plan on continuing mentoring undergraduates in my lab and contribute to teaching courses at the University of Michigan before my dissertation defense.

As an NSF fellow, I hope to apply to the GROW program that would help expose me to other researchers approaching similar problems, but from different perspectives. Research in experimental and computational mechanics in France would compliment my goal of incorporating multi-physical phenomena into curved crease origami analysis. I believe that exposing myself to these unique perspectives is essential for collaboration and deciding the direction of my research.

My long-term goal is to pursue a research position at a university in order to continue exploring concepts in origami-inspired structures while also satisfying my desire to educate future engineers and researchers. Having helped establish a lab at the University of Michigan with my advisor this past summer has exposed me to the challenges and benefits of research at a university. I flourish in the abundance of problems that I can help solve through research and aspire to apply my knowledge after graduate school to addressing structural obstacles with larger social ramifications.

***Broader Impacts:*** I believe that the progress of structural engineering depends on increasing and diversifying the pool of students and researchers in the field. The variety of perspectives brought by different people increases the purview of the community and can lead to new problems beyond structural behavior being solved. My goal for the future is to expose non-engineers, especially younger people deciding where to go in their careers, to structural engineering. I will pursue this goal by conducting workshops and talks in schools and libraries about origami and its role in infrastructure. My research group currently plans on talking at the Ann Arbor public library in December which will be a useful experience in exploring how to connect the art of origami, a topic easily understood by children, to our research on structural behavior. I hope that during my PhD we can expand this effort to underrepresented groups in Detroit's recovering neighborhoods (only a half hour drive from the University of Michigan).

I am passionate about addressing problems regarding the LGBTQ+ community and its relationship with engineering. Although more companies today are increasing their efforts to diversify their STEM employees, there is still a noticeable faux pas surrounding gender and sexuality in engineering. I plan on working within the oSTEM group at the University of Michigan, an LGBTQ+ oriented STEM community, to further increase awareness of LGBTQ+ people in my field. I plan on attending the oSTEM conference held annually, presenting posters of my research and reaching out to high school and undergraduate students in hopes of fostering acceptance of LGBTQ+ people within civil engineering and further diversifying the field.

Next summer, I will also conduct a workshop for the GISE program at the University of Michigan, a week-long summer program which exposes middle school girls to science and engineering. By providing hands-on experience with small scale origami structures under loading, I hope to inspire a new generation of researchers and engineers with perspectives that will push the field towards a more holistic approach to problem solving.

I believe that my prior experiences in research and industry along with my personal goals set me up for an exciting and fulfilling graduate experience. My curiosity for structural analysis and my desire to educate people about the broad impact structural engineering has on society will push the field in a direction unseen before. With help from the NSF, I believe that structural engineering, specifically curved crease origami, can be used to solve problems that permeate through society.