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I had been a firefighter paramedic for nearly four years before I left for Iraq as a civilian contractor for the Department of Defense (DOD). After two continuous years in Baghdad, I became blissfully numb to the daily small arms and rocket-propelled grenade (RPG) attacks on our outpost. However, one night, I truly thought my time had come when I awoke face down on the floor, with my hands on my head and a constant pounding in the background. I could hear the RPGs whistling overhead, when a 190 kg Shahin-I rocket detonated less than 50 yards from my station, leaving my ears ringing and my adrenaline at an all time high. In the coming days, I would replay that night over and over thinking about how fortunate I was to survive.

Leading up to that night I had talked for years about my desire to study engineering, but I lacked the confidence needed to drop my career and income to go back to school full-time. After a period of introspection, I became very serious about what I wanted out of life and vowed that nothing – not self-doubt, nor petty excuses – would keep me from my goals. I finished my contract with the DOD, and upon arriving home, enrolled in classes at my local community college. My calculus professor was the first to notice my talents in mathematics, and after I completed his course, he offered me a teaching assistant (TA) position. As a TA, I often created physical models to teach mathematical concepts, an idea that resonated well with my students. Taking complex ideas and simplifying them made an impactful difference on my students and proved rewarding for me as well, fueling my desire to become a professor after the completion of my Ph.D.

Although returning to school did not prove academically challenging for me, external factors such as finding the funding needed to pay for school and my mortgage forced me to work 40 hours a week on top of a full-time class schedule. It wasn't until I qualified for academic scholarships, along with a paid research position, at the end of my third year of college that I was able to focus on research. At that time I was introduced to Dr. Forrest Masters (Associate Dean for Research and NSF CAREER awardee) who was looking for a mechanical engineering student to compliment a multi-disciplinary team of civil, electrical, and computer engineers to design and build a new wind tunnel at the structures and materials laboratory at the University of Florida (UF). This wind tunnel project, funded by NSF (#1520843), would become one of the largest and most complex in the world. The objective of this research is to replicate boundary layer conditions of rough and laminar air flow for variable topology in order to study wind effects on structures. The boundary layer growth is a strong function of the roughness of the floor, so in order to change the shape of the boundary layer, the floor would have to morph with high precision. The data collected by this wind tunnel will be used to investigate the effects of dynamical wind loads on structures. Once the analysis is complete, it will be utilized to update building codes and standards for storm conditions which will inevitably save money and lives all over the world.

My contribution to this project was the design and creation of a roughness element actuator which would allow for rapid and dynamic changes to the topology of the wind tunnel floor by varying the elements' cross-section. Because the wind tunnel required the *installation of 1200 roughness elements* under a raised floor at a maximum cost of $180 each, it was imperative that I optimize for complexity, cost, manufacturability, and actuation time to maintain the timeline and budget. At this point in my undergraduate career, I had only taken an introductory design course, yet I was tasked with leading the roughness element design, so I sought guidence from Dr. Michael Griffis (a mechanical design professor) to develop a mechanism to actuate the roughness elements. Dr. Griffis introduced me to more advanced concepts in the design process enabling me to optimize the design for multiple variables. Creating a design matrix to incorporate all possible design choices as well as their corresponding criteria, helped me identify the most critical components and issues. One major concern was the cost constraint which identified that only one motor could be used. This created a problem since the motor would need to actuate the translation as well as the rotation of the element. I analyzed the friction created by various actuation methods and found that using an Acme type lead screw was the most efficient and cost effective. However, the element being on a lead screw created another problem since the wind flow would cause a torque to act on each element. To solve this problem, I calculated the amount of torque each element would experience and used this result to properly size the motor based on its detent torque. I created three prototypes which coupled both translation and rotation of the element while satisfying all design criteria, and as a team, we selected one that best fit the design of the subfloor. The final design was manufactured and installed and *satisfied the allotted budget requirement of $200,000*. Currently, the design is working as intended and has required little maintenance.

Along with my research for Dr. Masters, Dr. Loc Vu Quoc asked me to serve as a TA for his intermediate engineering analysis course. This position inspired me to create a YouTube channel[1] that focused on teaching the methods used to solve the types of problems presented in class. Although my lecture series was meant to accompany the material presented at UF, it proved helpful for students all over the world. Currently, the video series has *more than three thousand views from over 20 countries*. The surprising popularity of my series of advanced math lectures has motivated me to continue expanding the topics covered to more broadly impact the academic community. The opportunity to teach, receive feedback and answer questions from such a diverse audience serves to enhance my teaching ability as I prepare for a career in academia.

To diversify my experience as an engineering student, I accepted a co-op internship with Johnson and Johnson Visioncare. After successfully completing several smaller projects, I was challenged to create a device that could perform a mechanical measurement of a packaging seal ring featuring a complex geometry and measuring only 2 mm wide. The project goal was to reduce measurement time from 5 minutes to 30 seconds for an unskilled worker, with a measurement error of less than one percent. To better understand the object of interest, I used a profilometer to find which areas of the seal ring profile varied the least in my sample size. I identified an area that varied in height by less than one micron and used this location as a measurement point for all packages. After designing a micrometer probe tip that utilized this measurement method, I ran contact simulations for various seal geometries in a computer modeling program. Based on the simulation data, I created a function for the error between the known value and the simulated measurement as a function of position error and tip manufacturing tolerances. Ultimately I completed a cost analysis indicating the device had the potential to save *more than $1 million a year in productive hours, leading the company to move forward with the prototype*.

The varied design experience I acquired during my co-op proved beneficial in the graduate level solid mechanics course I took during my senior year. The subject combined my skills in mechanical design with my abilities in mathematics and sparked my interest in the experimental techniques in new and advanced materials. This interest led me to find Dr. Peter Ifju, a former NSF CAREER awardee, and expert in experimental solid mechanics, where I focused on digital image correlation techniques. I collaborated with Dr. Ifju on multiple inventions, the first of which involved the creation of a short water ski that allows for high performance in rough water. The shape of the ski was generated using airfoils with known drag performance in turbulent air and modifying them to work well in turbulent water. After creating a successful prototype, we submitted a provisional patent. I also assisted with the design of an artery clamp that rapidly stops an artery in the brain from bleeding while still allowing for blood flow. This project is a collaboration between a team of neurosurgeons, chemists, and medical device experts. Working in this type of team presents unique challenges since all members must simplify technical concepts into easy to understand metaphors. The neurosurgeons introduced us to the current device used in this type of surgery which requires the surgeon to measure the affected artery and select the correctly sized clamp to stop further bleeding. By incorporating a hydrogel attached to a plastic clip, my design allows use with a larger range of artery sizes as the hydrogel conforms to the artery shape, providing a variable amount of pressure based on the ratio of cross-linking polymers. To test which hydrogel worked the best, I built a device which simulates an artery rupture and used the clamp to stop the leak. As I move into a Ph.D., my work on this project is on-going.

After graduating *Magna Cum Laude*, and earning the *Two-year Scholar Commencement Award (for outstanding research achievements)*, I have been accepted to the Ph.D. program at UF where I will continue working with Dr. Ifju. This decision was due to an opportunity to work with the experimental characterization of soft matter. The soft matter lab utilizes a novel manufacturing method that allows polymers and living cells to be printed into a granular gel-like medium. Made from soft microscale polymeric particles, this gel-like medium acts as a non-Newtonian fluid that transitions between solid and liquid states depending on the shear rate applied. When a needle injects a polymer into the medium, the gel becomes a fluid in the local region of the volume change, then quickly resolidifies, trapping the polymer in place. Using this technique, complex 3D objects made of silicone, hydrogel, and even living cells can be created and suspended in place.[2] Research in this technique has applications to the 3D printing of biological tissue, flexible electronics, and pharmaceuticals. The discoveries to be made in the development of this novel technique are numerous, such as the characterization of the granular medium which supports the printed materials. As part of the study, I used digital image correlation and particle image velocimetry to create a method to derive the strain field due to the needle's movement within this medium. This method can be used to characterize the material response due to the printing of soft matter. I have continued to perfect this experimental technique increasing the quality of measurement and have submitted a paper to the journal of Experimental Mechanics that is under peer review. In May 2017 I will also present on this method at the Society for Experimental Mechanics conference.

Throughout my transition into engineering, my mentors have played a large part in my success, and it is important to me to continue that circle by mentoring those who come behind me. With my close ties to the military, I am uniquely qualified to help veterans succeed in school as I can relate to their experiences. Studies show that this group is especially susceptible to dropping out due to issues such as their inability to socially identify with their peers and disabilities resulting from their previous experiences. My military ties also extend to my sister who is a Major in the U.S. Air Force. I have seen how hard it has been for her to succeed in a male-dominated arena and, unfortunately, in the field of engineering I have witnessed similar problems for many of my female peers. I plan to be a part of the solution. My lab hosts a summer engineering workshop that invites female high school students on campus for hands-on experience to stimulate their interest in engineering. This type of mentorship has a valuable impact on the engineering community, and next year I will serve as a leader in this program.

I believe that the advancement of science is of the utmost importance, and my goals are to contribute to the community in meaningful and lasting ways. As a research professor at a research I university, I will continue to innovate and push the boundaries of scientific achievement while mentoring the next generation of researchers. The National Science Foundation has always been at the forefront of new and exciting research, and I it would be my honor to forge a lasting relationship that starts with this application.

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[1] https://www.youtube.com/channel/UCcSPnmzqZfQAvQ5GKCN5k5A

[2] Tapomoy Bhattacharjee, et al. *writing in the granular gel medium,* science advances25 sep 2015 : e1500655

Characterization of the material response for granular hydrogel by 3D printing soft matter

Background: The synthesis of human organs is no longer science fiction. A major challenge in the field of tissue engineering, however, is the ability to print 3D structures made of soft tissue-like matter, since gravity causes slumping of the tissue. Recently a technique has been developed to overcome many of the difficulties associated with printing soft materials. By using an extrusion needle and a granular micro-hydrogel medium as the support structure, soft matter structures of incredible complexity have been 3D printed [Fig.1 A,C].[1] Currently, slow raster speeds and small needles restrict the speed of the printing process. To increase the print speed, a thorough study must be done on the granular support medium (GSM). As the needle extrudes print material, it deforms the volume of GSM [Fig.1B,C] which changes the location of existing printed material. The GSM is comprised of < 1% (w/w) cross-linked poly(acrylic acid) copolymers in water. This suspension is a viscoplastic jammed solid which can support 50 Pa of pressure before yielding for 0.2% (w/w) concentration.[1] Much of the aforementioned existing body of knowledge for this GSM is based on polymer physics. Rheological studies of this material show it to behave like a Herschel-Bulkley fluid with a strain rate dependent yield stress and shear thinning behavior [Fig.1D], thus intensifying the complexity of this research study.[2,3] Because there is an upper limit to the printing speed due to turbulence induced by the needle,[2] a multi-needle approach is being developed to decrease printing time. However, printing with multiple needles introduces many technical challenges due to the multiple dynamic deformations of the printing space. An offset that matches this distortion of the printing space at the corresponding needle's location is required to print material in the correct location. To determine the path planning required for each needle, a computational method must be developed to simulate the response of the GSM due to perturbation.

Hypothesis: Using inverse methods with in situ measurements of the support materials' mechanical and rheological properties, a multiphysics finite element model to determine the deformation fields due to the printing of soft material in a GSM can be developed.

Research Plan: A model of the nonlinear material behavior of GSM will be determined using a first principals approach. This model will need to incorporate multiple dynamic effects such as the transition of the microgel between solid and liquid states and the shear rate dependent deformation field. To study these effects over a wide range of printing speeds, needle diameters, and polymer concentrations, experiments will be developed for use in the GSM. A real-time volumetric digital image correlation (DIC) technique will be developed to observe and measure the deformation field within the GSM. The strain field is derived from the displacement field which will provide insights on the solid to liquid transition regime. I have created a 2D DIC technique that measures the bulk in-plane deformation of the GSM due to a controlled disturbance [Fig.1B]. This approach serves as the basis for the development of the in situ volumetric DIC technique in which multiple planes will be correlated simultaneously in real time.

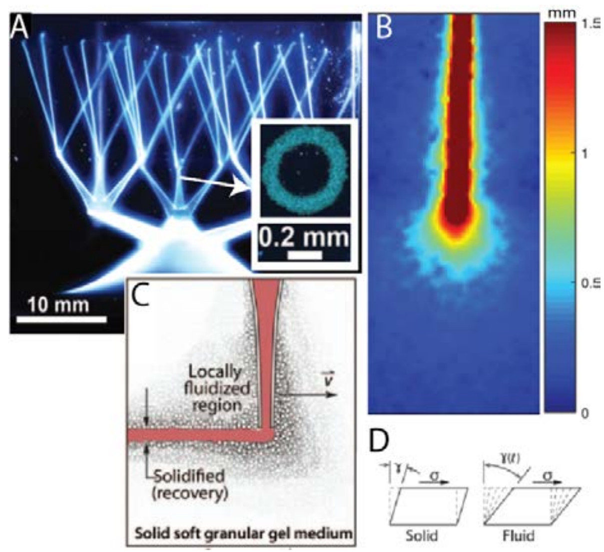

Figure 1 A. A complex structure printed in the granular medium. B. The deformation field created by the movement of a needle. C. Liquefaction and resolidification of the GSM. D. The GSM has elastic deformation at low strain and fluid deformation at high strain

Every phenomenon that involves the mechanical behavior of materials can be simulated using numerical methods. Because the physics of the GSM in response to stress is not well developed, an inverse method, such as the virtual fields method (VFM), will be applied in order to extract constitutive mechanical parameters from full-field deformations. I will define a set of experiments based on VFM that utilize the experimental techniques of real-time volumetric DIC to define the variables which will create the strongest dependencies upon the model. By setting up a geometric model and running multiphysics simulations, I will optimize for the error between the computer model and the empirical model by tuning the dependent variables. The complexity of this material is largely due to the transition of the material from a solid-like to a liquid-like regime. After studying this solid to liquid transition region, I will incorporate the results to adjust the model.

Intellectual merit: My experimental approach determines the deformation within a volume of viscoplastic materials in real time and has the potential to improve many aspects of in-situ experimental mechanics. Currently, volumetric DIC requires confocal imaging which is limited to the steady state behavior and fails to capture rate-dependent phenomena. The incorporation of the VFM into a multiphysics model has the potential to enhance current computer modeling techniques in the field of solid mechanics. If a multiphysics model cannot be created, the data I generate can be used to create empirical lookup tables that can approximate the displacement fields due to the superposition of deformation modes. I plan to publish the techniques in journals such as Computational Mechanics and Experimental Mechanics and present at distinguished conferences such as the Society for Experimental Mechanics. This dissemination will open the door for collaboration and further developments in these fields.

Broader impacts: Increasing the manufacturing speed and accuracy of a 3D printer which can print living cells as well as polymeric soft matter has far-reaching implications in our society. This manufacturing technique has the potential to spawn an entirely new section of the medical industry which will enable the creation of new jobs and advanced healthcare devices such as the synthesis of a surrogate brain. Based on a computerized tomography (CT) scan, this surrogate will allow brain surgeons to practice on a patient's brain before surgery increasing the success rate of the procedure. Because my lab incorporates such diverse yet interconnected goals, it is the perfect place to inspire the next generation of researchers. By hosting summer workshops, which invite high school women in the surrounding area to design experiments and learn about concepts in engineering, we aim to diversify the industry so that the broadest range of ideas will be incorporated into the scientific community. This mentorship, along with my interest in aiding veterans in the transition from the military to academia, will have lasting impacts on our society. By continuing my lecture series on YouTube to include more topics in engineering, I will enhance my teaching abilities while helping students regardless of where they live. This experience will be leveraged as I become a supervised teacher for a mechanics of materials course where I will incorporate my research by introducing the topic of rate dependencies in material characteristics to my class. By including my lab research in the course work, I hope to broaden the students' perspective and stimulate interest in research while maintaining relevance to the coursework.

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[1] Bhattacharjee, et al. *writing in the granular gel medium,* science advances25 sep 2015 : e1500655
[2] Giuseppe et al. *Characterization of Carbopol® hydrogel rheology for experimental tectonics and geodynamics*
[3] LeBlanc et al. *Stability of High Speed 3D Printing in Liquid-Like Solids*

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Good

Explanation to Applicant

His research plan is well construed. He is well on his way to creating a strong publication record. However, his application did not demonstrate close attention to detail. His letters of recommendation were mixed in terms of enthusiasm levels.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

He has significant teaching experience, including creating a YouTube channel with videos of difficult concepts. He is able to explain the broad goals of his research.

Summary Comments

He writes well.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

The applicant's academic path is highly atypical. Directly out of high school, he worked as a professional firefighter for three years in the United States and then as a contractor in Baghdad for two years. While in Iraq, he survived a life-threatening experience when a rocket propelled grenade exploded within 50 years from his station. He developed strong leadership skills in a highly stressful environment. But he realized that he wanted to challenge himself and follow his dreams and study engineering once he finished his contract with the DOD. After returning from Iraq, he enrolled in a local community college and after graduation enrolled at the University of Florida (UF). He received his Bachelor of Engineering degree from UF with a GPA of 3.78/4.0. At UF, he held a number of TA ships including one in a course on Intermediate Engineering analysis. He developed a YouTube channel that teaches concepts in mechanical engineering based on this course that has become popular with students from several countries. In the summer of 2014 he carried out research in the Civil Engineering Department under the supervision of Professor Forest Masters (on an NSF funded project) to design and install wind tunnel roughness elements, in order to study wind effects on structures. In August 2015, he started to work for Professor Peter G. Ifju of the ME Department and has now decided to do Ph.D. under his supervision. His proposed research in the general area of soft materials is a very exciting and novel consisting of cutting edge theoretical and experimental work. The soft matter lab utilizes a novel manufacturing method that allows polymers and living cells to be printed into a granular gel-like medium. Using this technique, complex 3D objects made of silicone, hydrogel, and even living cells can be created and suspended in place.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

The broader impact of his work on the medical field is immense with far-reaching implications on our society. Research using this technique has applications to the 3D printing of biological tissue, flexible electronics, and pharmaceuticals. This manufacturing technique has the potential to spawn an entirely new section of the medical industry which will enable the creation of new jobs and advanced healthcare devices such as the synthesis of a surrogate brain. His personal connection to women in the military has led him to become committed to increasing the participation of women in STEM areas.

Summary Comments

The applicant has taken a nontraditional path to education and has achieved great success in it. He has carried out high quality research as an undergraduate in collaboration with Ph.D. students and faculty. His has been active in important outreach work. A perfect candidate for the GRFP fellowship!

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

The applicant has an outstanding academic record with many awards and has successfully completed graduate level coursework. He participated in substantial research and design efforts as an undergraduate, and demonstrated the required creativity and innovation to meet optimization objectives, including optimizing actuators for a wind tunnel and a Johnson and Johnson prototype device. His research plan shows an in-depth understanding of the technical issues and research path.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Very Good

Explanation to Applicant

He went above and beyond the duties of a teaching assistant in creating a widely viewed YouTube video series, demonstrating experience in multimedia for the classroom. He plans to be a leader in a summer engineering workshop for female high school students and states a commitment to helping veterans succeed in school. His research has the potential to benefit society in many applications and could greatly improve 3D printing and DIC techniques.

Summary Comments

His experience prior to academia as well as his academic projects demonstrate leadership, multi-disciplinary teamwork skills, and motivation, capabilities that will enable him to excel as a faculty member. His unique background provides experience for him to serve as a role model to mentor under-represented groups, especially veterans.