University-Industry-Navy Collaboration in Development and Delivery of Additive Manufacturing Short Course to Naval Personnel

Jennifer G. Michaeli
Old Dominion University
jgmichae@odu.edu

Justin Yates
Francis Marion University
JYates@fmarion.edu

Michael Polanco
Old Dominion University
mpola002@odu.edu

Gug Sretsy
Applied Systems and Technology Transfer
gug.sresty@ast2.net

Jack Scott
Applied Systems and Technology Transfer
john.a.scott@ast2.net

Todd Coursey
US Navy Mid Atlantic Regional Maintenance Center
Todd.coursey@navy.mil

Abstract

This paper describes the collaboration between Applied Systems and Technology Transfer, LLC (AST2), Francis Marion University, US Navy and Old Dominion University's Naval Engineering and Marine Systems Institute (ODU NEMSI) to develop and deliver a short course to train military personnel on critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment as part of the DARPA MENTOR II program. This paper discusses the curriculum, the delivery methodology, and assessment. This paper also discusses other cooperative efforts that have grown from this partnership.

Introduction

There are many ways the US Navy and US Marine Corps are exploring how to use 3D printing to save time and money both shoreside and on deployment. At the Mid Atlantic Regional Maintenance Center (MARMC) in Norfolk, VA and at the Marine Expeditionary

Force Operations at Camp Pendleton near San Diego, CA, sailors and marines can take a broken item, create a 3D scan of the part to convert it to a computer-animated design, and then print out a reproduction of the part using a 3D printer. The printed plastic part can directly replace the broken component if it is plastic, or can be used as a prototype for a metal-printed part if the broken component is metal.

Replacing a broken component is a significant challenge for forward-deployed forces, particularly for Navy vessels that are far from shore and the nearest military installation. It may take a week or even months to locate, procure and transport a part to the vessel, thus impacting its mission while costing a significant amount of money to expedite fabrication and shipping. During wartime, these equipment failures and logistical support challenges can impact military readiness levels. Innovative manufacturing technologies, additive manufacturing equipment (AM or 3D printers) in particular, can alleviate a number of these concerns and make the required replacement part available on the same day. Recent efforts initiated by MARMC to equip USS Kearsarge and USS Truman with 3D printers, and the successful part replacements completed on USS Truman indeed demonstrate the potential of an enormous opportunity to adapt AM for design and fabrication of replacement parts while simultaneously empowering sailors to solve challenges [1], [2]. Navy's Print the Fleet Initiative targets the development of systems that will allow commercial AM equipment to produce required spare parts that meet specifications including precision under the vibration, humidity and other adverse conditions expected onboard [3].

However, unleashing this potential is not without many challenges, including workforce development and personnel training. Although simple in concept, 3D printing in practice can be a challenge for many that often leads to frustration and technology intimidation. A primary cause of this is the lack of training and support. Collaborators from AST2, Francis Marion University, US Navy and ODU NEMSI teamed together to develop and deliver a short course to train military personnel on additive manufacturing as part of the DARPA MENTOR II program. This paper discusses the curriculum, the delivery methodology, provides student and instructor feedback, and gives several examples of the course impact. This paper also discusses other cooperative efforts that have grown from this partnership.

Curriculum Overview

This additive manufacturing short course curriculum introduces military personnel to critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment. Students learn the history, current status and explore future uses of additive/advanced manufacturing. Principal additive manufacturing technologies are studied. Students learn and apply modeling and design applications. Students, individually, and as members of multi-disciplinary product development teams innovate and design products and solutions to real-world challenges, evaluate their conceptual designs through an iterative process and then create their designs and through remote use of digitally controlled prototyping and additive manufacturing equipment. Highlights of the curriculum are discussed below.

Section 1 of the "Design Thinking for Additive Manufacturing" curriculum guide [4] provides an introductory overview to additive manufacturing. The introduction to additive manufacturing topics are important to convey to the students in the seminar. Regardless of the level of knowledge each student possesses, any piece of information conveyed in this section of the course can be beneficial to the students in one way or another. When a discussion on the background behind additive manufacturing took place with the students, who had some prior experience with 3D printing, many of them were still surprised to learn some of the things they didn't know (i.e.: history behind 3D printing, advantages vs. disadvantages, material properties of plastic grades, etc).

Section 2 discusses 3D Modeling and CAD software. This is a very integral element to the additive manufacturing process. Learning how to use CAD can help the user understand the comprehensive procedure behind additive manufacturing, especially the why's and the how's behind the process. While this wasn't covered in depth in the MARMC course due to the students' advanced capability to produce CAD models, this module should be covered to some degree. That degree will depend greatly upon the students' overall level of knowledge on the subject matter.

Section 4 begins to delve into the design process. The design process, although not covered in the week-long seminar, is an important concept for students to learn, but many of these basic principles are somewhat intuitive. In other words, for a group of people who learn better by doing and not simply by attending a lecture, many of these principles will come naturally to them as they go through the design process. Reviewing the subject may be best suited for those who may need a lecture on the importance of design before starting the actual design process through CAD, though, at best, a little overview may be necessary for those with experience in CAD design (i.e.: 10 step design process, why designs are made the way they are, etc).

The same thing could be applied for the "design process in detail" section of the curriculum, located in Section 6. However, regardless of the knowledge level, this should be covered with all students as this gets down to the heart of the steps behind accomplishing designs of various parts. Emphasizing the process of design through this step-by-step process (i.e.: brainstorming, iterations, etc) can help the students to both get familiar with the process as well as practice these steps to get better at design.

The use of additional tools for design purposes, (Section 7),is a subject matter that could easily be combined with the design process lecture. The overall goal for these series of lectures is to emphasize the importance of making a good design and what steps users need to take to make that happen. While this is good information to learn, devoting a lecture to properly ranking each design factor may be excessive for this seminar course, adding unnecessary steps to learning about the importance behind the design process, depending on experience of the students.

As covered in Sections 9 and 11, the different types of additive manufacturing techniques are very important and interesting to convey. The instructor went over these techniques with the MARMC students and they were very intriqued by the information shared. It is believed that due to the widespread applicability behind 3D printing from biomedical to aerospace applications, this led to the students' curiosity about the subject to increase. In addition, since this lecture covers the steps the maker will perform to prepare a part for 3D printing, as well its advantages/disadvantages and the different types of additive manufacturing techniques that exist, obtaining exposure to these facts can inspire creativity and potential innovation to use resources beyond what they currently have access to. Prior to the course, the students had used their knowledge to build small demonstration parts from plastic using their printers. Figures 1 and 2 show some examples of the kinds of parts they possess the capability to make.

Figure 1. Plastic Screw

Figure 2. Chess Piece

Projects to reinforce the learning modules are incorporated in Sections 3, 5, 8, 10 of the course material.

Course Delivery

The course was delivered to military personnel in two different settings: a week-long seminar at the Mid-Atlantic Regional Maintenance Center (MARMC) in March 2016; and a week-long seminar at the Marine Expeditionary Force Operations at Camp Pendleton near San Diego, CA in April, 2016 which focused on 3D printer assembly and operation. The purpose behind the instruction is to familarize military personnel on critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment and to prepare the personnel to successfully pass on the instruction to other personnel, thus a “train the trainer” concept of instruction. This is the first time MARMC and USMC have hosted a course of this nature.

During the weeklong seminar conducted by ODU and AST2, the objective was to build the students’ competency in order to perform hands-on tasks using their INVENT3D printers. As part of the course, students became familar with its features and assembled all parts of the printers. A picture of the INVENT3D printer can be found in Figure 3 [5].

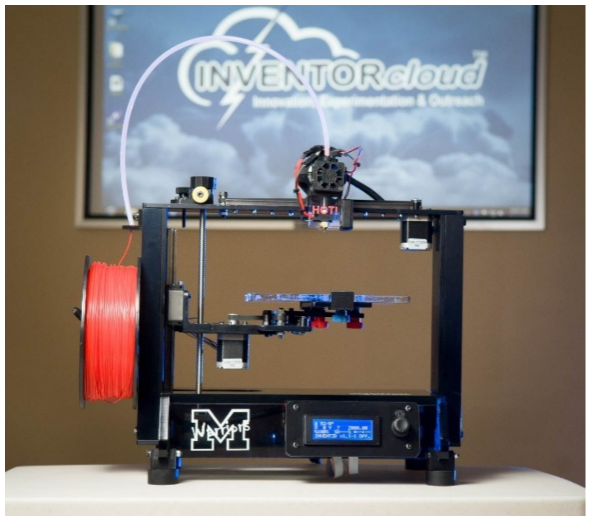


Figure 3. INVENT3D printer

The INVENT3D Printer overview [5] consists of the following teaching components:

- Overview of 3D Printers
    - Summary of How 3D Printers Function
    - Detailed Discussion of How 3D Printers Function Via Firmware Printer Control Software
- Characteristics and Function of INVENT3D Printer Components
    - Fasteners
    - Motors and Drives
    - Printer Box
    - Printer Control and Software
    - Print Head
    - Print Bed

ODU and AST2 mentored each student through assembly of the INVENT3D desktop printers (from motor assembly to filament loading). Three printers were setup in teams consisting of 2-3 students each. Figures 4-8 conveys instruction of printer setup to military personnel.

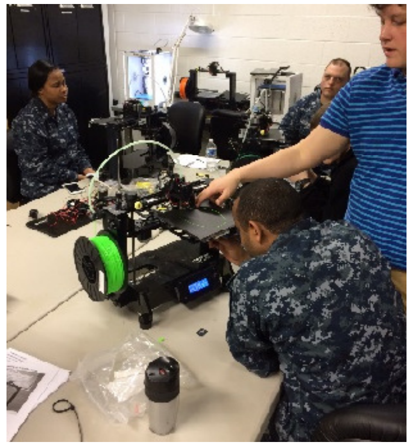


Figure 4. Setup of the INVENT3D printer

Figure 5. Assembly of the INVENT3D

Figure 6. Assembly and experimentation with the INVENT3

Figure 7. Assembly and troubleshooting the INVENT3D

Figure 8. Assembly and troubleshooting the INVENT3D

Course Assessment

Students from each course were asked to complete a post-assessment survey. Feedback on the short courses was overwhelmingly positive. Results from the USMC and MARMC short courses are highlighted below in Tables 1 and 2.

Table 1: Student Assessment for USMC Short Course

		Highly Disagree	Disagree	Neither Agree nor Disagree	Agree	Highly Agree
1	The course was well organized.	0	0	0	84%	16%
2	The course gave a good introductory overview of additive manufacturing.	0	0	0	33%	67%
3	The topics covered in ths course are relevant to my job.	0	0	0	33%	67%

4	The course objectives met my training needs.	0	0	0	33%	67%
5	The activites used in the course were appropriate and helped me to learn.	0	0	0	16%	84%
6	The instructor was knowledeable on the subject.	0	0	0	0	100%
7	The instructor presented the material clearly and understandibly.	0	0	16%	50%	34%
8	The course materials were presented on an appropriate level for the introductory course.	0	0	0	33%	67%
9	Overall the course was valuable to me.	0	0	0	0	100%
10	I would recommend this course to my colleagues.	0	0	0	0	100%

Table 2: Student Assessment for MARMC Short Course

		Highly Disagree	Disagree	Neither Agree nor Disagree	Agree	Highly Agree
1	The course was well organized.	0	25%	0	75%	0
2	The course gave a good introductory overview of additive manufacturing.	0	0	25%	50%	25%
3	The topics covered in ths course are relevant to my job.	0	0	0	75%	25%
4	The course objectives met my training needs.	0	0	0	100%	0
5	The activites used in the course were appropriate and helped me to learn.	0	0	25%	75%	0
6	The instructor was knowledeable on the subject.	0	0	0	100%	0
7	The instructor presented the material clearly and understandibly.	0	0	25%	75%	0
8	The course materials were presented on an appropriate level for the introductory course.	0	0	50%	25%	25%
9	Overall the course was valuable to me.	0	0	0	100%	0
10	I would recommend this course to my colleagues.	0	0	0	100%	0

Impact on Navy

Sailors with little to no previous experience in AM and all from non-manufacturing backgrounds were trained on INVENT3D and 3D CAD design and engineering concepts during the short course. During the trianing, sailors readily mastered the AM and CAD concepts. Following the training, sailors applied those concepts to achieve several innovative projects to design, build and implement replacement parts that improved operational performance and achieved cost savings. As an example, sailors onboard the USS Truman developed the Tru Clip design. The Tru Clip design is a simple 3D printed device designed to fix broken handheld radios used on the ship and is shown in Figures 9 and 10. According to the Navy, clasps on the handheld radios used across the ship were breaking over and over again, costing the Navy $615 for each replacement piece. The Tru Clip was manufactured using the INVENT3D printer and has saved the Carrier over $40,000 in six months, with a potential to save over $1M per year after fleet-wide application [6].

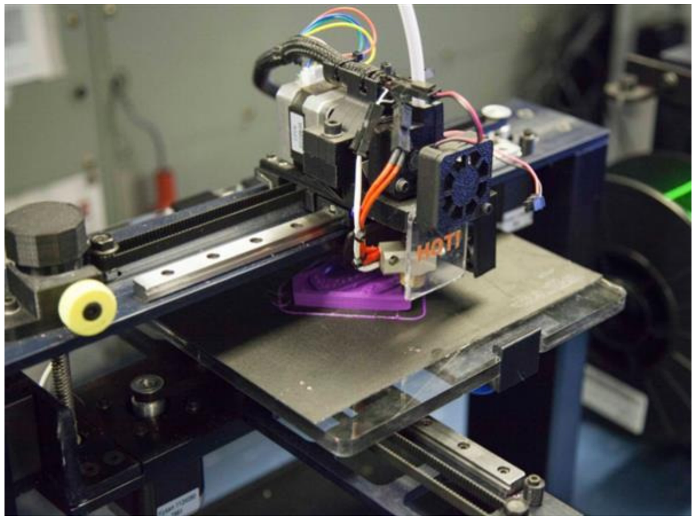


Figure 9: INVENT3D Printing a Tru Clip onboard the USS Truman [6]

Figure 10: Tru Clip in Use onboard the USS Truman [6]

Examples of other designs developed, manufactured and used include non-procurable items as well. A second example is printing plastic housing for pigtail adapters on Combat systems shown in Figure 11 that were constantly cracking and could not be replaced without reordering the complete part – resulted in average monthly savings of $8,000 and has Navy-wide application for significant savings. A third example is a throat guard shown in Figure 12 that created a fitting readily available to connect the Nitrogen Purge Kit within a short timeframe and prevented a work stoppage that could have exceeded 7-10 days to acquire the same fitting from an off-ship supplier.

Figure 11: Hydra P7100 Housing Adapter

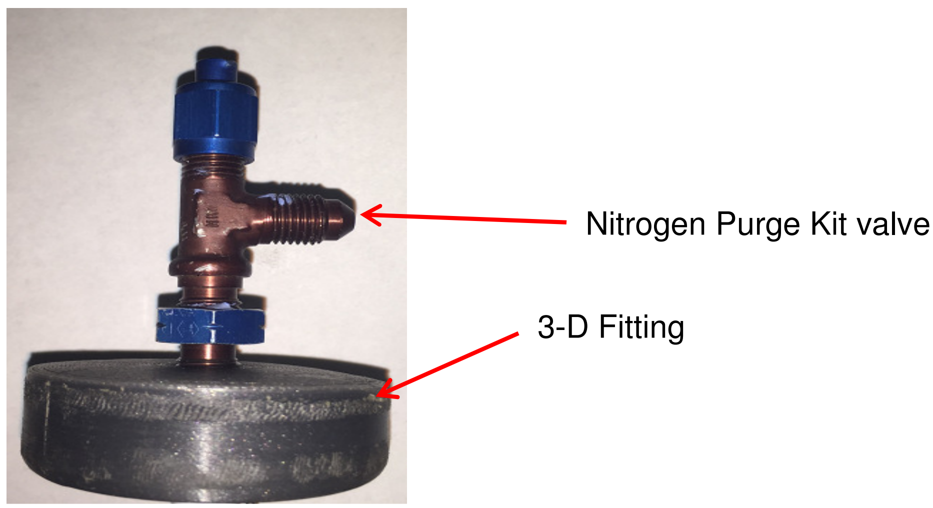


Figure 12: Nitrogen Purge Kit Fitting for F/A-18 Maintenance Team

Impact on USMC

Marines at Camp Pendleton and Camp Lejeune attended a 2-day training workshop in the use of INVENT3D printer use and design. Within days after training, Marines started designing and producing much needed replacement parts. Few examples are highlighted below.

- A critical part of the Amphibious Attack Vehicle (shown in Figure 13) was designed and manufactured in one day; the part would have taken over 200 days to procure through normal processes improving operational readiness by over 199 days.
- Numerous items for amplifier units, such as shown in Figure 14, were designed and produced within hours at a cost of 2 to 25% of supply cost and saved considerable delay in procurement

Figure 13: Power-Take-Off Yoke Shifter Replacement Part for AAV

Figure 14: AN/VRC 110 Vehicular Amplifier Unit Replacement Parts

Recommendations for the future

The course curriculum provided a very good outline on what can be covered in an additive manufacturing short course. However, the course outline is subjective depending on the experience level of the students. Before the instruction, the experience level of the core attendees of the course should be assessed so the lesson plans can be crafted accordingly.

In general, all the lesson plans discussing the design process should be consolidated into one lesson plan (Sections 4-8). The lesson could begin by going over the design process as well as briefly reviewing different procedures that are traditionally used in design.

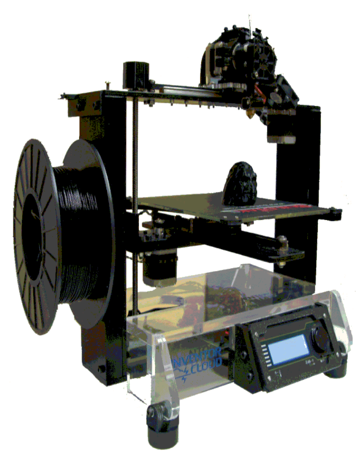
Since additive manufacturing mainly focuses on the physical aspects behind building parts from the ground up, the hands-on aspect should continue to be emphasized throughout the course. Students should also look at industrial-based printers used in academia and industry. This will allow the students to obtain well-rounded knowledge on the advantages, disadvantages, and appropriate uses of different additive manufacturing techniques. Since students are mainly able to obtain knowledge "by doing", the course should continue to emphasize project-based learning pedagogy.

The lesson plans listed in the curriculum, such as introduction to additive manufacturing, CAD and model conversion, and different forms of additive manufacturing, should remain in the course. The instructor observed that the students were enthusiastic when they learned about these processes since it related to what they were doing. Also, allowing the students the freedom to design in CAD and understand their 3D printers as they wished increased their comfort-level with the course.

The INVENT3d instruction manual was in draft form at the time of the MARMC seminar. Feedback on the manual was valuable and will be incorporated into the final draft of the instruction manual.

Other Cooperative Efforts

Other cooperative efforts that have grown from this dynamic partnership are outlined below:



- Under DARPA's MENTOR program, developed a distributed design and manufacturing technology integrating 3D printers and other subtractive equipment. Developed a virtual, rapid prototyping laboratory that is used by thousands of students to learn the concepts of developing design solutions and produce items using 3D printers that are available through INVENTORcloud.
- Developed a rugged and inexpensive printer, INVENT3D, manufactured over 200 of the printers, and deployed them in over 100 schools, Army and Navy installations, and on two Navy vessels. Sailors developed practical solutions, developed designs, fabricated and utilized numerous solutions that saved the US Navy thousands of dollars [7].
- Integrated INVENT3D printers into MARMC's FabLab, trained sailors in design thinking and additive manufacturing to develop problem solving skills.
- Deployed mini-fab labs consisting of INVENT3D printer; design work station and a desk top CNC Machine on two US Navy ships.
- Collaborating with SPAWAR and USMC at Camp Pendleton; Marines assembled INVENT3D printers in fewer than 3 hours, and designed and manufactured parts in less than 1 week after training. Commercially available technologies are designed for use in laboratories and plants under controlled and stable (stationary) conditions. Their adaption by the Navy and USMC may present some challenges due to the shock, impact and vibration forces experienced onboard Navy vessels. Additionally, large commercial printers are designed to achieve 'capacity' for production plants. Military aplications require rapid prototyping capability for unique applications as opposed to production capacity – smaller and flexible printers may be more appropriate.

Conclusions

3D printing in recent years has caught the attention and interest of the United States (US) Navy. There are many ways the US Navy and US Marine Corps are exploring how to use 3D printing to save time and money both shoreside and on deployment. This paper described the collaboration between Applied Systems and Technology Transfer, LLC. (AST2), Francis Marion University, US Navy and Old Dominion University's Naval Engineering and Marine Systems Institute (NEMSI) to develop and deliver a short course to train military personnel on critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment as part of the DARPA MENTOR II program. This paper discusses the curriculum, the delivery methodology, and assessment. The outcome of the efforts to date reinforce the team members confidence that with good training and inexpensive equipment, 3D printing can made significant impacts and provide great returns. Parts can be made when and where needed to improve operational readiness, as demonstrated by both US Sailors and US Marines.

References

1. Digital Manufacturing Education and Training for the Warfighter, Operator and Maintainer, LT Todd E. Coursey, January, 2016
2. USS Harry S Truman Fabrication Lab, CDR Al Palmer, CDR Brady Drennan and LTJG Casey Staidl, Jan. 29, 2016.
3. Navy Beefs Up 3D Printing Efforts with New 'Print the Fleet' Program, Yasmin Tadjdeh, National Defense Industry Association, October, 2014.
4. "Design Thinking for Additive Manufacturing R5." October 21, 2015.
5. "Understanding the INVENT3D Printer R3." March 6, 2016.
6. "USS Harry S. Truman sailors invent 3D printed 'Tru Clip' that will be used by astronauts on ISS" June 3, 2016. http://www.3ders.org/articles/20160603-uss-harry-s-truman-sailors-invent-3d-printed-tru-clip-that-will-be-used-by-astronauts-on-iss.html.
7. Navy Experience with Additive Manufacturing and Cost Savings, LT Todd E. Coursey, March 2016.

Biographies

JENNIFER G. MICHAELI, PhD, PE is the Director of the Naval Engineering and Marine Systems Institute (NEMSI) and an Assistant Professor in Engineering Technology Department in the Batten College of Engineering and Technology (BCET) at Old Dominion University (ODU). Dr. Michaeli received her BS in Naval Architecture and Marine Engineering from Webb Institute, MS in Ocean Systems Management from Massachusetts Institute of Technology and PhD in Mechanical Engineering from Old Dominion University. Dr. Michaeli, a licensed Professional Engineer in the state of Virginia, worked as a naval engineer in both the public sector and shipbuilding industry where she led new programs in design and engineering, construction oversight, testing and fielding of advanced marine vessels and new technologies for the U.S. and Foreign Naval Forces. For her contributions to naval engineering, she was awarded the Rosenblatt Young Engineer of the Year award by the American Society of Naval Engineers and the RADM Melville Award for outstanding

ISBN 978-1-60643-379-9

technical achievement by the Naval Surface Warfare Center, Carderock Division. At ODU, she oversees the marine engineering curriculum, leads a diverse portfolio of research programs for the US Navy and is actively engaged in STEM initiatives to maintain a sustainable professional workforce in the naval engineering enterprise. Dr. Michaeli was selected as the Old Dominion University's Rising Star for 2015 and 2016 and was awarded ODU BCET's Excellence in Research award in 2016. Dr. Michaeli is the corresponding author for the paper and may be reached at jgmichae@odu.edu.

MICHAEL POLANCO is currently a second-year PhD student at Old Dominion University in the Department of Mechanical and Aerospace Engineering. Mr. Polanco was raised in Newport News, VA. He attended Penn State for his Bachelor's degree in Mechanical Engineering and afterwards spent five years working as a contractor for NASA Langley Research Center working at the Landing and Impact Research Facility. During his time there he has several conference proceedings as lead author and co-author and journal papers as co-author, one of which recently won the Best Paper Award for the Journal of Aerospace Engineering. He later pursued and obtained a Master's Degree from ODU, which resulted in a journal publication in the Journal of MEMS, MOEMS, and Micro/Nanolithography. He currently has assigned duties for the College of Engineering including 3D printing, Motorsports Lab supervision, and teaching the Freshman Engineering seminar. He will be pursuing an internship with Naval Surface Warfare Center Carderock this Summer 2016.

GUGGILAM C. SRETSY Mr. Sresty is an engineer and scientist with over 30 years of experience in broad areas of science and engineering, and is CEO of Applied Systems & Technology Transfer, LLC (AST2). He is currently working with a number of Department of Defense and academic organizations to develop a collaborative design and manufacturing technology utilizing INVENTORcloud. Prior to joining AST2, Mr. Sresty has worked at IIT Research Institute (currently Alion Science and Technology) and Parsons Corporation where he has developed and implemented a number of novel technologies for waste processing, remediation, and energy production and processing. He has authored a number of publications, handbook chapters and patents, and received numerous awards and recognitions from national professional organizations. Mr. Sresty has also served on a number of Government and Industrial advisory boards.

JACK SCOTT Mr. Scott is founder and President of Applied Systems & Technology Transfer, LLC (AST2). AST2 provides technology solutions and professional services to government and commercial clients. He has developed INVENTORcloud which creates a virtual learning and collaboration environment by integrating hardware capabilities, software applications and a dynamic curriculum for use in secondary, post-secondary and industry settings. He designed the INVENT3D Printer which is manufactured by AST2 with secondary and post-secondary students participating in a work-based learning program. Mr. Scott concluded a successful career with Parsons, an international engineering, design, technical services and construction firm with over $4 billion in revenue and 14,000 employees as President and Chief Operating Officer. He was responsible for all aspects of operations of one of the world's largest engineering and construction companies, executing mega projects in infrastructure and defense. Prior to Parsons, Mr. Scott had a successful career with the US Army Corps of Engineers and the Program Manager for Chemical

Demilitarization. He is Chairman of exp.federal, which provides U.S. Federal clients best-in-class services in the architecture, engineering, operations & maintenance, and mission critical support services domain. Mr. Scott has been a leader in promoting collaboration between industry and academia. Mr. Scott serves on the Youngstown State University (YSU) Presidents Council, as well as the YSU STEM Council. He also serves on both the Industrial Engineering and School of Engineering advisory councils at Texas A&M University. He earned numerous awards and recognitions from universities and professional organizations including the Captains of Industry Award, Institute of Industrial Engineers. Mr. Scott earned ME in Industrial Engineering from Texas A&M University.

JUSTIN YATES is an Assistant Professor in Industrial Engineering at Francis Marion University in Florence, South Carolina. He graduated from the University of Buffalo with a PhD in Industrial and Systems Engineering. He has a diverse background in multi-criteria decision making, transportation and logistics analysis, simulation, optimization, and spatial analysis. Prior to joining the faculty at Francis Marion University, he was an Assistance Professor at Texas A&M University.

LT TODD COURSEY is currently the Fabrication Laboratory Project Officer at Mid Atlantic Regional Maintenance Center (MARMC) in Norfolk, VA. He enlisted in the US Navy in 1998 as a Nuclear Machinist Mate. After completion of the Nuclear Field training pipeline he reported to USS THEODORE ROOSEVELT (CVN 71) where he served as the Chief Machinery Operator and later onboard USS DWIGHT D. EISENHOWER (CVN 69) as the lead Quality Assurance Inspector for Machinery Division during her RCOH in Newport News Shipyard. In 2004, LT Coursey was selected for instructor duty at Nuclear Field "A" School in Charleston S.C., during which time he completed his BS degree in applied science and technology and was selected for Officer Candidate School (OCS) in August 2009. Following completion of OCS, LT Coursey reported aboard USS ASHLAND (LSD 48) and served as the Shipboard Maintenance and Material Officer during her Midlife Overhaul. Upon completion of his tour, he transferred into the Engineering Duty Officer community.