CNC MACHINING AND METROLOGY TRAINING: ACE PROGRAM UPDATE

Tony Schmitz[1,2], Aaron Cornelius[1], Jake Dvorak[1], Jose Nazario[1], Emma Betters[1,2], Scott Smith[2], Craig Blue[2], Joannie Harmon[3], Mark Morrison[3], Tyler Blevins[3], and John Hopkins[3]
[1]Department of Mechanical, Aerospace, and Biomedical Engineering
University of Tennessee, Knoxville, Knoxville, TN 37996, USA
[2]Manufacturing Science Division
Oak Ridge National Laboratory, Oak Ridge, TN, 37830, USA
[3]IACMI – The Composites Institute, Knoxville, TN 37932, USA

ABSTRACT
This paper provides an update on the workforce development activities supported by America's Cutting Edge (ACE), a national initiative for machine tool technology development and advancement. ACE is supported by the Department of Defense Industrial Base Analysis and Sustainment program from the Office of Industrial Policy. Both the online and in-person components of the computer numerically controlled machining and metrology training programs are summarized and participation information is provided.

KEYWORDS
Education, training, workforce, machining, metrology

INTRODUCTION

The existing shortfall in the US manufacturing workforce has been well-documented and broadly discussed. For example, a 2018 Deloitte report predicts up to 2.4M manufacturing jobs may go unfilled by 2028 and that these workforce limitations could place $454B in production at risk in the US [1].

Due to the increasing connectivity between systems and widespread automation, including computer control of nearly all manufacturing equipment, the required skills are evolving with the new digital manufacturing paradigm. This places new demands on efforts to prepare the next generation workforce. Not only must the education and training efforts evolve, but the target audience is broad. The existing workers must be up-skilled to keep pace with new technology. Community college and trade school curricula must be expanded to provide not only a fundamental understanding of manufacturing processes, but must also provide exposure to digital communication and cybersecurity. Universities must prepare machine designers and entrepreneurs, for example, to energize the US machine tool industry.

To address workforce challenges in the machining industry, the America's Cutting Edge (ACE) training program was developed at the University of Tennessee, Knoxville and launched in December 2020 in collaboration with Oak Ridge National Laboratory and IACMI – The Composites Institute through support from DoD's Industrial Base Analysis and Sustainment (IBAS) program. There are currently two modules; both are offered at no cost.

The online computer numerically controlled (CNC) machining training curriculum is composed of:

- a machining tutorial, which covers topics including chip formation, tool wear, machining processes, machining equipment, CNC machining, computer aided manufacturing (CAM), and work holding
- CAM instruction through multiple lessons using an example part
- a machining dynamics tutorial, which describes the importance of considering machining vibration when selecting machining parameters in CAM software
- CAM lessons that leverage CAM+, a stand-alone app that simulates machining performance
- an introduction to machining cost
- multiple choice quizzes to assess learning and track progress.

The online metrology training curriculum is composed of:

- an introduction to manufacturing measurements, which covers measurement transducers for displacement, velocity, acceleration, strain, temperature, part dimensions, surface finish, and internal geometry
- an introduction to measurement uncertainty, which includes a definition of terms, a description of measurement uncertainty evaluation, and a case study for density measurement
- multiple choice quizzes to assess learning and track progress.

The intent of the ACE program is to educate and train the next-generation machine tool workforce, including future manufacturing engineers, machine tool designers, entrepreneurs, machinists, metrologists, and others.

FIGURE 1. Locations for 1588 CNC machining participants from 46 states.

FIGURE 2. Locations for 580 industry participants for CNC machining.

ACE PARTICIPATION

CNC machining

Since its December 7, 2020 launch, the program has grown rapidly. As of August 26, 2021, there were 1588 online participants from 46 states. These participants include 508 from industry (37%) and 1008 students from four-year colleges and universities, two-year community colleges, and high schools (63%). The US locations for the participants are displayed in Fig. 1. The industry locations are shown in Fig. 2. The student breakdown includes: 836 from colleges and universities, 56 from community colleges, and 116 from high schools; see Fig. 3. Among the 1588 participants who have started the online training, 507 (32%) have completed all training modules and had certificates awarded from IACMI.

FIGURE 3. Locations for 1008 students in CNC machining. Black symbols are for colleges and universities, blue symbols for community colleges, and orange symbols for high schools.

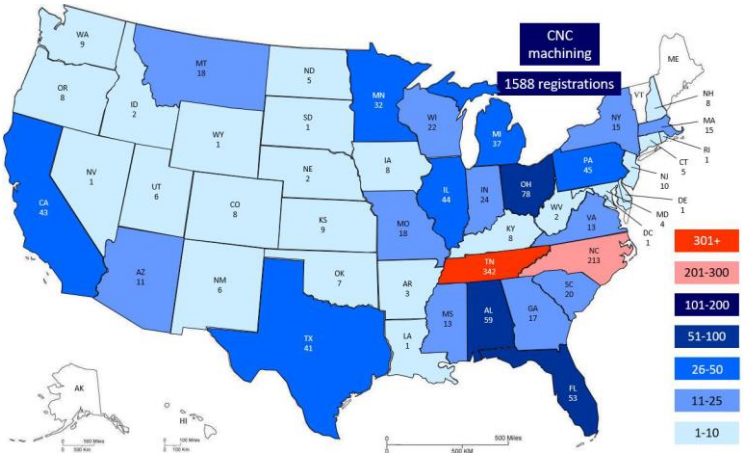

FIGURE 4. CNC machining participants by state.

Figure 1 shows that the registrations have the highest density in the Eastern US, although the upper Midwest, Texas, and West coast are also well-represented. The states with the highest numbers of online participants are listed. Figure 4 presents all registrations by state.

1. Tennessee, 342
2. North Carolina, 213
3. Ohio, 78
4. Alabama, 59
5. Florida, 53
6. Pennsylvania, 45

7. Illinois, 44
8. California, 43
9. Texas, 41
10. Michigan, 37

Eight one-week, in-person CNC machining training sessions were also completed from May to August, 2021 at three locations in Knoxville, TN. Those participants that completed the online training were eligible.

- May 10-14, 7 participants, University of Tennessee, Knoxville
- May 24-28, 10 participants, University of Tennessee, Knoxville
- June 7-11, 9 participants, University of Tennessee, Knoxville
- July 19-23, 11 participants, University of Tennessee, Knoxville
- June 7-11, 5 participants, Pellissippi State Community College
- June 14-18, 6 participants, Pellissippi State Community College
- July 19-23, 9 participants, Oak Ridge National Laboratory's Manufacturing Demonstration Facility
- August 9-13, 10 participants, Oak Ridge National Laboratory's Manufacturing Demonstration Facility

The 67 in-person participants represented nine states and included: 45 students (six high school), three educators (university, community college, NIST MEP), five engineers, six machinists, and eight veterans. The gender breakdown was 58 males and nine females (13%).

FIGURE 5. Toolpath programming using CAM software.

FIGURE 6. CNC machining by participant.

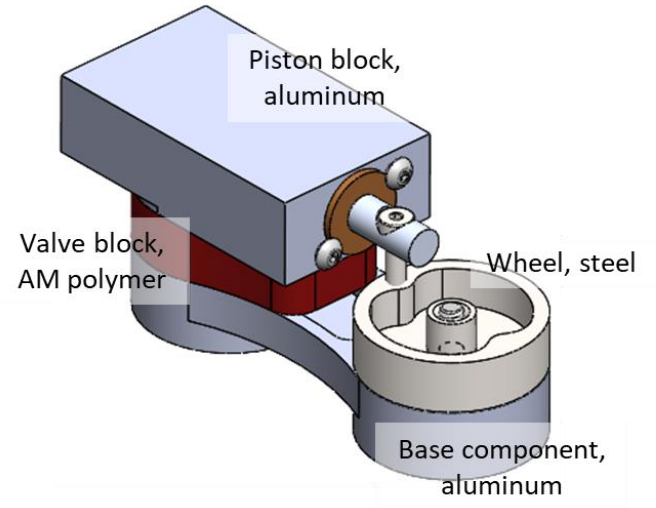

FIGURE 7. Oscillating piston air engine produced during in-person CNC machining training.

The five-day (8:30 am to 4:30 pm) in-person training included the use of CAM software to program toolpaths for four parts; see Fig. 5. These toolpaths were then used by the participants to machine the parts; see Fig. 6. Finally, the participants assembled the parts to produce an oscillating piston air engine; see Fig. 7.

The topics for each day of the five-day schedule are summarized. These activities include both classroom and laboratory sessions.

1. Monday – machining review, M/G code introduction, machine air engine base component
2. Tuesday – machining dynamics review, workholding, datums, machine piston block
3. Wednesday – machining cost review, machine valve block

4. Thursday – metrology review, machine wheel, assemble air engines; see Fig. 8
5. Friday – CAM+ review, on-machine tap test and chatter example, air engine part swap/assembly, logo machining, program evaluation

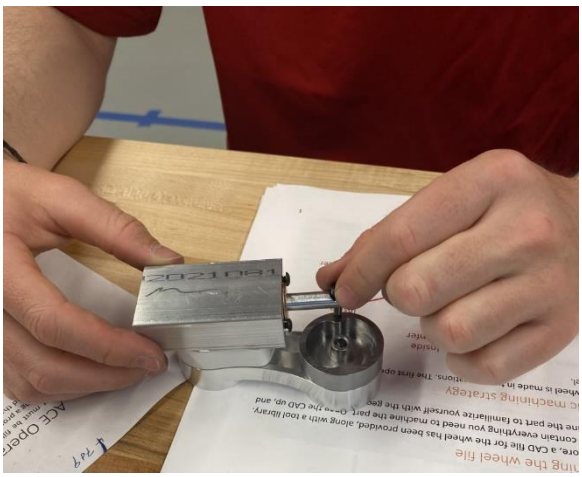

FIGURE 8. Assembly of oscillating piston air engine by CNC machining training participant.

Metrology

Since its March 16, 2021 launch, the program has grown to more than 300 participants. As of August 26, 2021, there were 303 online participants from 35 states. These participants include 136 from industry (45%) and 167 students from four-year colleges and universities, two-year community colleges, and high schools (55%). The US locations for the participants are displayed in Fig. 9. The student breakdown includes: 148 from colleges and universities, 12 from community colleges, and 7 from high schools. Among the 303 participants who have started the online training, 94 (31%) have completed all training modules and had certificates awarded from IACMI.

FIGURE 9. Locations for 303 metrology participants from 35 states.

Figure 9 shows that the registrations have the highest density in the Eastern US. The states with the highest numbers of online participants are listed. Figure 10 presents all registrations by state.

1. Tennessee, 64
2. North Carolina, 21
3. California, 15
4. Florida, 10
5. Ohio, 9
6. Illinois, 7
7. New Mexico, 7
8. Alabama, 6
9. Indiana, 6
10. Pennsylvania, 6

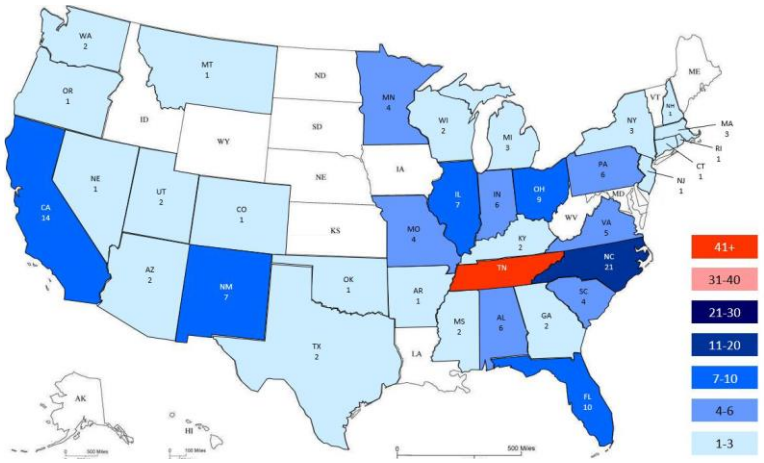

FIGURE 10. Metrology participants by state.

CONCLUSIONS

This paper provided an update on the workforce development activities supported by America's Cutting Edge (ACE), a national initiative for machine tool technology development and advancement. Both the online and in-person components of the CNC machining and metrology training modules were summarized and participation information was provided.

Details were given about the eight in-person CNC machining training sessions held at the University of Tennessee, Knoxville, Pellissippi State Community College, and Oak Ridge National Laboratory during Summer 2021. The 67 participants received training in both the classroom and laboratory; see Figs. 11 and 12.

Each of the participants rated the training either 4/5 or 5/5 during the post-training assessment. All stated that they found both the classroom and

laboratory sessions to be helpful. Selected quotes are included in the following paragraphs.

FIGURE 11. Classroom instruction was provided during the in-person training events.

"As a mechanical engineer, this ACE bootcamp is helping me to have a practical mindset in terms of designing something with the latest machining equipment and technology that can be manufactured efficiently in the US." – Air Force active duty, graduate student

"The online portion of ACE has been beneficial because I have no prior experience with CNC machining and getting the foot in the door with the online learning and now seeing it first hand and physically be able to do it is a great advantage to me as a hands-on physical learner. Being able to do it myself has given me a lot more confidence in my abilities to continue." – Aerospace engineering student, Air Force veteran

"Unmatched machining development program. Before ACE, I must confess I was quite concerned for the machining industry. It seems the suppliers and in-house providers I work with base their entire machining experience on tribal knowledge and arbitrary experimentation. To find the online curriculum and hands-on training that ACE provided…was a godsend." – Practicing engineer in the forging and machining industry

"The tap test demonstration is for real. The industry has battled chatter for years but learning the science behind chatter and how to avoid chatter conditions is transformational." – Third-generation machinist in family-owned company

"ACE on-line and hands-on CNC training has given me insight into a future career. ACE has shown me the importance of time and efficiency when producing a product and how energy and cost efficiency in CNC machining relates to environmental engineering." – High school student from underserved community

"ACE has reassured me that women are made for machining! We have acute attention to detail, our ability to hear higher pitches will help diagnose issues sooner, and there is actually room to move up within the industry." – Graduate student in materials science

"ACE hands-on experience with the CNC machines which will directly help me as a start a summer machining internship and pursue a career in manufacturing." – High school student

"Our country has great value in untapped human resources and ACE training, at no cost, has immense potential to extract diamonds in the rough." – Senior fitter

"Patriotism, that's one reason I became interested in ACE. The US cannot progress without building back its domestic manufacturing. ACE has taught me improved methods of finding machining stability without requiring years of experience." – Graduate student and Army veteran

FIGURE 12. Laboratory instruction included CNC machining, tooling setup, fixturing, work offsets and probing, and part measurement.

Moving forward, additional partners to host the in-person events will be identified and training materials will be provided in the form of comprehensive “instructor kits”. This is part of an agenda that includes a national roll-out of the ACE program.

To learn more about ACE or to register for the training modules, visit the following web sites.

CNC machining
https://mtrc.utk.edu/ace/

Metrology
https://mtrc.utk.edu/ace/ace-metrology/

ACKNOWLEDGEMENTS
The authors acknowledge funding from the Industrial Base Analysis and Sustainment program. This manuscript has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the US Department of Energy (DOE). The US government retains and the publisher, by accepting the article for publication, acknowledges that the US government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for US government purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan).

REFERENCES

1. https://www.forbes.com/sites/willemsundbladeurope/2020/04/23/the-labor-shortage-is-still-coming-stay-prepared/#2d31ef453892.